A conceptual socio-environmental systems model of flood vulnerability in Kosi Basin, India

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Abstract

The paradigm shift in flood risk management from a focus on flood hazard to flood risk requires a perception of flood events within a broader socio-environmental system context. To understand socio-environmental systems, scientific knowledge must be integrated with local knowledges. This paradigm shift began in developed countries like the UK in the early 1990s. There has also been a shift in the mind-set toward flood risk management in developing countries like India, but there is still an implementation gap at the ground level.

This research pursues a soft system methodological approach to understand the socio-environmental system in Kosi Basin, India, from the perspective of local knowledges. The stakeholders involved in the research were the communities living in the Kosi Basin, non-government organisations and local government officials. On-field data was acquired using participatory modelling, which involved semi-structured interviews and workshops. The interview transcripts helped define the temporal and spatial characteristics of the Kosi Basin system. It was recognised that the Kosi Basin system consists of three sub-systems with monsoon and non-monsoon variations, namely 1) the waterlogged community, 2) the Kosi west embankment community, and 3) the community living within the Kosi embankments.

Workshop data was used to structure the human-flood interactions in these three sub-systems into causal loop diagrams, which helped understand the interactions and feedbacks in the system. Moreover, a cyclic model depicting the annual behaviour of the Kosi Basin system was drawn. This model highlighted that the three sub-systems have different system dynamics and that there is no single homogenous pathway toward enhancing system resilience. The leverage point heuristic was used to identify places in the sub-systems where positive, sustainable changes can be strategically introduced to provide resilience to the at-risk communities residing in the Kosi Basin. The findings of this work show that local knowledges are instrumental in achieving a better understanding of a socio-environmental system. These new knowledges can act as a way forward to design and deliver robust and sustainable flood risk management policies to enable positive transformation.

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Chapter 1. Introduction

1.1. Flood risk management paradigm shift

Understandings of flooding have evolved within environmental scholarship from a perception of flood events as hazards to viewing them as phenomena of complex socio-environment systems that carry differentiated degrees of risk for various actors within a system. According to Wisner et al. (2004:4), "The crucial thing about understanding why disasters happen is that it is not only natural events that cause them". They framed risk as resulting from complex interactions between floods and humans and is not limited to the physical aspects of flooding. Indeed, flood risk has been defined in the academic literature as a function of flood hazard and vulnerability (Alexander, 1991, Skakun et al., 2014). It is evident from Alexander (1991) that the notion of flood risk (rather than hazard) has been around since the 1990s, but only recently has the concept of risk become dominant in the literature.

Evidence in the flood hazard paradigm suggests that the hydrologists attempted to include flood risk in the hydraulic models with technological advancements. Studies include coupled hydrological-hydraulic model (Xu et al., 2022), the economic aspect of flooding (Ballesteros-Canovas et al., 2013), and GIS use for flood risk mapping (Sinnakaudan et al., 2003) to assess flood risk quantitatively. However, quantitatively assessing flood risk does not include the dynamic relationship between floods and humans (Levin et al., 2013), and this technical approach leaves the local stakeholders on the periphery in the policymaking domain (Raymond et al., 2010, Andersson et al., 2015, Lindahl et al., 2015). On the contrary, the social scientist in the vulnerability paradigm focused on society’s vulnerability to flooding, giving attention to the subjectivity of local perspectives using bottom-up approaches (Tapsell et al., 2010, Dessai and Hulme, 2004). However, the vulnerability paradigm focuses mainly on the social dimensions of flood risk (Tapsell et al., 2010), and vulnerability is treated as a static entity. Moreover, little consideration is given to the physical parameters in the social sciences approach. Therefore, both in policymaking and academic research, the hazard and vulnerability paradigms focus on the components of socio-environmental systems, i.e., hazard paradigm for the physical system and the vulnerability paradigm for the social system, undermining the dynamically complex human-flood interactions.

On a broad scale, in the context of flood risk management, there is still a lack of fundamental understanding of the interplay between physical and social processes (Di Baldassarre et al., 2015). Understanding the importance of the dynamic relationship between physical and social systems, the hydrologists in the International Association of Hydrological Sciences adopted “Panta Rhei- Everything flows” as the overarching theme of its scientific decade 2013-2022. This initiative stressed the importance of interdisciplinary research in understanding the complex interactions between physical and social systems. Exemplified by the Panta Rhei initiative, recent years have seen a change in approach to flood risk management practice (Montanari et al., 2013), especially in the western parts of the world. In Europe, countries such as the UK, Netherlands and Germany include the impact of climate change in their flood risk management policies (Bubeck et al., 2017).

In the global south, the prevailing paradigm of flood response remains focussed on reducing physical hazards, and flood management policies explicitly target physical, structural and emergency responses in countries such as India (Mohanty et al., 2020), Pakistan (Tariq and Nick, 2012), and Malaysia (Shafiai and Khalid, 2016). With monsoonal weather patterns domination, at-risk communities are in danger of flooding every year in these countries. Therefore, the flood control measures employed by the government are unable to provide a sustainable solution for reducing vulnerabilities in at-risk communities.

1.2. Kosi Basin, India

In the context of a developing country such as India, for decades, physical structural defences and emergency response have been used for managing floods, and vast resources have been expended in maintaining these flood defences (Mohanty et al., 2020). However, social vulnerability increases are often observed even after flood defences are maintained. The Kosi floods of 2008 are an example of the ineffectiveness of the conventional method for controlling floods (Dixit, 2009). Past flooding in Bihar has led to a significant economic and social loss in the lives of the Kosi Basin communities (Mishra et al., 2008, UNDP, 2009, Jha and Raghavan, 2008). Consequently, flood management plans and processes in India drafted by the Government of India have started to incorporate social dimensions and recognise the importance of local knowledges. For example, at a state level, the Bihar state disaster management plan considers the community as the most important stakeholder in the disaster management process, stressing the importance of a participatory approach in the guiding principles of their disaster management plan (BDMA, 2014). Therefore, the Bihar state disaster management authority recognises the importance of the inclusion of at-risk communities to develop sustainable solutions to the flooding problem in the Kosi Basin.

Nevertheless, there is still an implementation gap, with systems perspectives and social concerns rarely translated into actions on the ground; instead, the conventional flood control strategy in response to floods remains prevalent (Mohanty et al., 2020). An overwhelming 3.5 million people in Bihar were affected by the 2008 floods due to the embankment failure during floods (Dixit, 2009). Moreover, at ground level, the current flood management system lacks active engagement with at-risk communities (Prasad, 2005). Therefore, the Kosi Basin is a perfect socio-environmental system to conduct this research to include the at-risk Kosi Basin communities to understand the impacts of the flood on the people.

1.3. Flood risk management practice and research gaps

Sustainable solutions demand an interdisciplinary approach (Montanari et al., 2013), stretching far beyond the engineering and science disciplines (Arnold and Wade, 2015) and viewing floods as a socio-environmental system. However, the complexity involved in the socio-environmental systems makes them challenging to involve in the decision-making process for flood risk management. Sayers et al. (2002) outlined several challenges associated with flood risk management practice within the perspective of complex systems, namely:

1) Variable loading: This challenge highlights that flood events are highly unpredictable, and forecasts are not available beyond a few days into the future.

2) Consequence is a combination of load and response: The impact of floods is a combination of loading on the system

and vulnerability of the communities residing in the floodplains.

3) Accommodation of complex and uncertain responses: The man-made interventions, including flood defences, have a highly uncertain response to loading.

4) Spatial interactions: This challenge showcases the impact of flood defences that might increase the risk of flooding downstream. Increased erosion or sedimentation, with time, in the riverbed can lead to unexpected behaviour of the river system in the future.

5) Temporal interactions: Flood risk is dynamic over different time scales, including geomorphological, ecological and climate changes. Social and economic changes also occur over time, which can influence the vulnerability of the at-risk communities residing in the flood plains.

6) Stakeholders value rivers differently: The challenge is that there are no established criteria for establishing 'acceptable' risks from flooding concerning different pressures acting on rivers and their floodplains. The priorities and needs of stakeholders vary according to the local context. Therefore, flood risk management needs to respond to these different priorities and needs of different stakeholders.

Addressing these challenges, especially 2, 3, 5 and 6, is the foundation for improving understanding of how the at-risk communities are impacted by flooding. Moreover, meeting these challenges would be essential in modelling the interactions and feedbacks between humans and floods. Given the flood risk paradigm that foregrounds complexity, relationships and social vulnerabilities within ecological/political/economic contexts, certain research gaps that need to be addressed are mentioned below, followed by a discussion on these research gaps:

1. Vulnerability dimensions: Exploring the dimensions of vulnerability experienced by local communities in flood-prone and economically impoverished contexts.

2. Local knowledges: Exploring the kind of knowledge that local communities draw on to articulate change and vulnerability.

3. System causality: Understanding the systemic causes and relational lock-ins that give rise to these vulnerabilities.

4. Bridging the gap: Integrating or intersecting this local knowledge with other forms of knowledge.

5. Systemic solutions: Deriving the systemic possible 'solutions' to flood risk and social vulnerabilities.

Research gap 1 focuses on the multifaceted nature of vulnerability. Flood exposes the community members to the threats of physical, social, economic, health, cultural, personal and psychological insecurities (Ariyabandu and Fonseka, 2009). The degree of vulnerability varies with the community’s capacity of absorbing, responding, and recovering from the event’s impact (Westgate and O'Keefe, 1976). In Kosi Basin, this degree of vulnerability in the communities is hugely influenced by the caste structure in India (UNDP, 2009). The caste system (UNDP, 2009) and the recurring floods (Kumar et al., 2013) have compounded impact the communities, i.e., impacting the marginalised communities more than dominant community members. Therefore, the poor, women, minorities, children, the elderly and disabled are the most vulnerable people in a society (Tapsell et al., 2010), especially in a context like Kosi Basin. This heterogeneous nature of vulnerability (Ziegler, 2012) fosters the need to explore the social inequalities and processes (Maskrey et al., 2016) that make some people more vulnerable than others in Kosi Basin.

Research gap 2 stresses the need to explore the kind of knowledge that local communities draw on to articulate change and vulnerability. Local knowledges can be defined as "understandings, skills and philosophies developed by societies with long histories of interaction with their natural surroundings" (UNESCO, 2017). As defined by Raymond et al. (2010), local knowledges refers to lay, informal, personal, usually tacit or implicit but conceivably expert. Involving people who live and experience flood risk and adapt to it are enriched with local knowledges (Maskrey et al., 2019). These people have years of lived experiences with flood which makes them the expert in their local context.

However, the most vulnerable community members are often marginalised and excluded from decision-making processes, and the majority of disaster management policies are still based on top-down frameworks (Tapsell et al., 2010, Weichselgartner and Kasperson, 2010). Examples include the study conducted in Chennai, India, for integrated flood management by Suriya and Mudgal (2013) and the study of the Cooum River and Environs in Chennai, India, by Bunch (2003). These studies understand the systems approach's importance but emphasise scientific knowledge for understanding the system behaviour. Even though these studies use a systems approach to understand the system, they lack the value that local knowledges can provide. The top-down approach emphasises the importance of national government intervention over local actions (GNDR, 2011, Weichselgartner and Kelman, 2014, Sandaran and Selvaraj, 2021). Therefore, these top-down policy-making approaches are not always well suited for the grounded realities in every local context (Mistry et al., 2016a).

However, local knowledges have the potential to play a prominent role in building governance strategies to sustainably manage natural resources (Blom et al., 2010, Voß and Bornemann, 2011). Examples can be found in science-policy arenas and agreements such as the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES). This independent intergovernmental body recognises the significance of local knowledge and supports a diversity of knowledge systems for decision-making and informing international biodiversity assessments (Díaz et al., 2015). Therefore, collaborating with these at-risk communities and eliciting these local knowledges provides an opportunity to listen to and consider these situated knowledges (Haughton et al., 2015). However, the role of local knowledges is still undermined by the policy makers in the context of environmental policy-making, even with their potential governance and management of socio-environmental systems (Mistry et al., 2016a). Examples include undermining the fire management community-owned solutions in the tropical forests and savannah ecosystem in Guyana, Brazil and Venezuela when designing fire management strategies (Mistry et al., 2016b). Therefore, to utilise, these lay, informal, personal, usually tacit or implicit but conceivably expert knowledges, this research takes the epistemological position to involve local knowledges to understand the human flood interactions in Kosi Basin.

Research gap 3 focuses on understanding the systemic causes and relational lock-ins that give rise to these vulnerabilities. In order to understand vulnerabilities existing in Kosi Basin, it is vital to view vulnerability as a system of systems: 'systemic point of view' using a systems-based approach and not thinking of the system as an individual entity: 'systematic point of view'. The paradigms such as flood hazard or flood vulnerability are based on systematic view, i.e., they consider one-way relationships (Ludwig et al., 2001) which presents a misleading representation of how socio-environment systems behave (Levin et al., 2013).

Vulnerability is dynamic in nature and is highly influenced by complex interactions of humans and floods (Boelens, 2014). The socio-environmental systems perspective views flooding as a 'system of systems', having complex interactions between social and physical systems (Montanari et al., 2013). These changes, in the case of Kosi Basin includes embankment breach which can enormously increase vulnerability in the already vulnerable marginalised community stakeholders (Turner Ii et al., 2016), who are interacting with monsoons annually. Therefore, adopting a systemic view is important to understand the systemic causes and relational lock-ins that give rise to these vulnerabilities.

Research gap 4 highlights the need to bridge the gap between this local knowledge with other forms of knowledge. The understanding of flood risk in Kosi Basin is limited due to lack of involvement of local knowledges in flood risk research or policy domains. In the context of land use practices, Mistry and Berardi (2016) suggested that to bridge this knowledge gap, it is crucial to understand the problem situation at the ground level by engaging with the local communities and then seek relevant scientific expert knowledges to devise actions to solve the problem. This process of bridging the knowledge gap can be transferred to bridging the gap between local and scientific knowledge for flood risk management in Kosi Basin, in both research and policy domain. The new knowledges elicited from local knowledges and structured into a systems model can complement the traditional flood risk management approach and are essential to achieve the challenges present in flood risk management.

Research gap 5 centres on deriving possible 'solutions' to flood risk and social vulnerabilities. The possible solutions to flood risk and social vulnerabilities will require applying system thinking to look at the 'whole' rather than parts of the system. Solutions to a tightly linked system cannot be applied in isolation. All the elements in a system are linked and change in one key element can produce a change in the whole system (Schweizer and Renn, 2019). There are different dimensions of vulnerability involved, such as economic, social, political and finding solutions would require an interdisciplinary collaborative working environment (Mai et al., 2020). Different actors from the relevant field including the community stakeholders have to come together and collaborate to provide pathways for deep transformational systemic changes. However, an attempt of interdisciplinary collaboration might result in different options on how the transformation arises or recognised (Feola, 2015). Nonetheless, having a platform to discussion and communicate provides opportunities to widen our perceptions and understandings towards option appraisal to implement policy reforms (Fisher et al., 2022).

Therefore, a flood risk paradigm necessitates systems approaches. However, the application of systems approaches is under-explored in a local context and with relevance to flood policy. This thesis focusses on foregrounding the local knowledge of communities in the Kosi Basin in particular, thereby deriving novel perspectives on social vulnerability, system complexity, and identifying new arenas for effective and ethical responses to socio-environmental maladaptation. This research therefore adopts novel methodologies to generate this kind of knowledge, thereby helping to bridge traditional science-driven flood management with insights from social sciences. The research questions posed based on the research gaps along with the thesis structure are mentioned below in Section 1.4.

1.4. Research questions and thesis structure

This research aims to understand flood risk by analysing complex human-flood interactions and feedbacks through a socio-environmental systems lens using local knowledges. This thesis addressed four research questions linked to the research aim and are presented below in Table 1-1.

Table 1-1 Research Questions

S.no.	Research Questions
1	What are the local knowledges present in a socio-environment system?
2	How can these knowledge be elicited based on the socio-demographics of a local context?
3	What systems of causality exist within the flood-prone Kosi Basin?
4	How do the systems of causality reveal and characterise flood risk and vulnerability?

The methodology adopted to answer the research questions mentioned above (Table 1-1) is divided into three parts: 1) representation, which contains the details of methods used to identify the stakeholders for participation and stakeholder engagement; 2) formalisation, which contains the details of tool and techniques used for abstraction and analysis of data elicited through stakeholder engagement; 3) interrogation and synthesis, which contain the details of methods adopted for visualising the feedback loops to identify the root drivers of the flood risk and vulnerability of at-risk communities in Kosi Basin. The methodological overview to answer the questions mentioned above is presented below:

Research question 1 asks about what local knowledges are present in a socio-environment system. This research question is informed by research gap 1 and 2. In this thesis, research question 1 is achieved by identifying and mapping the stakeholder spectrum in flood risk management, Kosi Basin. Stakeholder mapping is used to identify the spectrum of actors in the case study region and establish the breadth of local knowledges present in the area. The details of achieving research question 1 are presented in the structure representation stage covered in Chapter 5.

Research question 2 asks how these local knowledges can be elicited based on the socio-demographics of a local context. This research question is informed by research gap 2. Participatory modelling offers a practical means to elicit the range of views that local stakeholders hold, and a co-production of a collective view of the human-flood interactions can be obtained. Co-producing a collective view offers opportunities to build consensus and identify socially acceptable solutions (Maskrey et al., 2016). Throughout the thesis, participation modelling is used as a means of collaboration and capacity building among the stakeholders. The benefits of the participatory approach are based on two key challenges a) accessibility and b) complexity (Maskrey et al., 2016). A range of methods, tools and techniques such as semi-structured interviews (Section 5.3.3) and rich pictures (Section 6.2.2) were used to elicit local knowledges and selected based on the socio-demographics of the system, i.e. making the participatory process accessible. The details of the elicitation process are present in the structural representation stage in Chapter 5 and the behavioural representation stage in Chapter 6.

Research question 3 asks how these elicited knowledges can be used to understand causal relationships between actors and elements in the case study. This research question is informed by research gap 3. This research question refers to the second benefit of the participatory process, i.e., complexity. Understanding the causal relationships required adopting a complex systems perspective and producing a systems model. Therefore, techniques capable of representing the complex interactions between humans and floods were required.

It is crucial to understand the system structure, i.e., the system boundaries (spatial, temporal and social characteristics), to understand the system complexity. Thematic analysis (Section 5.4.1) was carried out for structural formalisation to understand the problem and define the system structure. The details of the formalisation of the system structure are presented in Chapter 5. Furthermore, causal loop diagrams were used for behavioural formalisation to understand the system behaviour (Section 6.5.1). Causal loop diagrams offer opportunities to formalise the interactions and feedbacks in the system (Barbrook-Johnson and Penn, 2022) and are therefore adopted to build the systems model of flood vulnerability in Kosi Basin. The details of the formalisation of causal loop diagrams and their interrogation are presented in Chapter 6 and Chapter 7, respectively.

Research question 4 asks how the causality systems reveal and characterise flood risk and vulnerability. This research question is informed by research gaps 4 and 5. The extracted key characteristics from interrogating the causal loop diagrams helped determine a community's flood risk and vulnerability. The system dynamics provide opportunities to identify leverage points (Abson et al., 2017) to define the root causes of flood risk in communities. Identifying the root drivers of flood risk and vulnerability offer the potential to stress the argument that the traditional flood risk management strategies focus on the source and extent of flooding, neglecting the vulnerabilities in the socio-environmental systems. Chapter 8 argues the importance of vulnerability dimensions in flood risk management policies. Moreover, the findings of this thesis stress the need to look at the system as a whole rather than parts, i.e. adopting a systemic view (Koskinen, 2013) for devising flood risk management solutions. The details of the leverage points heuristic are mentioned in Chapter 8.

A thesis structure (Table 1-2) is provided below with a brief guided narrative of the chapters, which will act as a road map for navigating the thesis.

Table 1-2 Thesis structure

Chapter	Description
Chapter 2 Literature Review	Reviews the paradigm shift in flood management from protecting/controlling flood hazards to managing flood risk. Explores how the paradigm shift has led to a view of the complex problem of flooding as a socio-environment system. Results of this chapter include identifying research gaps in the methods used for the current flood risk management approach.
Chapter 3 Methodological Overview	Explores systems thinking, soft system methodology and critical thinking adopted to understand complex problem situations. Provides an overview of the methodology adopted in this research to understand and analyse the socio-environmental system with respect to flood risk management. Results of this chapter include an overview of the novel methodological framework adopted in this research.
Chapter 4	Presents a case study analysis that allows us to assess the extent to which socio-environmental systems are addressed and/or considered within the flood risk management practice of Kosi/India.

Chapter	Description
Kosi Basin: A socio-environmental system	Provides an overview of the physical and social characteristics of the Kosi Basin socio-environmental system. It also includes the history of how Kosi embankments were built. Results of this chapter included explanations about why Kosi Basin is a good fit for the research
Chapter 5 System Structure	Covers the answers to research questions 1 and 2. Contains the details of methods adopted for structural representation and structural formalisation for deriving the system structure. Involves identifying and mapping the local flood risk management stakeholders in Kosi Basin, India, followed by stakeholder engagement for understanding the problem situation of floods in Kosi Basin, India (Structural representation). Details the thematic analysis process used to formalise the system structure (Structural formalisation). Results of this chapter included the production of system boundaries.
Chapter 6 System Behaviour	Covers the answers to research questions 2 and 3. Includes the details of stakeholder engagement for abstracting themes, variables and relationships among the variables (Behavioural representation). Details the abstraction of themes, variables and relationships among the variables and the building of causal loop diagrams using the abstracted relationships (Behavioural formalisation).

Chapter	Description
	Results of this chapter included the production of causal loop diagrams.
Chapter 7 System Interrogation	Covers the answers to research question 3. Details the interrogation of the causal loop diagrams to derive the root causes of flood risk and vulnerability in Kosi Basin. The interrogation was conducted by analysing the socio-environmental system's feedbacks and crucial exogenous variables. Results of this chapter included abstracted key system characteristics and dynamics.
Chapter 8 System Synthesis	Covers the answers to research question 4. Compares the identified sub-systems and conceptualises the Kosi Basin system to illustrate the spatial and temporal scale of human-flood interactions. Utilises the leverage point heuristic to explore places where sustainable intervention solutions in local flood risk management can be introduced. Results of this chapter include the identification of shallow and deep leverage points.
Chapter 9 Discussion	Summarises and discusses the research findings and returns to the research questions. Discusses the implication of the thesis for flood risk management in India.

Chapter	Description
	Explores broader implications of the developed methodology for flood risk management paradigm research and policymaking. Provides the limitations of the research and recommendations for future research and policymakers.
Chapter 10 Conclusion	Summarises the main findings and original contribution to knowledge arising from the research. Reflects on the new knowledge that the research has contributed.

1.5. Researcher's positionality

A number of features of the researcher's positionality were pertinent to the geography and thematic focus of this research. As such a practice of personal reflexivity was adopted throughout the project. Key features that shaped the approach and experience of the research were her cultural background, gender as well as her academic background.

Being a native of India with roots from a village, the researcher's views and values were shaped by her cultural background. As a result, the researcher made particular assumptions regarding the culture and prevailing patriarchal norms existing in such communities. These assumptions helped the researcher in managing her behaviour which enabled her to win trust within the community. Moreover, being a native Hindi speaker helped in communicating with the people and conducting the research smoothly. Not being a Maithli speaker herself created a barrier in communicating with some of the community members, however, the NGO members helped her in addressing this issue. Most importantly, having witnessed the struggles of poverty, gender discrimination and impact of disasters while residing in India instilled in her a deep motivation of the need to empower of these flood-impacted communities.

Her gender also played an important role. It helped the researcher connect with the women and adolescent girls in the area and they felt comfortable to speak with the researcher. Being a woman might have been a barrier in engaging with the government officials, however, the researcher's academic background helped her in gaining trust of the government officials as well.

Also, the participants were appreciative and respectful of the researcher's higher educational background and were eager to participate expecting that the research will help in bringing their story to the people across the world and bring some positive changes.

The researcher has an undergraduate degree in civil engineering and a postgraduate degree in water resources management. Coming from an engineering background, the researcher viewed flooding as a physical phenomenon and did not have much knowledge about the qualitative aspect of flooding. However, the curiosity to understand the human flood interactions and the decision to undertake PhD in Geography encouraged the adoption of more social science perspectives. Moreover, having been trained in the very paradigm that constrained effective governance responses to social vulnerability gave the researcher an understanding of the depth of the challenge. As a result, the researcher was able to recognise the need to understand the impact of gender, caste and patriarchal norms on society and that shifted her research practice to a multi-method approach.

The researcher's familiarity with qualitative management models enabled her to identify new ways of thinking that could be brought into vulnerability studies and create new bridges across disciplines. The proof can be seen in how the thesis has been presented and framed. There is an instance where the researcher has used references from business management rather than environmental sciences for defining the stakeholder spectrum (Figure 5-2) in Chapter 5.

The researcher faced two challenges in particular. She had to explain to the community members that the researcher's purpose is to conduct research and is not there to provide monetary incentives in form of food, seeds, or WASH facilities, which has been the prevailing norm in the area followed by NGOs, government, and other organisations. The researcher's privilege as a PhD student studying in a western country inadvertently promoted heightened expectations. While this identity as a university student opened doors, it had to be balanced with a clear communication of the realistic outcomes of the project. Essentially it came with an ethical imperative to manage expectations. Therefore, the researcher verbally conveyed the project aims and also, distributed the project details in written form.

The underlying ethical issue in this research project was working with poor and vulnerable people. Therefore, the researcher was prepared to signpost research participants to support systems but was generally met by a sense of resignation – especially among the Dalit community. It was clear during conversations with the community members that they believed only monetary help can aid their vulnerable position.

1.6. Chapter summary

The big challenge in flood risk management currently is how the paradigm shift in flood risk management is causing practitioners to re-think the sources of information they use, the methods of analysis, and the usefulness of the flood management solutions being employed. Therefore, to move from flood risk management (with a focus on structural defences and emergency responses) to a risk paradigm that encompasses complexity and social context, a systemic view (Koskinen, 2013) of the whole flood system is needed. However, adopting a systemic view is challenging and it is pertinent to address these challenges for providing sustainable flood risk management solutions. Therefore, this thesis attempts to address these challenges and provide a route for practitioners to navigate through these challenges. A system conceptualisation for the Kosi Basin socio-environmental system has been developed with the motive to generate knowledges abstracted from local knowledges that can complement the traditional flood management approach to inform a general framework for informing decision-making (Mount et al., 2016).

Chapter 2. Literature review

2.1. Chapter overview

This chapter focuses on reviewing the paradigm shift in flood risk management from flood hazard (Section 2.2) to flood risk (Section 2.3), both in research and practice. Since the 1960s, the global flood management paradigm has been evolving. Perspectives amongst scholars have evolved from early understandings of flood events as discrete hazards to contemporary paradigms that consider floods as features of complex socio-environmental systems that can be managed through addressing multi-faceted dimensions of risk and vulnerability.

The flood hazard paradigm (Section 2.2) is a traditional flood management paradigm that focuses on reducing flooding probability via structural interventions (Section 2.2.1.1) and hazard mapping (Section 2.2.1.2). A significant amount of research has assessed flood hazards quantitatively, but these approaches have remained focused on physical parameters (Cardona, 2003). Only engineering aspects, i.e., scientific expert knowledges, were used to design strategies for managing floods, focusing on physical or economic aspects of flooding.

In the 1980s, the flood hazard paradigm was challenged by the vulnerability paradigm (Section 2.4). The vulnerability paradigm has focused on subsets of vulnerability components, i.e., social, physical, economic, political, cultural and technological variables, to understand flood risk. This approach has developed vulnerability ranking using both quantitative (Section 2.4.1) and qualitative (Section 2.4.3) approaches. In addition, this approach has given importance to both scientific experts and local knowledges (to an extent) for data collection. However, this approach typically does not consider human-flood interactions and feedbacks, which are integral to understanding floods as a whole (Di Baldassarre et al., 2015). Therefore, the overall system dynamics of flood events contributing to human disaster and loss have been poorly understood.

The need to acknowledge the dynamic human-flood interactions led to the view of the flood system as a socio-environmental system (Section 2.5). Flooding is viewed as a 'system of systems', having a complex relationship between physical and social systems through the lens of a socio-environmental systems perspective (Sivapalan et al., 2012, Di Baldassarre et al., 2019). A socio-environmental system perspective is adopted in this research acknowledging the need to include complex dynamic interactions between humans and flood.

2.2. Flood hazard paradigm

The natural sciences approach considered floods as natural events and used physical aspects of flooding to manage the flood. This understanding reflected an ontological perspective that associated disasters exclusively with the physical phenomena causing them (Cardona, 2003). This perspective underpinned management strategies that considered floods as external events affecting the unprepared society (Fleuvrier, 1995). The common terminology adopted for assessing floods was 'flood hazard', defined as the physical and statistical aspects of flooding, i.e., flow velocity, extent and depth of inundation, and return period of the flood (Vojtek and Vojteková, 2016).

The flood hazard paradigm is considered the first contemporary paradigm (Gaillard and Mercer, 2012) and this period marked the beginning of flood hazard assessment managing the likelihood of flooding. Traditional flood management strategies, i.e., structural (Section 2.2.1.1) and non-structural measures (Section 2.2.1.2) were used to prevent or control floods (Suriya and Mudgal, 2013). Studies were based on the physical properties of flooding, including the river's catchment area (Brierley and Fryirs, 2000), streamflow (Villarini and Smith, 2010, Riis et al., 2008), discharge (Emmett and Wolman, 2001, Bjerklie et al., 2003), hydrology (Wang et al., 2020, Di Baldassarre et al., 2011), and sediment load (Lenzi et al., 2003, Altunkaynak, 2009). Moreover, the 1990s were seen as the International Decade for Natural Disaster Reduction by United Nations, assuming that the disasters were the natural/physical phenomenon causing them (Cardona, 2003, Alexander, 1991).

2.2.1. Flood hazard assessment tools

2.2.1.1. Structural management responses

The flood hazard paradigm focuses on structural measures such as dikes, embankments, and reservoirs to prevent, reduce or control flood hazards. Embankments are features usually constructed from the earth along the two banks of a naturally flowing river, which are used to confine the river stream. Their primary purpose is to minimise flood damage by serving as protection against flooding (Vojtek and Vojteková, 2016). Embankments are constructed such that they are resistant to the hydrostatic pressure from the river, erosion, and seepage. In the early 1900s, the USA adopted structural measures such as levees, outlets, and reservoirs for protection against the overflow of the alluvial lands of the Mississippi Valley (Taylor, 1904). In the UK, after the Thames tidal flood of 1928, the committee on Thames Flood Prevention was formed in 1931 (DCTFP, 1933). The committee focused on preventing future flooding damage and making recommendations for further measures (DCTFP, 1933). As a result, structural measures such as flood defence barriers were built (Horner, 1976).

2.2.1.2. Flood hazard mapping

With technological advancement, flood hazard management solutions such as hazard mapping using hydraulic modelling (Zhou et al., 2021, Alho and Aaltonen, 2008) or hydrodynamic models (Moore and Jones, 1998) have been employed. Flood hazard assessment can be used to reduce flood losses by providing a way for decision-makers to predict, analyse, and manage the impacts of floods (Zhou et al., 2021, Duan et al., 2012). Moreover, this technological advancement has paved the way for non-structural measures for flood management in research, such as land use planning (Duan et al., 2012, Zhou et al., 2021), prediction of physical damage (Wobus et al., 2017), flood warning (Johnson et al., 2005).

The focus of these tools has been on the physical aspects of flooding; therefore, the knowledges incorporated in these tools are exclusively scientific expert knowledges (Gaillard and Mercer, 2012). The input data for flood hazard assessment includes hydrological, topological, and land use cover (WMO, 2013) gathered using hydrological modelling, remote sensing, fieldwork or ground surveys (Sy et al., 2019). Tools such as GIS (Geographical Information System) are used to identify and analyse flood hazards in flood-affected areas. The approach used for flood hazard assessment can be probabilistic or deterministic (Di Baldassarre et al., 2010), and as a result, flood hazard maps are produced to manage floods in this approach. Evidence form the studies such as coupled hydrological-hydraulic model (Xu et al., 2022), the economic aspect of flooding (Ballesteros-Canovas et al., 2013), GIS use for flood risk mapping (Sinnakaudan et al., 2003), attempts to assess flood risk quantitatively.

Governance in the UK has been provided as an example. The 1998 Easter floods in the UK demonstrated that structural defences alone could not deal with future flood risks and failed due to overflowing reservoirs (Bye and Horner, 1998). These structural defences were built based on the physical parameters of floods and did not consider the unintended consequences these structures can have on communities in the future. Following the Bye report, the flood hazard management paradigm started shifting towards a more strategic integrated approach to water and land management, focusing on public awareness, consistent national standards for flood warnings, land use planning and development control (Johnson et al., 2005). Moreover, after the autumn 2000 floods, the Department for Transport, Local Government and The Regions issued guidance 'PPG 25: Development and Flood Risk', which recognised the significance of land-use planning to flood risk management (DTLR, 2001). As a result, the Environment Agency distributed Indicative Floodplain Maps (based on probability modelling) to the local planning authorities in England and Wales (Nathalie et al., 2005). However, it was acknowledged by the government that over-reliance on technological solutions for flood warnings raises questions about acceptance and accessibility to disadvantaged and disabled groups (Johnson et al., 2005). Moreover, these initiatives were not focusing on the flood consequences and were incorporating flood hazard to showcase flood risk.

2.2.2. Flood hazard paradigm critique

The structural management responses to flood risk act in isolation, focusing only on the physical systems (IPCC, 2022). These options fail because of the long-term impacts generated due to the flood management strategies. They create unintended flooding in the future, impacting the environment and disrupting the lives of the people residing near them. Moreover, the structural management responses and techno-scientific approaches fail to include the dynamic complexities of human-flood interaction generating flood risk and also, the decision-making process for policy making generates distrust in people. These four disadvantages of the hazard paradigm are mentioned below.

2.2.2.1. Unintended flooding

A focus on flood hazards and hard engineering solutions can lead to unintended flooding elsewhere, e.g., downstream, on the other side of embankments, and increased frequency of large floods. Since the mid-20th century, the over-dependency and overreliance on structural measures have been criticised for their shortcomings (White, 1945), mainly in western, developed parts of the world, for their cost, lack of reversibility and societal impacts (Mustafa et al., 2015). These infrastructures are often expensive or inflexible to change (IPCC, 2022). One example is the 1997 Oder floods in Central Europe. In this case, flooding was caused not only by the failures of dikes but the seepage of water through the dikes and flood water penetration through the drainage system (Kundzewicz et al., 1999). The structural measure employed to provide protection unintentionally created more severe flooding in the future. In India, flood control works such as embankments and human interventions, including railways and highways in Kosi Basin, have led to severe drainage issues (Sinha, 2009a).

2.2.2.2. Environmental impacts

The environmental impact caused by structural measures is another aspect of concern (Johnson et al., 2005). Hard defences against floods reduce biodiversity and ecosystem resilience against climate change, constraining ecosystem services (IPCC, 2022). The structural measures disrupt the natural connection between water and land, reducing wetlands and compromising riparian flora and fauna (Plate, 2002). Therefore, the flood hazard paradigm ignores other environmental impacts, such as disconnecting rivers from floodplains and barriers to the movement of plants and animals along the river. However, in the latest report, 'Summary for policy makers' published by the Intergovernmental Panel on Climate Change, they argue that considerations for biodiversity and adaptation commitment in the long-term planning process reduce the risk of such adopting maladaptation (IPCC, 2022) i.e. using hard defences against flooding.

2.2.2.3. Neglected human-flood dynamics

Using structural measures to control and regulate the movement of water during a flood event is reactive in nature (Pahl-Wostl et al., 2013). It does not consider the vulnerabilities of communities to floods. The impact of flooding on people is also substantially a function of their ability to adapt and cope with the flood (i.e. community vulnerability) (Wisner et al., 2004), which is related to resource, power, agency, knowledge, history. These attributes contributing to flood risk are not considered in the flood hazard paradigm.

Structural management responses adversely affect the marginalised groups, i.e. low income households, ethnic minorities, indigenous people and informal settlements, by establishing and reinforcing existing inequalities (Mishra et al., 2008, UNDP, 2009). Flood hazard/risk mapping was a step forward from structural interventions because it paved the way for non-structural measures to prevent or control floods without relying on pure structural measures. However, quantitative assessment of flood risk undermines the dynamic relationship between floods and humans (Ludwig et al., 2001). These methods fail to account for how humans will interact with them in the future once they are built (Tapsell et al., 2010). Unintended consequences come with them because they are entirely abstracted from the cultural, social and economic contexts into which these interventions are placed (Tapsell et al., 2002, Wisner et al., 2004).

2.2.2.4. Top-down approach

The techno-scientific approaches, suitable for modelling and appraising flood hazards, are inaccessible to certain stakeholders without technical expertise (Mosse, 2001). Therefore, this approach can a) marginalise communities with years of lived experiences with floods on the periphery of the decision-making process and b) neglects the dynamic complexities in the human-flood interactions. Absent from the decision-making process, the communities struggle to understand how the policies and intervention options are identified and appraised (Mosse, 2001). This approach leads communities to distrust the scientific experts and lack support for the intervention options (Maskrey et al., 2016, Mosse, 2001).

2.3. Flood risk paradigm

Since the 1980s, the dominance of hazard-oriented prediction strategies based on technical interventions has been increasingly challenged by the alternative paradigm of vulnerability as the starting point for risk reduction (Bankoff, 2004). The objective of this paradigm was to manage the flood consequences by understanding and reducing the vulnerabilities existing in the communities at risk of flooding. Therefore, the focus of this paradigm is on the social system. It was realised that absolute protection is neither achievable nor sustainable (Tanaka et al., 2011), and consequences arising from floods are integral to understand for planning effective flood management strategies. Wisner et al. (2004: 61) suggest that "there is little value in confining attention mainly or exclusively to hazards in isolation from vulnerability and its causes". Therefore, focusing only on flood hazards without understanding the flood vulnerabilities can result in ineffective and unjust management strategies.

However, the definition of vulnerability is still evolving, and thus there is no common conceptualisation of the term among scholars (Ford et al., 2018, Cutter, 1996, McEntire et al., 2010). Adger and Kelly (1999) argued that vulnerability exists within systems independently of external hazards. It is generally viewed as an inherent property of a social system arising from its internal characteristics, which may be termed 'social vulnerability', determined by factors such as poverty and inequality, marginalisation, food entitlements, access to insurance, and housing quality (Wisner et al., 1994, Adger and

Kelly, 1999). Liverman (1990) argued that vulnerability incorporates various political, economic, environmental, and social activities and processes at the individual and more significant scale levels. Moreover, Cutter et al. (2003) argued that social vulnerability is most apparent after a hazard event has occurred, different patterns of suffering and recovery can be observed among certain groups in the population (Cutter et al., 2003).

Moreover, vulnerability is a heterogeneous concept (Ziegler, 2012); while all people living in hazardous areas are vulnerable, the social impacts of hazard exposure often fall disproportionately on the most vulnerable people in society – the poor, minorities, children, the elderly and disabled (Tapsell et al., 2010). Vulnerable groups are often the least prepared for an emergency, have the fewest resources with which to prepare for a hazard, tend to live in the highest-risk locations in substandard housing, and lack knowledge or social and political connections necessary to take advantage of resources that would speed their recovery (Dunning and Durden, 2011). Even though there are different definitions of vulnerability which can be applied in different contexts, the definition adopted in for the context of this research is that vulnerability is "the characteristics of a person or group and their situation that influence their capacity to anticipate, cope with, resist and recover from the impact of a natural hazard (an extreme natural event or process)" Wisner et al. (2004:11).

With the vulnerability paradigm, it was understood that 'natural disasters' are not only triggered by natural events but are associated with the social, economic, political and ecological context (Wisner et al., 2004). Incorporating these notions of vulnerability leads to an understanding of flood risk as being a function of both hazard and vulnerability (Alexander, 1991, Vojtek and Vojteková, 2016, Birkmann, 2006). This paradigm shift led to the evolution of the flood risk paradigm. Figure 2-1 shows the flood risk management paradigm's timeline and its progression over the years. The graph results showcase the results of published articles on the 'web of science' website for the last two decades (2001-2020). It can be observed that there has been an increase in the published articles with the term 'flood risk management' since 2001—a cumulative of 2289 published articles by 2020. It shows that over time, the relevance of the term 'flood risk management' has increased in the last two decades (2001-2020).

In addition, the cumulative published articles in flood risk management were searched along with four categories, including the terms: 1) "vulnerability", 2) "system", 3) "vulnerability" AND "system", 4) "vulnerability" AND "system" AND "system dynamics". This search was done to determine the degree to which literature on flood risk considers vulnerability and systems perspectives. The 'flood risk management' AND 'vulnerability' category has 417 published articles till 2020. The first published article found on the web of science website was in 2002 on managing flood risk in the UK by integrating social and technical perspectives (Brown and Damery, 2002). However, the vulnerability concept had already come into focus in the 1970s, emerging from the social science approach in response to the hazard-oriented paradigm of disasters (Schneiderbauer and Ehrlich, 2004) (Section 2.4).

The 'flood risk management' AND 'systems' category has 658 published articles, and the concept became well known with the Panta Rhei Initiative started in 2013 (Montanari et al., 2013) and is discussed in detail later in Section 2.5. The combined articles for ‘flood risk management’ AND ‘system’ AND ‘vulnerability’ are 138, starting in 2007. Examples include articles focusing on the challenges in England’s flood risk management policy and practices (Johnson et al., 2007) and urban flood risk management challenges concerning the different spatial and temporal scales (Zevenbergen et al., 2008). However, for ‘flood risk management’ AND ‘system’ AND ‘vulnerability’ AND ‘system dynamics’, there were three publications in which a system dynamics approach has been used to either assess resilience (Gotangco et al., 2016, Feofilovs et al., 2020) or vulnerability (Mallick et al., 2017) to flood risk. Details about flood vulnerability assessment are mentioned in Section 2.4, followed by socio-environmental systems (Section 2.5).

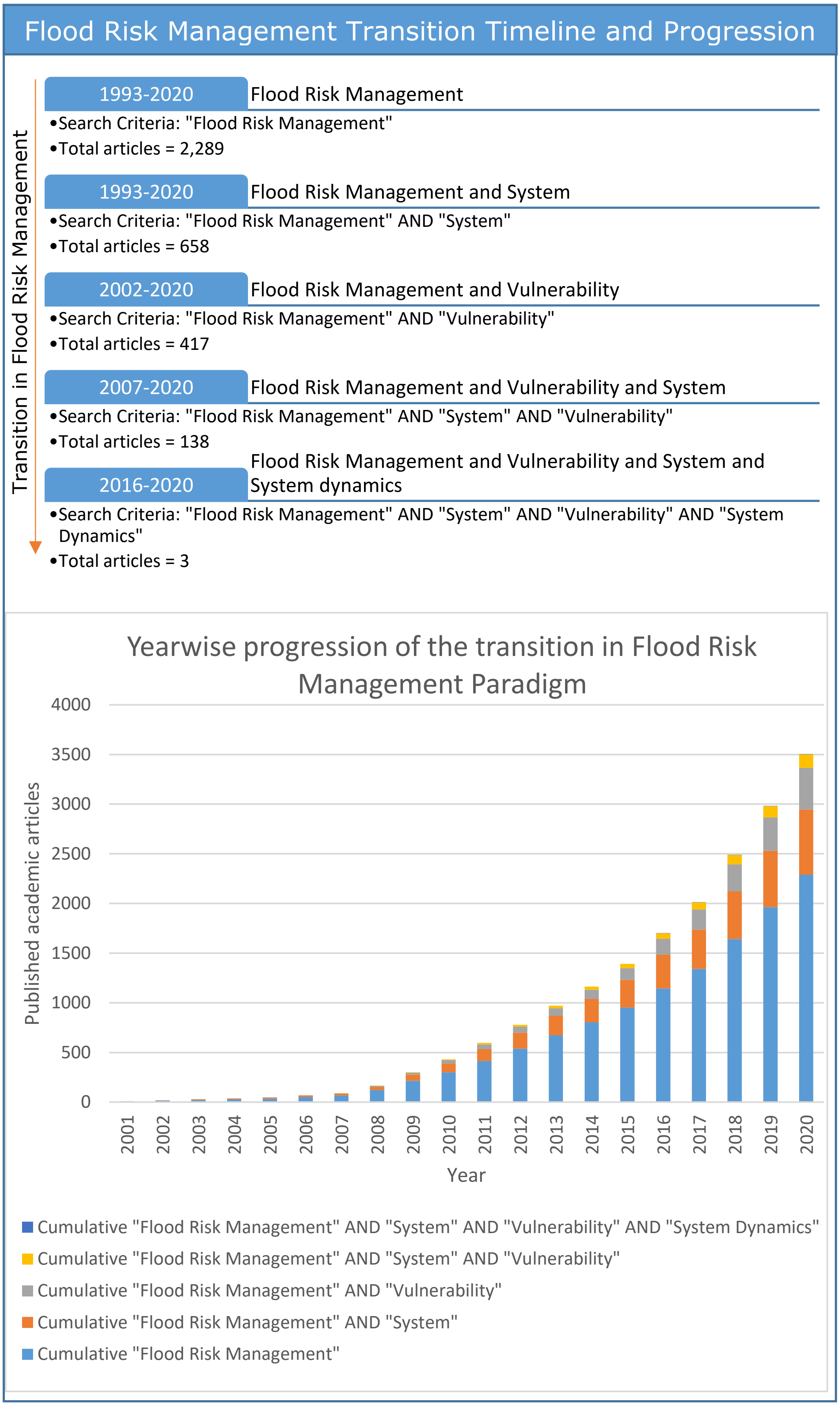


Figure 2-1 Flood risk management paradigm transition timeline and published articles (WOS, 2021)

2.4. Flood vulnerability paradigm

At the international level, the inclination in the policymakers started shifting towards the 'vulnerability paradigm' (Gaillard and Mercer, 2012) because of the unintended consequence and environmental impacts resulting from employing the flood hazard paradigm solutions to flood risk. Therefore, in 2005, the Hyogo framework for action was adopted. The Hyogo Framework was a global initiative started by the United Nations office for disaster risk reduction in 2005 with a goal to substantially reduce disaster losses by 2015 (UNISDR, 2005). It was a 10-year plan focusing on building the resilience of nations and communities to disasters. This plan focused on the development of a "system of indicators of disaster risk and vulnerability at national and sub-national scales that will enable decision-makers to assess the impact of disasters on social, economic and environmental conditions and disseminate the results to decision-makers, the public and population at risk" (UNISDR, 2005:7). Hyogo framework was an important milestone in considering the vulnerability element in flooding to increase resilience in communities to flood risk.

The term resilience gained prominence in disaster management after Hurricane Katrina (Twigger-Ross et al., 2014). Resilience has been defined differently in the literature based on the context. Adger (2006) defined resilience as the ability of a community to withstand external shocks to its social infrastructure. ENSURE (2009:30) defined resilience as "the ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions. Therefore, "contrary to some conceptualizations where resilience and vulnerability are oppositional, we propose that there is overlap within these concepts [vulnerability and resilience] so that they are not mutually exclusive, nor mutually inclusive. There are many characteristics that influence only the vulnerability or only the resilience of a community. On the other hand, there are social characteristics that influence both vulnerability and resilience (socioeconomic status, education, and insurance, for example)" (Cutter et al., 2008:602).

With a shift towards vulnerability-driven flood risk management, flood risk assessment focussed less on natural hazards and their quantification and more on identifying, assessing, and ranking vulnerabilities to make the communities disaster-resilient (Birkmann, 2006, Maskrey, 1993, Lavell, 1996, Bogardi and Birkmann, 2004). A number of different vulnerability assessment approaches have been adopted, differing in their vulnerability descriptions, variables, theoretical frameworks, and methodologies (Nasiri et al., 2016). Broadly, vulnerability assessment approaches lie along a spectrum of quantitative to highly qualitative tools and techniques (Singh and Zommers, 2014).

2.4.1. Quantitative assessment of vulnerability

Frameworks and metrics are developed to capture physical and social dimensions of vulnerability within the quantitative assessment of vulnerability (Jackson et al., 2017). The advantage of the vulnerability index-based approach is that it helps the decision-makers compare the vulnerability in diverse spatial scales (Balica et al., 2012), which could assist in prioritising investments to reduce future potential flood impacts

(Merz B., 2007, Huang et al., 2012). Furthermore, the approaches recognise the importance of the social elements, acknowledging both the physical and socio-economic elements of vulnerability in flooding.

Different methods have been established to conduct vulnerability assessments focusing on different aspects of flood vulnerability. Studies such as Kaoje et al. (2021) and Leal et al. (2021) calculated the quantitative physical vulnerability index for floods using an indicator-based methodology. However, in these studies, the flood risk was only considered in terms of physical damages to exposed elements. Other studies have incorporated socio-economic parameters for studying flood risk. These include methods that involve combining techniques such as fuzzy logic (Udnoon et al., 2021), analytical hierarchy process (Duan et al., 2012), and principal component analysis (Mavhura et al., 2017) with hydraulic or hydrological models using GIS. These studies prioritised scientific expert knowledge to inform metrics of flood vulnerability.

Some authors such as de Brito et al. (2018), Bodoque et al. (2016), Bergstrand et al. (2015), Carreño et al. (2007) and Nguyen and Van Nguyen (2019) used participatory approaches for data collection involving local people, NGOs aimed to assess the socio-economic aspects of vulnerability. In these studies, importance was given to participation in the initial stages of their projects to collect data, but quantitative methods were adopted to analyse flood vulnerability in the later stages. Therefore, these studies have considered local perspectives for assessing vulnerability, but these local people were not allowed to participate in decision-making. Therefore, quantifying vulnerability in this manner carries the same demerits of the techno-scientific approach adopted in the flood hazard paradigm, such as modelling the linear relationship between humans and floods and neglecting the complexities of this relationship (Section 2.2.2.3).

2.4.2. Critique of quantitative assessment of vulnerability

Quantitative assessment of vulnerability has similar limitations to the techno-scientific approach used in the flood hazard paradigm, such as 1) considering the linear relationship between hazard and vulnerability (Alwang et al., 2001) and 2) top-down management (Weichselgartner and Kasperson, 2010), explained below.

2.4.2.1. Dynamic nature of vulnerability not considered

The prevalent definition of vulnerability adopted in these methods was "the degree of loss to a given element at risk or set of such elements resulting from the occurrence of a natural phenomenon of a given magnitude and expressed on a scale from 0 (no damage) to 1 (total loss)" (UNDRO, 1980:5). However, vulnerability is a dynamic, complex and nuanced phenomenon (Adger, 2006, Tapsell et al., 2010). While certain socio-economic descriptors can be assessed robustly using quantitative measures (e.g. gender, income distribution and age) (Birkmann, 2006), some scholars have argued that quantifying vulnerability reduces its impact and dismisses its complex nature (Alwang et al., 2001). As such, subjective concepts such as the threat of harm and psycho-social impacts are often more effectively elicited using qualitative assessment of vulnerability.

2.4.2.2. Top-down governance

Top-down structures of management incorporate quantitative measurement approaches by default. However, "vulnerability can be subjective, and top-down disaster protection strategies tend to ignore social dynamics and, therefore, do not improve the situation because the at-risk people are not made visible, are not reached or not included in decision-making processes" (Tapsell et al., 2010: 20). Therefore, the top-down strategies can remain socially isolated (Weichselgartner and Kasperson, 2010). These strategies ignore the experiences of vulnerable communities and plan strategies for these communities without involving them (Weichselgartner and Kelman, 2014, Sandaran and Selvaraj, 2021).

2.4.3. Qualitative conceptualisation of vulnerability

During the mid-20th century, the social element of vulnerability gained momentum. Social scientists stressed that vulnerability is not only physical or economic but involves social dimensions (Cardona, 2003). Cannon and Twigg (2003) argue that social vulnerability is much more than the likelihood of buildings collapsing and infrastructure being damaged. Furthermore, there are instances of catastrophe in which hydrological extremes had not been the primary cause of the catastrophe; instead, social processes and governance failures that result in vulnerability have made extreme events catastrophic (Lane, 2014). Therefore, flood risk is not only limited to the potential physical damage or demographic determinants but has a social, cultural and political character (Cardona, 2003), as usually involved in the quantitative assessment. Capturing local contexts in ways that are true and accurate, i.e., social dynamics, institutions, culture, and history, necessitates a qualitative assessment of vulnerability (Tapsell et al., 2010). Overall, the qualitative assessment of vulnerability puts the at-risk communities back into the equation of flood risk and stresses that flood risk is also based on the social vulnerabilities existing in the communities.

A useful heuristic for conceptualising vulnerability is the diamond analogy (Figure 2-2). It conceptualises the multifaceted nature of vulnerability as including cultural, physical, systemic, social, economic, territorial, institutional, and organisational elements (Parker et al., 2009). In the diagram, the 'physical' facet is viewed as the susceptibility to, or potential for, structural damage to buildings, vehicles, infrastructure, and lifelines (heat, food, water). 'Systemic' vulnerability is associated with where and how an event might propagate through systems and their susceptibility to an inability to function (e.g., lifelines). The susceptibility to, or potential loss of, indigenous beliefs, customs, related artefacts and ways of life refers to the 'cultural' facet. The cultural facet may include cultural independence and the superimposition of ideas and concepts from external sources. The 'organizational' facet might refer to the potential for loss and reduced ability to recover caused by the exposure of individuals, communities, or local economies to the adverse consequences of an organization's critical shortcomings. The 'institutional' facet broadens the focus on institutional arrangements and the potential consequences of the critical shortcomings of institutions and institutional arrangements. In its most extreme case, the breakdown of national governance could be an outcome signified in part by corruption (Wisner et al., 2004). 'Territorial' vulnerability, a contested concept within social and political science, implies a unit of space and territoriality. The model views territoriality as a unique, dynamic assemblage of cultural, historical and present-day beliefs, customs, attitudes, assets and capital which characterize, or even define, a specific space or territory and its linkages with other territories (Tapsell et al., 2010). 'Economic' vulnerability is viewed as the susceptibility to, or potential for, loss of economic assets and productivity. The economic element includes the loss of the livelihoods such as assets support and the wealth and economic independence they create, together with financial deprivation, debt dependence and the ability to recover from the losses. 'Social' vulnerability in itself can be treated as a distinct, multifaceted entity, a second diamond structure within the social vulnerability facet of the vulnerability diamond and characterised by the same attributes on a scale more closely focused on the social. Such attributes incorporate(ing) livelihood, housing, security, and gender issues, among many others. Social norms and customs, international, national and private and public law may regulate these' (Parker et al., 2009). This diamond analogy provides a powerful description of different elements involved in vulnerability, but the process of how these elements interact and feedback is not recognised. Therefore, it treats vulnerability as a static entity.

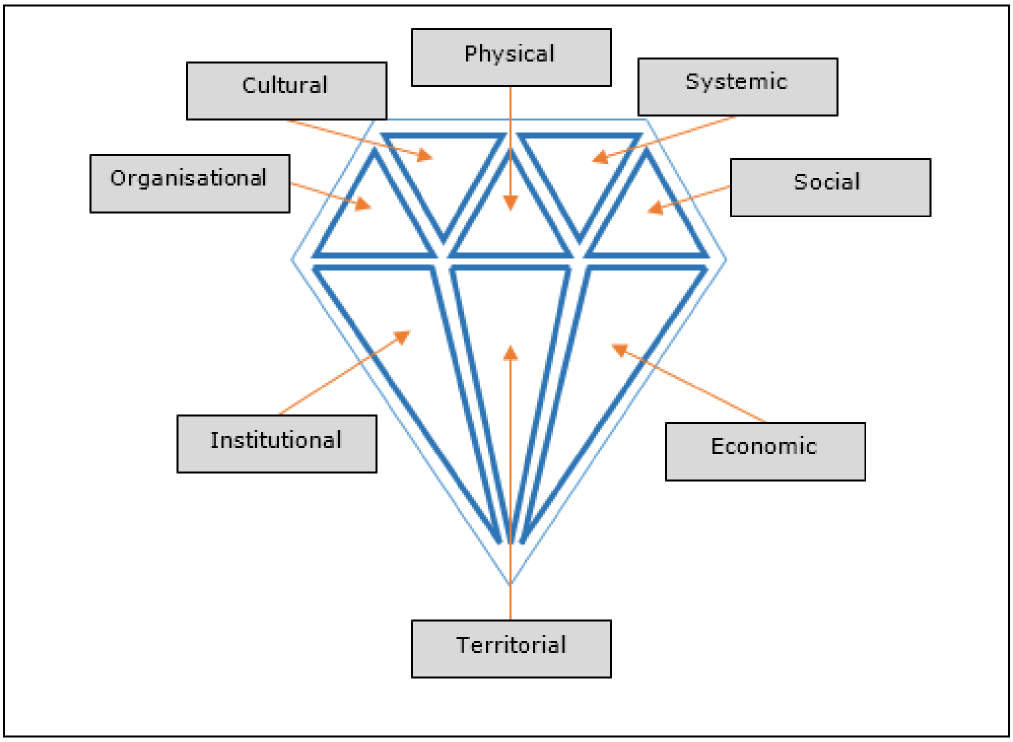


Figure 2-2 Diamond analogy illustrating the multifaceted nature of vulnerability (Parker et al., 2009)

Another example of a vulnerability analysis model is Bohle's double vulnerability structure (Figure 2-3). This conceptual framework for vulnerability analysis has two sides: external and internal. The external side 'exposure' is related to the exposure to risks and shocks, and the internal side 'coping' relates to the capacity to anticipate, cope with, resist and recover from the impact of a hazard (Bohle, 2001). The external side is related to the exposure to risks and shocks. It is influenced by Political Economy Approaches (e.g., social inequities, disproportionate division of assets), Human Ecology Perspectives (population dynamics and environmental management capacities) and the Entitlement Theory (which relates vulnerability to the incapacity of people to obtain or manage assets via legitimate economic means). The internal side is called coping and relates to the capacity to anticipate, cope with, resist and recover from the impact of a hazard. This side is influenced by the Crisis and Conflict Theory (control of assets and resources, capacities to manage crises and resolve conflicts), Action Theory Approaches (how people act and react freely as a result of social, economic, or governmental constraints) and Model of Access to Assets (mitigation of vulnerability through access to assets). From the social geography perspective, this two-sided vulnerability structure distinguished between external and internal vulnerabilities. However, the sides are not independent of each other, and feedback exists between the exposure to floods and coping with floods. This feedback needed to be included in the study to understand the cause-and-effect relationships existing in the problem situation.

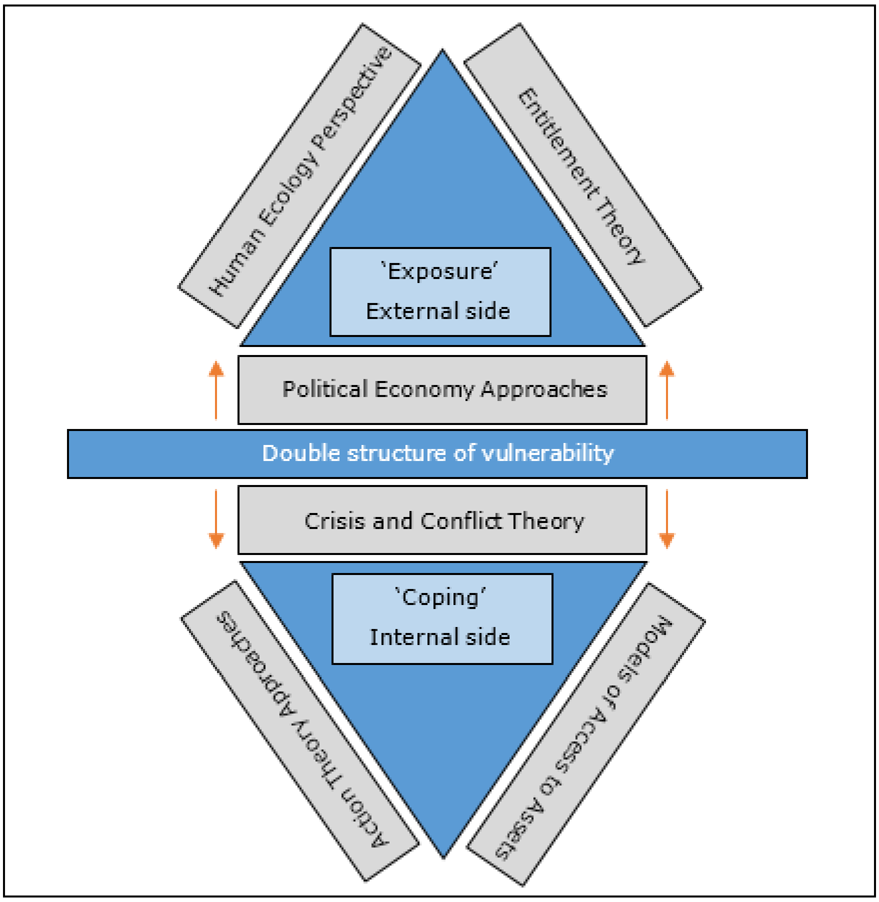


Figure 2-3 Bohle's conceptual framework for vulnerability analysis (Bohle, 2001)

2.4.4. Critique of qualitative assessment of vulnerability

These conceptual models proposed by social scientist help understand the social aspects of risks, socio-economic parameters and how society adapts to flood risk. It went beyond the scientific expert knowledges and utilised local knowledges to understand the vulnerabilities existing in a community to floods. With vulnerability in focus, the flood management paradigm shift slowly started progressing towards integrated flood management approaches covering both environment and socio-economic responses (Pahl-Wostl et al., 2013, Mustafa et al., 2015).

However, viewing vulnerability as a static entity, irrespective of whether it is assessed quantitatively or conceptualised qualitatively, limits predicting the system's behaviour, missing vital interactions and feedbacks among the social and physical systems over time. To date, in the context of flood risk research, there remains a lack of fundamental understanding of the interplay between physical and social processes (Di Baldassarre et al., 2015). These interactions are vital to be understood to support the sustainable development of society in today's changing environment (Montanari et al., 2013), with pressures such as climate change and population growth.

2.5. Socio-environmental system

There has already been advancement in recognising the importance of human-flood interactions in hydrological sciences. The IAHS Decade on Predictions in Ungauged Basins (PUB), 2003–2012, was an initiative by the International Association of Hydrological Sciences aimed at formulating and implementing science programs with the focus of engaging the hydrologists and the scientific community around the world to make reliable predictions/forecasts in ungauged basins (Sivapalan et al., 2003). The PUB decade achieved substantial success in improving international cooperation and demonstrated that the science community came forward collaboratively (Montanari et al., 2013, Blöschl et al., 2013), as evidenced by the research efforts generated (Blöschl et al., 2013). Following PUB's success, the International Association of Hydrological Sciences adopted a new scheme – Panta Rhei, which aimed at understanding the complex interactions between humans and hydrology by augmenting the traditional focus on physical catchment with considerations of co-evolving social and physical systems. It stressed the importance of interdisciplinary science in achieving this aim (Mount et al., 2016). There has been advancement in the understanding of these complex interactions using system thinking (e.g. Di Baldassarre et al. (2013), Sivapalan et al. (2012), Lane (2014)).

In its new scientific decade, 2013-2022, the international association of hydrological sciences introduced "Panta Rhei - Everything flows". Panta Rhei aims to conduct research activities dedicated to understanding the dynamic relationship between physical and social systems, stressing the importance of interdisciplinary research. With the Panta Rhei initiative, there has been a change in approach to flood risk management (Montanari et al., 2013), especially in the western parts of the world. Understanding floods as a hazard has evolved to view them as socio-environmental systems, having complex interactions and feedback among humans and floods. The concept of a socio-environmental system suggests that both physical and social systems are interconnected and that human actions are integral to nature (Adger, 2006). Socio-environmental systems can be defined as "Tightly linked social and biophysical subsystems that mutually influence one another. Example: human behaviours, decisions, and policies influence the status of ecosystems (e.g., water quality) that, in turn, influence human beings' quality of life and future decisions" (SESYNC, 2012). And a social system is defined as "any group of people who interact long enough to create a shared set of understanding, norms, or routines to integrate action, and established patterns of dominance and resource allocation" (Gunderson and Holling, 2002:107). A biophysical system is defined as the system that includes water, soil, air, flora and fauna, including the flood prone-area elevation and the structural measures (like embankments and dikes) in place to control flooding (Mens et al., 2011). These socio-environmental systems are composed of different known or unknown states or changes that might lead these systems to behave unpredictably (Clayton et al., 1996). Hence, it can be said that a socio-environmental system is a 'system of systems' (Yaeger et al., 2014, Arnold and Wade, 2015), having complex interactions at play (Tikunov and Trofimov, 1995), which can have significant implications on the physical world and its inhabitants (Turner Ii et al., 2016).

There has been an adaptation of a holistic approach to understanding these complex interactions involving both scientific expert knowledges and local knowledges. This shift has been a positive step towards understanding the feedbacks and interactions among the subsets of such complex systems. Understanding the basic structure of how people interact with water is complex, extending to the physical, social, cultural and spiritual parameters (Boelens, 2014). In the past, linear, one-way relationships were often used in flood hazard and vulnerability approaches (Sections 2.2 and 2.3). The limitation of these one-way relationships is that they do not consider the feedbacks produced as a result of these relationships and are instrumental in ascertaining the overall system's behaviour. According to Liu et al. (2007), integrated studies of coupled human and natural systems reveal new and complex patterns and processes that are not evident when studied separately by social or natural scientists. Liu et al. (2007) synthesised six case studies worldwide showing that couplings between human and natural systems vary across space, time, and organisational units. They also exhibit non-linear dynamics with thresholds, reciprocal feedback loops, time lags, resilience, heterogeneity, and surprises. Furthermore, past couplings have legacy effects on present conditions and future possibilities (Liu et al., 2007). These observations about these one-way relationships suggest that they present a misleading representation of how socio-environment systems work (Levin et al., 2013).

The unidirectional approach of the flood hazard paradigm may have been more appropriate when anthropogenic influences were not significant. However, the interactions between physical and social systems have changed as the socio-economical characteristics and societal changes are taking place at a larger scale due to the increase in the population growth rate and new connections. As a result, more significant feedback needs to be understood, assessed, modelled, and predicted by adopting an interdisciplinary approach (Montanari et al., 2013). Timmerman (1981), in the early 1980s, already indicated that vulnerability is a term of such broad use as to be almost useless for a detailed description at present, except as a rhetorical indicator of areas of most significant concern. In his work on vulnerability and resilience, Liverman (1990) concludes with a touch of irony that real vulnerability may lie in the inadequacy of our models of social systems and concepts.

A systems perspective puts emphasis on relationships rather than precise mathematical predictions. As such, it is better suited to analyse complex socio-environmental phenomena such as flood risk. Especially the formulation of social components (Loucks, 2015) in the socio-environmental systems is uncertain because these components are difficult to measure or predict (Gober and Wheater, 2015). The requirement to have better representation and understanding of feedbacks operating within and between the catchment and social, economic and infrastructure systems demands the development of a new generation of models that include coupled physical and human system components (Troy et al., 2015). This gap opens up new opportunities for using new types of data and information sources so that improved knowledge and understanding of the interactions occurring within and between physical and social systems can be gained and formalised. A summarised table (Table 2-1) has been produced to compare and understand the paradigm shift in the flood risk management discussed in this chapter.

Table 2-1 Summary table for the paradigm shift in flood risk management

Approach	Focus	Tools and techniques	Knowledges used and nature of assessment	Limitations	Examples
Hazard management paradigm (started in the 1960s)					
Approach of natural science	Floods are external events affecting the unprepared and unknown society (Fleuvrier, 1995)	Structural measures such as dikes, levees, flood defence barriers (Horner, 1976), river embankments (Nusser and Baghel, 2014)	Scientific Expert Knowledges Top-down approach Quantitative in nature	Cost, lack of reversibility, societal (Mustafa et al., 2015) and environmental impact (Johnson et al., 2005, Plate, 2002) Reactive in nature (Pahl-Wostl et al., 2013) and absolute protection is neither achievable nor sustainable (Tanaka et al., 2011)	Taylor (1904); Horner (1976), Taylor (1904); Horner (1976)

Approach	Focus	Tools and techniques	Knowledges used and nature of assessment	Limitations	Examples
Techno-scientific approach	Focuses on providing the hazard assessment to reduce flood losses by providing a way for decision-makers to predict, analyse, and manage the impacts of floods (Zhou et al., 2021, Duan et al., 2012)	Non-structural measures such as hazard mapping using hydraulic modelling (Zhou et al., 2021, Alho and Aaltonen, 2008) or hydrodynamic models (Moore and Jones, 1998), flood warning (Johnson et al., 2005), Land use planning (Duan et al., 2012, Zhou et al., 2021)	Scientific Expert Knowledges Top-down approach Quantitative in nature	Focuses mainly or exclusively on the hazard in isolation from vulnerability and its causes (Wisner et al., 2004)	Zhou et al. (2021); Wobus et al. (2017); Duan et al. (2012)
Vulnerability paradigm (came into focus in the 1980s)					

Approach	Focus	Tools and techniques	Knowledges used and nature of assessment	Limitations	Examples
Approach of applied science (Quantitative vulnerability)	Focused on integrated flood risk management approaches covering both environment and socio-economic responses (Pahl-Wostl et al., 2013, Mustafa et al., 2015)	Vulnerability index-based approach Combines techniques such as fuzzy logic (Udnoon et al., 2021), analytical hierarchy process (Duan et al., 2012), principal component analysis (Mavhura et al., 2017) with hydraulic or hydrological models using GIS	Predominantly scientific Expert Knowledges and/or sometimes local knowledges (to an extent) to collect socio-economic data. Top-down approach Quantitative in nature	The vulnerability elements introduced in these approaches are quantitative (Duan et al., 2012). Quantifying vulnerability reduces its impact and dismisses its complex nature (Alwang et al., 2001)	Kaoje et al. (2021); Leal et al. (2021); Udnoon et al. (2021); Duan et al. (2012); Mavhura et al. (2017); de Brito et al. (2018), Kaoje et al. (2021); Leal et al. (2021); Udnoon et al. (2021); Duan et al. (2012); Mavhura et al.

Approach	Focus	Tools and techniques	Knowledges used and nature of assessment	Limitations	Examples
					(2017); de Brito et al. (2018)
Approach of social science (Qualitative vulnerability)	Social scientists stressed that vulnerability is not only physical or economic but involves the social dimensions (Cardona, 2003), putting the at-	Vulnerability models such as pressure and release model (Wisner et al., 2004), access model (Wisner et al., 2004), diamond analogy (Parker et al., 2009)	Conceptualisation of vulnerability Qualitative in nature	Considers risk as a 'social construct,' ignoring the physical and environmental impacts, which are key components of flood risk.	Parker et al. (2009); Wisner et al. (2004); Harvey et al. (2009); Bohle (2001), Parker et al. (2009); Wisner et al.

Approach	Focus	Tools and techniques	Knowledges used and nature of assessment	Limitations	Examples
	risk communities back into the equation			A lack of fundamental understanding of the interplay between physical and social processes (Di Baldassarre et al., 2015)	(2004); Harvey et al. (2009); Bohle (2001)
Flood risk management paradigm – Socio-environmental based (came into focus in the 2000s)					
Systems based approach	Suggests that both physical and social systems are interconnected and that human actions are integral to nature (Adger, 2006)	Systems thinking technique is used to understand complex interactions (Arnold and Wade, 2015)	Can be either local knowledges or scientific expert knowledges or both Both qualitative and quantitative data is involved		Di Baldassarre et al. (2013); Srinivasan (2015); Di Baldassarre et al. (2013); Srinivasan (2015); (Suriya

Approach	**Focus**	**Tools and techniques**	**Knowledges used and nature of assessment**	**Limitations**	**Examples**
					and Mudgal, 2013); (Maskrey et al., 2016)

2.6. Chapter summary

In this chapter, the evolution of the flood risk paradigm was reviewed. It was understood that to manage floods, it is important to focus on floods being a socio-environmental system. Managing floods by focusing on flood hazards has led to intended flooding (Mustafa et al., 2015) and environmental impacts (Johnson et al., 2005). The flood hazard paradigm also neglects the dynamics involved in human-flood interaction (Ludwig et al., 2001), and the hazard-based policy implementation creates distrust in people (Ludwig et al., 2001). The flood vulnerability paradigm focuses on the social systems (Tapsell et al., 2010) and assess or conceptualise flood vulnerability as a static entity and does not consider the dynamic interactions between human and floods (Di Baldassarre et al., 2015).

With Panta Rhei, there has been an acknowledgement of systems perspective to view floods as socio-environmental systems (Montanari et al., 2013), recognising floods as a system of systems, i.e., social and physical systems. A systems perspective puts emphasis on relationships rather than precise mathematical predictions. Therefore, it opens opportunities to explore different types of knowledges to conceptualise the dynamic nature of flood systems (Mount et al., 2013). This research aims to understand flood risk by analysing complex human-flood interactions and feedbacks through a socio-environmental systems lens using local knowledges. Chapter 3 assesses the knowledge of the system and the tools and techniques to utilise those knowledges to conceptualise the system. The chapter provides the overview of the novel methodological approach adopted in this research for eliciting, abstracting, and analysing the socio-environmental system in this research.

Chapter 3. Methodological overview

3.1. Chapter overview

This chapter builds on the paradigm shift in flood management towards flood risk rather than flood hazard presented in Chapter 2. The focus of this chapter is to contextualise the methodological choices, providing a review of methods in order to select the most appropriate ones. Also, the chapter outlines the stages of the work undertaken in this research so the reader can follow.

The chapter explores methodological approaches to analyse risk through a systems lens. Since the early 1900s, and especially within the field of flood management, hard systems approaches have been dominant (Bunch, 2003) and associated with engineering-based solutions to manage flood hazards (Chapter 2). In contrast, this chapter explores the concept of systems thinking adopted in investigating soft systems (Section 3.2). Soft system methodology is an approach developed for business process modelling but is also applicable for general problem-solving. The soft system methodology is discussed in detail, covering an in-depth analysis of the modes available to study a problem situation and the conventional seven-stage model (Section 3.2.3) devised by Checkland and Scholes (2001). This seven-stage model using a multimethod approach (Section 3.3) forms the basis of the soft system methodology framework adopted in this thesis (Section 3.3).

The methodology framework adopted in this thesis is used in conjunction with a participatory approach (Section 3.5).

Participatory modelling provides an opportunity to integrate relevant knowledges into the institutional arrangements for policymaking, which is integral to broadening our understanding of disaster risk (Lauta, 2014). Lastly, the tools and techniques available to conceptualise a socio-environmental system are compared to select the most appropriate for this research (Section 3.6). System dynamics has its roots in problem-oriented modelling (Forrester, 1958), making it an appropriate tool for understanding complex, messy problem situations for soft system methodology. Moreover, it also works well with the participatory approach (Blair and Buytaert, 2016). Therefore, system dynamics modelling has been adopted to conceptualise the socio-environmental system in this research.

3.2. Systems thinking and soft system methodology

A systems perspective is necessary to understand the behaviour of interconnected social and physical parameters associated with flood events. Systems thinking has been conceptualised along a spectrum of analytical position, with the two ends being 'hard system' approaches and the other 'soft system' approaches.

3.2.1. Hard and soft systems

A hard systems approach, rooted in operations research and management science, focuses on applying structured methodologies, mathematical models, and optimisation techniques to analyse and solve problems. According to Checkland (1981), hard systems thinking is characterised by an emphasis on objective, measurable aspects of a system, striving for efficiency and optimisation within well-defined boundaries.

They are often characterised by quantifiable variables, and their behaviour can be predicted and controlled through mathematical or engineering models (Suriya and Mudgal, 2013). A hard system approach underpins systems analysis tools such as entity-relationship modelling or data-flow diagrams (e.g. flood hazard mapping (Vojtek and Vojteková, 2016)).

In contrast, a soft systems approach, as proposed by Checkland (1981), is more oriented towards understanding complex, socio-cultural, and human-centric issues. It recognises the subjective nature of the stakeholders' views, values, and interpretations, emphasising communication, learning, and the creation of shared understanding to reach a consensus on problem resolution. The basic assumption in soft system approaches is that there is more than one perspective to a problem and that human factors are critical (Suriya and Mudgal, 2013). In summary, the hard systems approach emphasises structured, analytical models and quantifiable elements to tackle problems, while the soft systems approach emphasises understanding diverse perspectives, cultural dynamics, and social elements to address complex issues (Checkland, 1981).

Both approaches are valuable in problem-solving and decision-making, with the choice between them depending on the nature of the problem and the level of complexity involved. However, there is a need for, and development of soft systems approaches over time. Essentially recognising that soft-systems approaches are more recent and have been developed in response to greater recognition that systems are messy and require different subjective viewpoints to be accommodated.

Environmental challenges, such as flood risk management, are increasingly understood as requiring systems perspectives, given their complex structures of interconnected social and biophysical elements. Examples in the academic literature such as Dyball and Newell (2014), Waltner-Toews et al. (2003) and Manfredo et al. (2014) argue that the challenging problems we face today, from world poverty to climate change, are a part of these complex structures of interconnected social and physical systems. As such, systems thinking provides an opportunity to understand the growing need to tackle these systems and understand their interconnectedness (Arnold and Wade, 2015). Moreover, viewing 'problems' as parts of an overall system, rather than reacting to present outcomes or events, potentially contributes to further developing the undesired issue or problem (O'Connor and McDermott, 1997).

Soft system methodology is particularly appropriate to understand flooding and related social vulnerabilities in the Kosi Basin. Le-Saint (1991) states that soft system methodology works best where a hard approach fails and where the setting of objectives or definition of what constitutes the problem is, in itself, problematic. In the Kosi Basin, attempts to apply hard approaches, i.e. embanking the river, have led to worsening the flooding situation (Mishra et al., 2008). A significant amount of damage occurs every year due to flooding, and a major flood event in 2008 created a loss of both life and property, affecting 30,000 families, causing 76 deaths and affecting a total of 3.5 million people (Dixit, 2009). There is an acute need for a long-lasting solution to provide resilience to the vulnerable communities residing in the Kosi Basin (Mishra et al., 2008).

Therefore, soft system methodology is particularly appropriate to understand flooding and related social vulnerabilities in the Kosi Basin (A detailed description of the Kosi Basin is provided in Chapter 4).

However, the main critique of systems approaches is that these approaches can artificially abstract complex social dynamics and hide important features in an attempt to convert a socio-cultural context into bounded variables that can be measured (Gillard et al., 2016). It raises important questions about who is doing the construction of the system and the pathways along which the system is being constructed. These questions are pertinent because they open up possibilities to identify the issues and causes of those issues in the current state of the system. In a context like Kosi, power dynamics play an important role and various perspectives are available such as technical experts, policymakers, NGOs, dominant and marginalised community members and gendered perspective (details in Section 5.2). However, until now only technical experts' views have been considered to understand the Kosi system and the condition of the Kosi Basin is only getting worse. Therefore, to identify who is doing the construction of the system and pathway of the Kosi system, a multimethod approach in conjunction with soft system methodology has been used in this thesis. This combination provided an opportunity to include the impacts of power structures which soft system methodology still lack (Jackson, 2019) (details in Section 3.3).

3.2.2. Set of steps in soft system methodology

The complexity of socio-environmental systems necessitates an iterative process to understand system structure and behaviour within a soft system methodology. The set of steps involved in soft system methodology (Figure 3-1) lies firmly within the tradition of action research, defined as a cognitive process that depends on social interaction between the observers and those in their surroundings (Baskerville and Wood-Harper, 1996). The first step aims to contribute both to the practical concerns of people in an immediate problematic situation and the goals of social science by collaboration within a mutually acceptable ethical framework (Rapport, 1970). As such, using this gathered information, a structured definition of the system depicting the current system behaviour can be derived in the second step. In the third step, a set of feasible and culturally-acceptable actions can be identified that can be taken to improve the problem situation rather than proposing a single, right solution or 'action' (Checkland and Scholes, 2001).

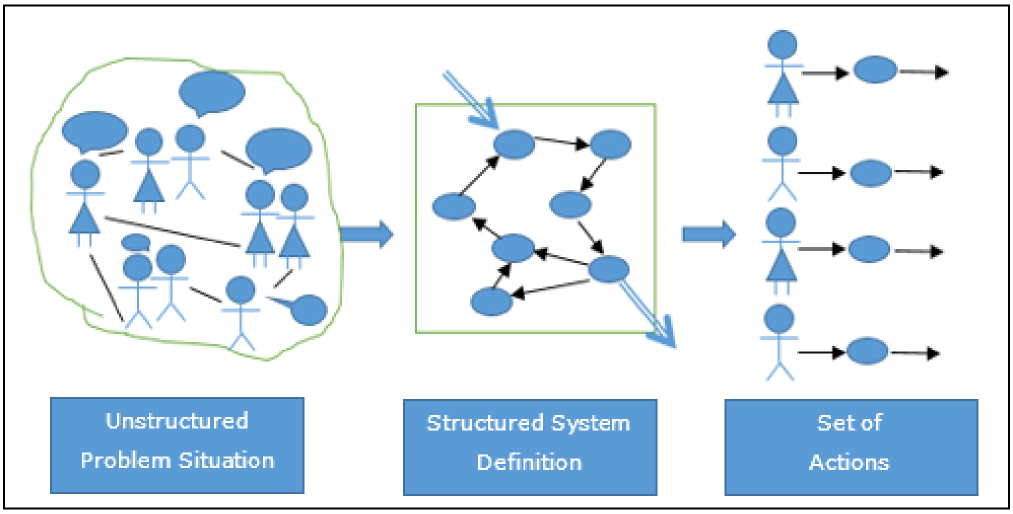


Figure 3-1 Set of steps involved in soft system methodology (Gasson, 2013)

3.2.3. Modes in soft system methodology

Soft systems methodology has been approached in two ways, known conventionally as Mode 1 and Mode 2 (Mingers and Taylor, 1992, Mingers, 2000). In Mode 1, soft system methodology is applied using a prescriptive seven-stage model (Table 3-1) developed by Checkland and Scholes (2001). The seven stages are generally followed in sequence developed by Checkland and Scholes (2001), with the researcher adopting an 'outsider' view (Mingers and Taylor, 1992, Mingers, 2000). In contrast, Mode 2 approaches the stages in a more flexible way (Checkland and Haynes, 1994), seeking to adopt the perspective of 'inside' actors within the system to make sense of the problem situation (Mingers and Taylor, 1992, Mingers, 2000). Therefore, Mode 1 is considered method-driven and focussed on knowledge creation, while Mode 2 is situation-driven and action-oriented, referring to 'doing work using soft system methodology' (Kreher, 1994). It is important to note that the conventional stages in Mode 1 were initially designed for business process modelling in 1981 (Checkland, 1981). The literature on soft system methodology approaches are mainly in healthcare (Augustsson et al., 2019), operational research such as designing workflow timetables (Mehregan et al., 2012), project management (Doloi, 2011), and supply chain management (Almotairi and Lumsden, 2009). It is worth emphasising that systems analysis has received widespread adoption in environmental management, and different frameworks such as human environment systems framework and sustainable livelihood approach have been developed (Binder et al., 2013). However, only a few studies in the field of flood risk management have used this approach (e.g. Bunch (2003), Suriya and Mudgal (2013), Dzulkarnain et al. (2019) and Rehman et al. (2019)). Understanding the basic structure of the complex interactions and building a conceptual model based on interactions between people and water involves physical, social, economic, spiritual and cultural parameters (Boelens, 2014). Involving these parameters provides complexity in modelling the system as it consists of both qualitative and quantitative data. However, soft system methodology is appropriate in modelling these complex systems and hence is adopted in this research.

3.2.4. Conventional seven stages in soft system methodology

The basic description of the conventional seven stages in soft system is provided in Table 3-1, followed by the in-depth description of these stages.

Table 3-1 Description of the conventional seven stages in soft system methodology (Checkland and Scholes, 2001)

Stages	**Description**	**Tools and Techniques used**
Stage 1 Problem situation defined	To understand the context and content of the problem situation as comprehensively and holistically as possible.	Interviews, observations, and workshops
Stage 2 Expressing the problem situation	Participants communicate the description of the problem situation in the	'Rich picture' technique

Stages	Description	Tools and Techniques used
	form of an abstract drawing of the problem situation.	
Stage 3 Root definition of relevant purposeful activity systems	To perform CATWOE analysis using the drawings created in stage 2. The results of CATWOE analysis are then used to derive root definitions defined as the core description of purposeful human/physical systems activities/interactions.	CATWOE analysis where, C = Customers, A = Actors, T = Transformation process, O = Owner, and E = Environmental constraints Root definition focusing on the underlying causes of system behaviour = A system to do X, by means of Y, in order to achieve Z
Stage 4 Conceptual models of the systems named in the root definitions	To define all the activities required to achieve the root definitions derived in stage 3. These activities will clearly define what the actors need to do in order to achieve the desired transformation.	Conceptual modelling such as causal loop diagrams.
Stage 5 Comparison of models and real world	To let participants, compare the model with the real-world situation and see if any changes are required. Also, to prioritise recommendations for the	Discussions with the participants to validate the conceptual model

Stages	Description	Tools and Techniques used
	changes which need to be made to existing activity systems.	
Stage 6 Systemically desirable culturally feasible changes	To gain input regarding the feasibility of prioritised changes from the system's stakeholders, i.e., 1) those affected by changes to the existing system and 2) people involved in implementing changes.	Discussions with the system's stakeholders
Stage 7 Action to improve the problem situation	To implement the feasible changes in a way that avoids upsetting too many people while still achieving the desired transformations	Implementing feasible and culturally acceptable changes

The following paragraphs provide an in-depth description of the seven stages involved in soft system methodology with some examples, where found necessary, to explain some processes. It was found instrumental to gain understanding of the processes involved in these stages to develop the methodological framework for this research.

In **stage 1**, participants' responses are recorded using interviews, observations or workshops to understand the content and context of the problem situation. Subsequently, to gather a visual representation of the problem situation, 'rich pictures' are drawn in **stage 2**. A rich picture is a representation of a problematic situation from the perspective of the participants, typically presented in the form of an abstract drawing describing the aspects of the system relevant to the problem definition (Checkland, 1981). Rich pictures are developed either collaboratively with participants in a workshop environment or, after a preliminary research into the situation, developed by a researcher or consultant and presented to stakeholders for validation or modification (Bunch, 2003). These pictures depict actors and elements in the focal system and indicate relationships among them, making it easier to identify and model the themes relevant to the problem situation. An example of a rich picture is presented in Figure 3-2, created during a study of the Adayar watershed, Chennai, India, by Suriya and Mudgal (2013). This rich picture depicts the host of activities along the river creating problems in the area. It also shows the responsible organisations written on the side of the rich picture.

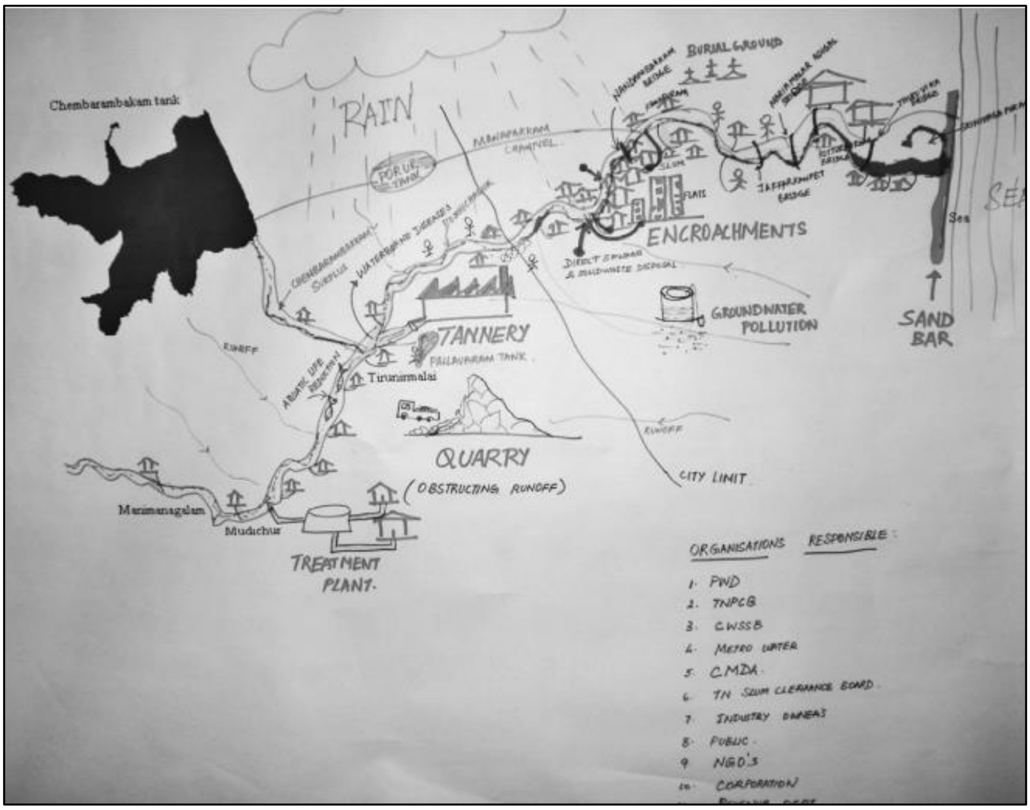


Figure 3-2 Rich picture developed by Suriya and Mudgal (2013)

Stage 3 focuses on defining the 'root definitions', the core description of the system's fundamental characteristics, focusing on the central issues relevant to the problem situation (Bunch, 2003). The rich picture helps express the problem situation, which is helpful to initiate thinking about the problem situation. However, a rich picture is unable to encode the dynamic interactions and feedback essential to model a system to understand its behaviour; these are brought out in the third stage.

In the third stage, the crucial aspects of the problem situation expressed in rich pictures are organised with the intention to highlight critical actors and fundamental characteristics (Bunch, 2003), i.e., the themes, interactions and feedback taking place in the system. CATWOE analysis provides a structured way of expressing and identifying the people, processes, and environment contributing to the problem situation (Suriya and Mudgal, 2013). The CATWOE stands for:

- Customers (C): the victims or beneficiaries of (T)ransformation process,
- Actors (A): those who would do (T)ransformation process,
- Transformation process (T): it is the process of conversion of input to output; (T)ransformation process should be related to X of the root,
- Weltanschauung (W): the worldview which makes (T)ransformation process meaningful in context,
- Owners (O): those who could stop (T)ransformation process; Most of the time, the owner is the person who formulates the longer-term aim Z, and
- Environmental constraints (E): visualising the systems border or systems level

This tool allows the identification of critical themes in the problem situation required to model the system and identify the key actors who can bring the required positive transformation change in the problem situation. The positive transformation here is the same described with the letter 'T' of CATWOE analysis. Therefore, CATWOE helps reduce the complex situation into key relevant systems (Bunch, 2003). Using the rich pictures, the participants or the researcher can draw out the descriptions of the human/physical systems activities/ interactions at play in the problem domain using CATWOE analysis.

A number of themes can be identified and explored using CATWOE analysis and modelled as systems, depending on the perspectives involved in expressing the problem situation (Bunch, 2003). These identified critical themes are used to develop a few core purposeful activities (Checkland, 1981), which are a one- or two-sentence description (root definition) of the core nature of the system (Bunch, 2003). A properly structured root definition comprises three elements: what, how, why and is of the form: A System to do X, by (means of) Y, in order to achieve Z, where:

- X – What the System does (The immediate aim of the system)
- Y – How it does it (The means of achieving that aim)
- Z – Why it is being done (The longer-term aim of the purposeful activity)

A root definition created by Suriya and Mudgal (2013:469) for their case study is presented as an example -

"A system to support more sustainable free flow of water within the boundary limits of the river, for a reasonable period of time (X), by means of developing a suitable flood management strategy, which is easy to operate and manage (Y), in order to reduce the tangible and intangible damages and create potential benefits to the citizens within the watershed (Z)."

Stage 4 uses this structured definition of the problematic situation and transforms it into a quantitative model structure for better insight into the situation. In the context of flood risk management, modelling techniques such as system dynamics (e.g. Rodriguez-Ulloa et al. (2011)), Bayesian network (e.g.

Scrieciu et al. (2021)), and agent-based modelling (e.g. Zhou et al. (2021)) have been used. However, in some cases, qualitative models have also been used (e.g. Rehman et al. (2019) and Dzulkarnain et al. (2019)). Deriving a conceptual model is a method of analysing the activities that need to occur to clearly define what the actors need to do to achieve the positive transformation to tackle the problem situation. In **stage 5**, a process of comparing models of relevant human activity systems and the expression of the problem situation is carried out via discussions with the participants. It also entails the exploration of recommendations for changes to the existing system (Checkland and Scholes, 2001). Afterwards, in **stage 6**, a discussion with the key stakeholders is held about the possible changes that can be introduced to the system. **Stage 7** involves the 'politics' of the intervention. The actions predicated in the previous stages of analysis must be implemented to avoid upsetting too many people while still achieving a positive transformational change in the system.

These stages mentioned above provide an in-depth description of the stages as defined by Checkland and Scholes (2001). However, in this research, Mode 2 approach of soft system methodology is adopted. In Mode 2, the conventional seven stages of Mode 1 are tailored to best suit the local context of the problem situation (Section 3.3). Mode 2 is situation-driven and action-oriented, referring to 'doing work using soft system methodology' (Kreher, 1994). It is important to understand that although this project does not focus on working with the local communities to implement change, instead, it aims to identify places where changes need to be implemented, principally focusing on generating knowledge. These knowledges consist of grounded realities that can inform management decisions in the context of complex problematic situations involving human activity (Checkland, 1981, Checkland and Scholes, 2001). Moreover, this research aims to understand the socio-environmental system from the perspective of stakeholders with local knowledges, which is an insider's perspective. Mode 2 is beneficial when understanding the system from an insider's perspective (Mingers and Taylor, 1992, Mingers, 2000) and, therefore, was considered appropriate for this research.

3.3. Critical systems thinking and multimethod approach

Soft system methodology follows the seven-stage approach as explained above in Section 3.2.4. However, some problems are highly complex and marked by irregularity, randomness, and disorder. This poses challenges for the neat abstraction of variables and relationships necessitated by many analytical tools utilised in systems thinking. The unpredictability of conducting such field research can offer challenges, thus a multimethod approach can help mitigate many caveats and limitations of systems research.

Mingers (2015) based their multimethodology approach on critical theory as it is pluralistic in both ontological and epistemological terms. "Thus with CR (Critical Realism) we can avoid the limitations of both empiricism and construction-ism whilst still making use of them as necessary. We begin with some events or occurrences that are puzzling or unwanted and then look for causal mechanisms that might be responsible for generating or maintaining them. This may well begin with data and/or discourse but will go beyond or beneath this to try and explain the phenomena not simply record it" (Mingers, 2015: 322). In summary, empiricism is a view based on facts and observation and constructionism posits that reality is socially constructed. These views have their limitations as their view of the system is epistemologically different. However, with critical realism, it is possible to accept an objective reality and challenge both empiricism and constructionism views. This perspective is particularly valuable because it enables contested terms (e.g., the 'government') to be interrogated as well as deeper narratives, meanings, and relationships to emerge. This is especially important when looking for root causes of phenomena or deep leverage points for change.

Jackson (2019) argues the impacts of power dynamics remain a challenge in system dynamics approaches. These issues challenged the seven stage SSM approach initially planned to be used in the research. During the analysis of the interviews (Stage 2), the researcher observed irregularities, randomness, and inconsistency in human-flood interactions resulting from the presence of power dynamics existing in the area (Table 5.5). These power dynamics were a result of caste-based power structure and gender discrimination.

Several approaches within critical theory focus on understanding and critiquing power dynamics such as Hegemony and Cultural Studies and Feminist Critical Theory (Jackson, 2019). For instance, Hegemony and Cultural Studies approaches explore how dominant groups in society maintain power through the control of ideas, cultural norms, and institutions (Glenzer, K., 2021, Williams R., 2001). It was visible during the interview data analysis, how caste-based power structures resulted in varied human-flood experiences of dominant and marginalised community stakeholders residing in Kosi Basin. On the other hand, Feminist Critical Theory addresses power dynamics through the lens of gender (Wigginton, B., & Lafrance, M. N., 2019) and exposes how patriarchal systems and societal norms marginalise and subjugate women. The interview data analysis also demonstrated gender discrimination due to patriarchal norms, which resulted in different human-flood interactions amongst men and women. Moreover, caste-based power structure added more pressure on women belonging to marginalised community, making them the most vulnerable within the community. The use of interview and workshop-based methods enabled these power dynamics to emerge in more nuanced ways than if a purely hard systems mapping approach was adopted.

Adopting a multimethod approach helped in the identification of power relationships amongst participants through the application of Critical Systems Heuristics. Critical Systems Heuristics is a framework for reflective practice based on system thinking and practical philosophy (Ulrich, W., Reynolds, M., 2020) that explicitly encourages a consideration of who would benefit or lose out from any intervention emerging out of the systems analysis (Hutcheson, M., Morton, A. & Blair, S.,2023).

Moreover, insights from these qualitative methods enabled power dynamics to be included in the CATWOE analysis and associated root definition (Section 6.3.1). Therefore, multimethodology has been adopted in this thesis to address the multidimensionality of the problem situation and the justifications for the methods have been presented in their respective chapters to maintain the flow of the thesis.

3.4. Framework of adopted soft system methodology used in this research

The methodology framework (Figure 3-3) adopted in this thesis is divided into three parts, which are derived from the basic principle used in the seven stages of the conventional soft system methodology:

System structure: The system structure refers to developing the structure of the socio-environmental system regarding flood risk management from the perspective of the participants. This part involves analysing and understanding the system's spatial and temporal characteristics and setting the boundaries for the present study. System structure covers stages 1 and 2 of the conventional seven-stage soft system model, which focuses on understanding the problem situation's context and content in a comprehensive and holistic sense.

System behaviour: In this part, the relevant human/physical system activities/interactions are elicited from the participants, and a conceptual socio-environmental model is created showcasing the identified interactions, which helps to understand the interactions and feedbacks in the system. This part covers stages 3 and 4 of the conventional model.

System interrogation and synthesis: System interrogation includes validating the conceptual model to see if the models fulfil the participants' expectations. Subsequently, the validated conceptual model would be analysed to find key characteristics of the system. System synthesis covers identifying places in the socio-environmental system where positive transformational changes can be introduced in local flood risk management planning. This part consists of stages 5, 6 and 7 of the conventional model.

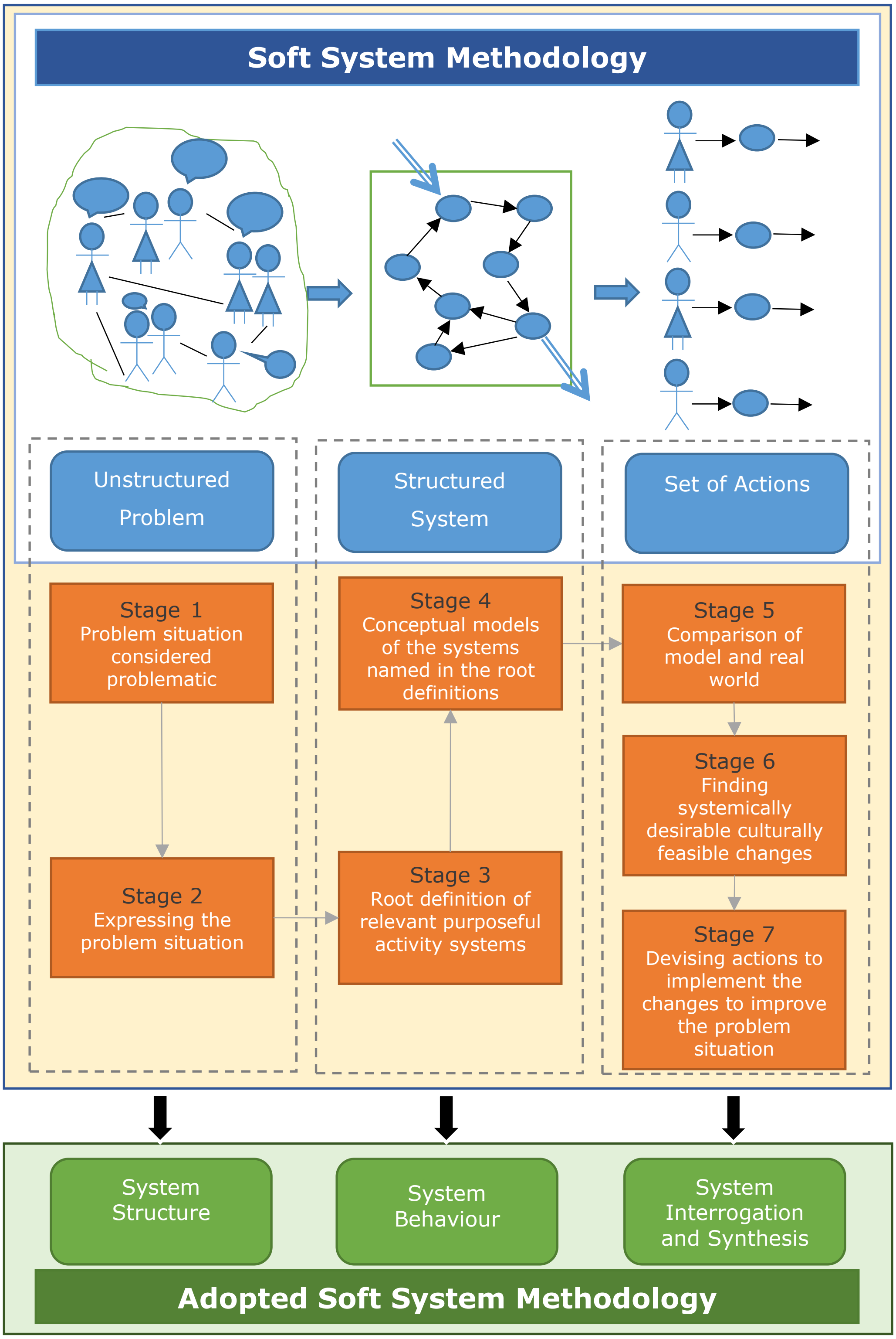


Figure 3-3 Framework of adopted Soft System Methodology (after Checkland and Scholes (2001) and (Gasson, 2013))

The detailed methodology structure is provided in Figure 3-4 and is briefly explained below. The first two parts (system structure and system behaviour) incorporate components of representation and formalisation, which are covered together in separate chapters in this thesis. Representation refers to the data collection process, the participants involved, and the methods, tools and techniques used to collect in-field data. Formalisation refers to the abstraction and analysis of the collected data.

1. **System structure** (covered in Chapter 5)

    - Stage 1 - Structure Representation: The participants for stakeholder engagement were identified, and a stakeholder engagement was conducted to understand 'what' the problems are that they face living in a flood-prone area.

    - Stage 2 – Structure Formalisation: Data elicited from the stakeholder engagement was analysed to understand the area's spatial and temporal characteristics and define the system boundaries.

2. **System behaviour** (covered in Chapter 6)

    - Stage 3 – Behaviour Representation: A second stakeholder engagement event was carried out to extract information about 'how' they were affected by the flooding situation. However, after this stakeholder engagement event the researcher was not able to carry out further steps with the participants due to travel restrictions as a result of

Covid-19. Therefore, the researcher carried out the CATWOE analysis on her own. This is presented in Chapter 6. The researcher recognises the limitation of this approach i.e., less than ideal input from the participants, however, the researcher has maintained the rigour nonetheless by using the data collected during the field visit to inform the CATWOE and root definition.

- Stage 4 - Behaviour Formalisation: The gathered data was used to drive out the relationships and feedbacks that exist in the system to build a conceptual model of the problem situation.

3. **System interrogation and synthesis** (system interrogation is covered in Chapter 7 and system synthesis in Chapter 8).

System interrogation:

- Stage 5 – System Validation and analysis: The participants were involved in verifying the built model to check if it fulfils their expectations. However, due to Covid-19, it was not possible to validate the built model with the participants. The second part of the interrogation was performed to analyse the built model to identify key characteristics of the system.

System synthesis:

- Stage 6 – System Interventions: Key characteristics of the model were assessed to identify places where sustainable transformational changes can be introduced to strengthen the local flood risk management decision-making.

- Stage 7 – System Recommendations: Recommending the identified changes.

The adopted methodology uses a mixed-method approach, involving both qualitative and quantitative methods, tools, and techniques at different stages for representing and formalising the system. Different participatory techniques were used in the representation to expand the breadth and range of the formalisation process (Busetto et al., 2020). However, the tools and techniques used in these stages are not discussed here. The description can be found in the respective stages in Chapter 5 (stages 1 and 2), Chapter 6 (stages 3 and 4), and Chapter 7 (stages 5, 6) and Chapter 8 (stage 7) to maintain the flow of the thesis.

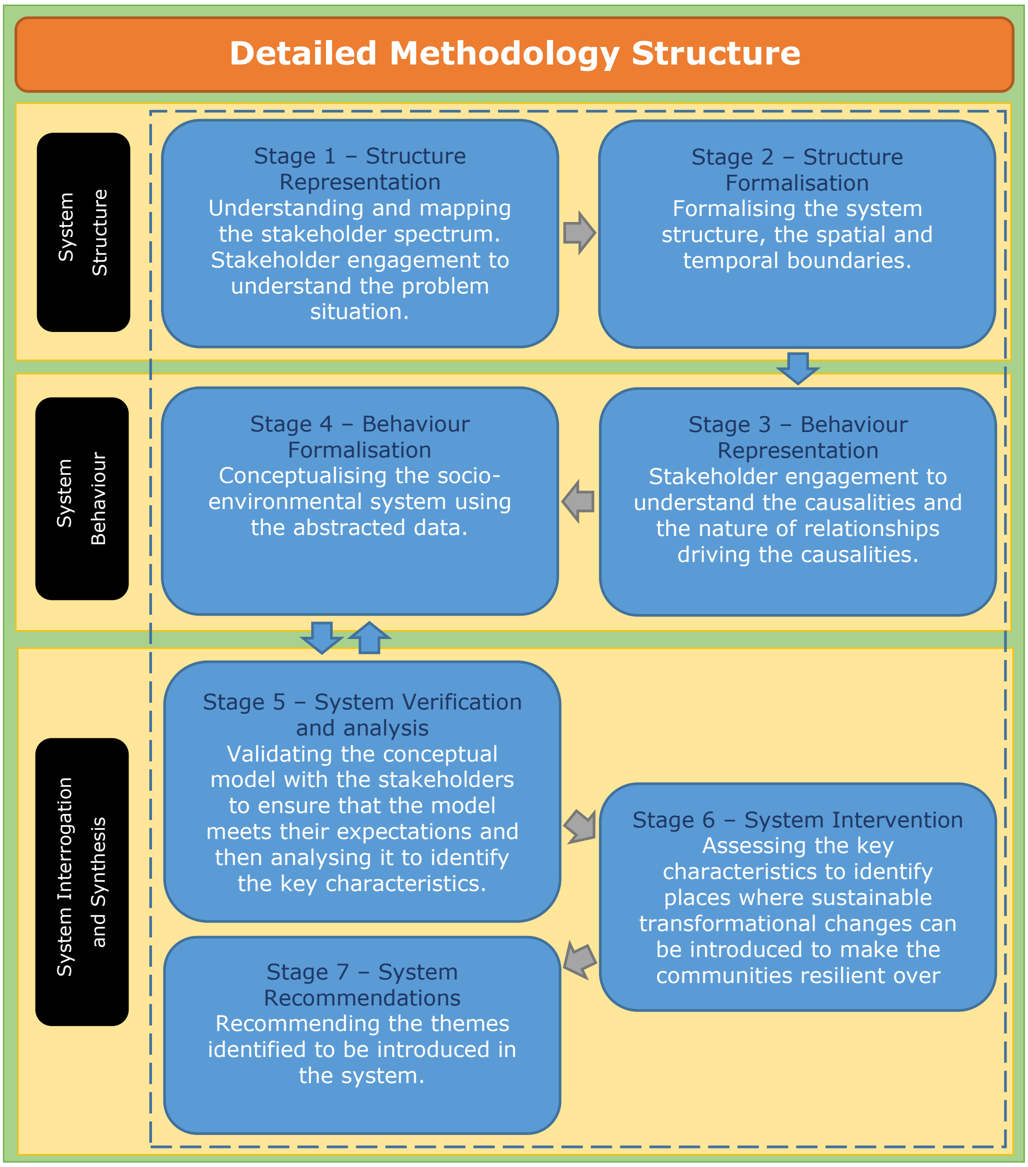


Figure 3-4 Adopted Soft System Methodology Structure

During the development of the system structure and building of the system behaviour, an ontological filter was used (Figure 3-5). An ontological filter is defined as a filter used to separate nuance present in the data elicited from the perceptions of the participants to logically interpret the perceptions into simplified form to define the system. The ontological filter is used to abstract and reproduce the collected qualitative data (during representation) in a structured form (during system formalisation) by logically interpreting the system dimension, e.g. to derive themes, variables and relationships between the variables to understand the problems faced in the real world (Rodriguez-Ulloa et al., 2011). The representation was required to be formalised because it cannot inform the decision-making process in flood risk management standalone as it is primarily qualitative and needs a refined structured form to define the system dynamics.

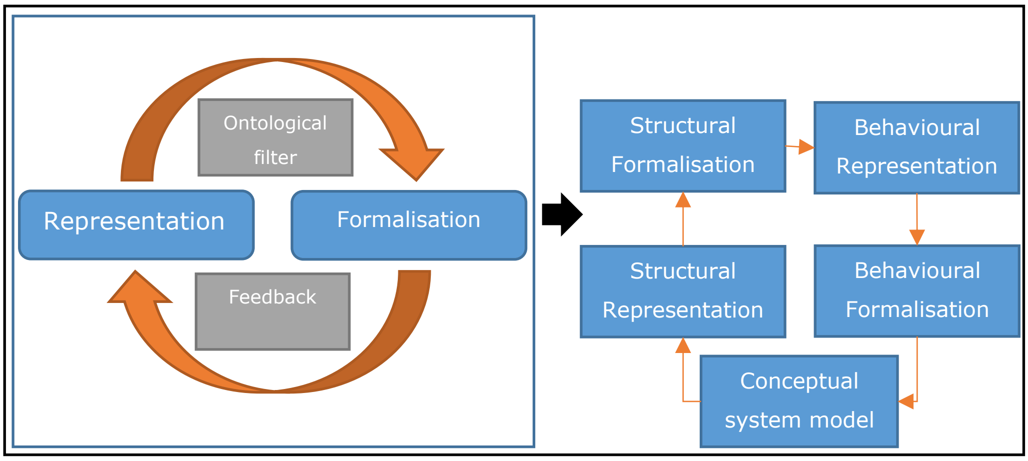


Figure 3-5 System representation and formalisation

Throughout the research, both representation and formalisation mutually informed one other, forming a loop (Figure 3-5). In this research, the results generated from structural formalisation were used to inform the behavioural representation of the system. This feedback was essential to optimise the efficiency of the representation and formalisation processes while defining the structure and analysing the behaviour. The resulting conceptualisation can provide new knowledge, which can help enrich the existing flood risk management policies. In practice, these new knowledges can be used for model appraisal, and the model can be further revised by repeating the representation and formalisation loop.

3.5. Justification for using participatory modelling to conceptualise the system

There is literature present in which the structure and behaviour of the socio-environmental system have been studied in the context of flood management. Di Baldassarre et al. (2013) theorised the complex human-flood interactions from a flooding perspective. Srinivasan (2015) also conducted a case study in Chennai, India, examining the socio-hydrological system addressing the bi-directional feedback in coupled human-water systems. Suriya and Mudgal (2013) have also used soft system methodology to study flood management in India but only involved scientific experts.

Expert scientific knowledge alone is increasingly seen as insufficient for informing decisions concerned with specific local contexts (Douglas et al., 2010, Eden et al., 2006, Cinderby and Forrester, 2005, Robbins, 2000, Wynne, 1993, Wynne, 1992). Stakeholder participation in vulnerability analysis for policymaking typically focuses on scientific expert knowledges (Rossignol et al., 2015, Edelenbos et al., 2017) and does not integrate traditional and local knowledge, which is essential for effective and ethical environmental management (Raymond et al., 2010) (Andersson et al., 2015, Lindahl et al., 2015). Instead, the decision-makers perceive stakeholder participation as a threat to the essential decisions for preparing to deal with severe crises (Warner, 2006).

In the context of integrated flood risk management, stakeholder participation has grown to be recognised as crucial (Renn, 2008) (Edelenbos et al., 2017). Accordingly, there has been an increase in academic papers and policies focusing on stakeholder participation in flood risk management (Thaler and Levin-Keitel, 2016, Leach et al., 2002), realising that the scientific expert knowledges being used in the decision-making for specific local contexts is seen as increasingly insufficient (Douglas et al., 2010, Cinderby and Forrester, 2005). Incorporating inaccurate and incomplete knowledges may result in poor formalisation of the socio-environmental system, resulting in an inaccurate and incomplete understanding of the complex system behaviour, hampering the design of effective and sustainable interventions (Arnold and Wade, 2015). In the case of implementing flood management, there have been examples of devastating floods worldwide, including the Kosi floods in 2008 (Mishra et al., 2008), the Yangtze River flood in 1998 and the New Orleans flood in 2005 (Andersen and Buhrman, 2007). The embankments in these cases were constructed to control the flood hazard. However, building levees permitted more housing development on the floodplain but reduced community resilience to flooding longer term (Di Baldassarre et al., 2013).

Disaster management is dependent on the social organisation (Albris et al., 2020) because disasters have social roots (Tierney, 2014). Mosse (2001) pointed out that these local knowledges, which are neglected in decision-making, are often generated and structured by the planning processes and outcomes. Therefore, for participation, these local knowledges can more accurately be viewed as elicitation of 'planning knowledges' rather than 'people knowledges'. These grounded realities about the vulnerabilities existing in these social systems enrich the groups of people with local knowledges (Robertson and McGee, 2003) of the complex human-flood interactions gathered through their lived experiences.

Moreover, socio-environmental systems are self-reflective (Musters et al., 1998) and involving the grounded realities of the at-risk communities would provide valuable data that can holistically enrich existing flood risk knowledge. These vital information/data can be elicited and integrated to formalise a socio-environmental system (Evans and Plows, 2007). This shift in 'who is doing the construction' would assist in conceptualising the socio-environmental systems from a grounded perspective of flood risk. Also, the decision-makers are starting to understand that involving communities, NGOs, and flood action groups in decision-making would gather support for the decisions made for flood risk management (Edelenbos et al., 2017), providing the process democratic legitimacy and also ensuring the quality of decisions (Stanghellini and Collentine, 2008, Michels, 2011).

In return, the new knowledge acquired from the participation process can then be used as feedback to inform local flood risk management decision-making (Raymond et al., 2010, Haughton et al., 2015), completing the loop. Moreover, providing new opportunities for eliciting feedbacks occurring between flooding and community resilience (Haase, 2013) and adaptation and learning processes (Mount et al., 2016).

Thus, for efficient disaster management, the adoption of a participatory paradigm is needed (Brown and Damery, 2002, Bunch, 2003, Reed et al., 2009, Suriya and Mudgal, 2013, Maskrey et al., 2016) so that both scientific and local knowledges can be effectively engaged in the co-production of the knowledge necessary to inform decisions (Callon, 1999). Integration of knowledges helps conceptualise the system in the form that best justifies understanding the real world and not just the physical damage. Therefore, integrating these relevant knowledges into the institutional arrangements for policymaking is integral to broadening the understanding of disaster risk (Lauta, 2014). Three benefits of a participatory paradigm are regularly cited (Fiorino, 1990, Stirling, 2006, Chilvers, 2008):

1. **Normative benefits:** Enhancing the citizen empowerment, equity and social justice in decisions and the evidence that underpins them (Renn et al., 2011, Bohmann, 1996);

2. **Instrumental benefits**: Enriching the legitimacy of evidence and decisions and the trust that is afforded to them (Gaddis et al., 2010, Voinov and Bousquet, 2010) and;

3. **Substantive benefits:** Improving the quality of the evidence underpinning the decisions which are ultimately made (Stirling, 1998).

The participatory process ultimately influences the conceptualisation of the socio-environmental system of the flows and interactions in the system and is instrumental in understanding the system. Therefore, a systematic participatory structure was designed for this research (Figure 3-6). In Figure 3-6, the researcher mentions two types of activities, i.e., stakeholder-led and researcher-led. The stakeholder-led activities represent the activities in which the participants share their knowledge and expertise regarding the system. In contrast, researcher-led activities refer to the activities the researcher undertook after eliciting the data to abstract the required information to build the system's model. Mediated modelling was advantageous in this research because it allowed the researcher to co-develop the conceptual model with the participants (Maskrey et al., 2016, Matthews et al., 2007). Working in parallel with the stakeholders helps in a) integrating different levels of expertise in building the model and b) co-developing the model so that it is understood and accepted by participants (Maskrey et al., 2016). The participatory process was divided into the parts of the framework of soft system methodology discussed earlier in Section 3.3, i.e., a) system structure, b) system behaviour and c) system interrogation and synthesis.

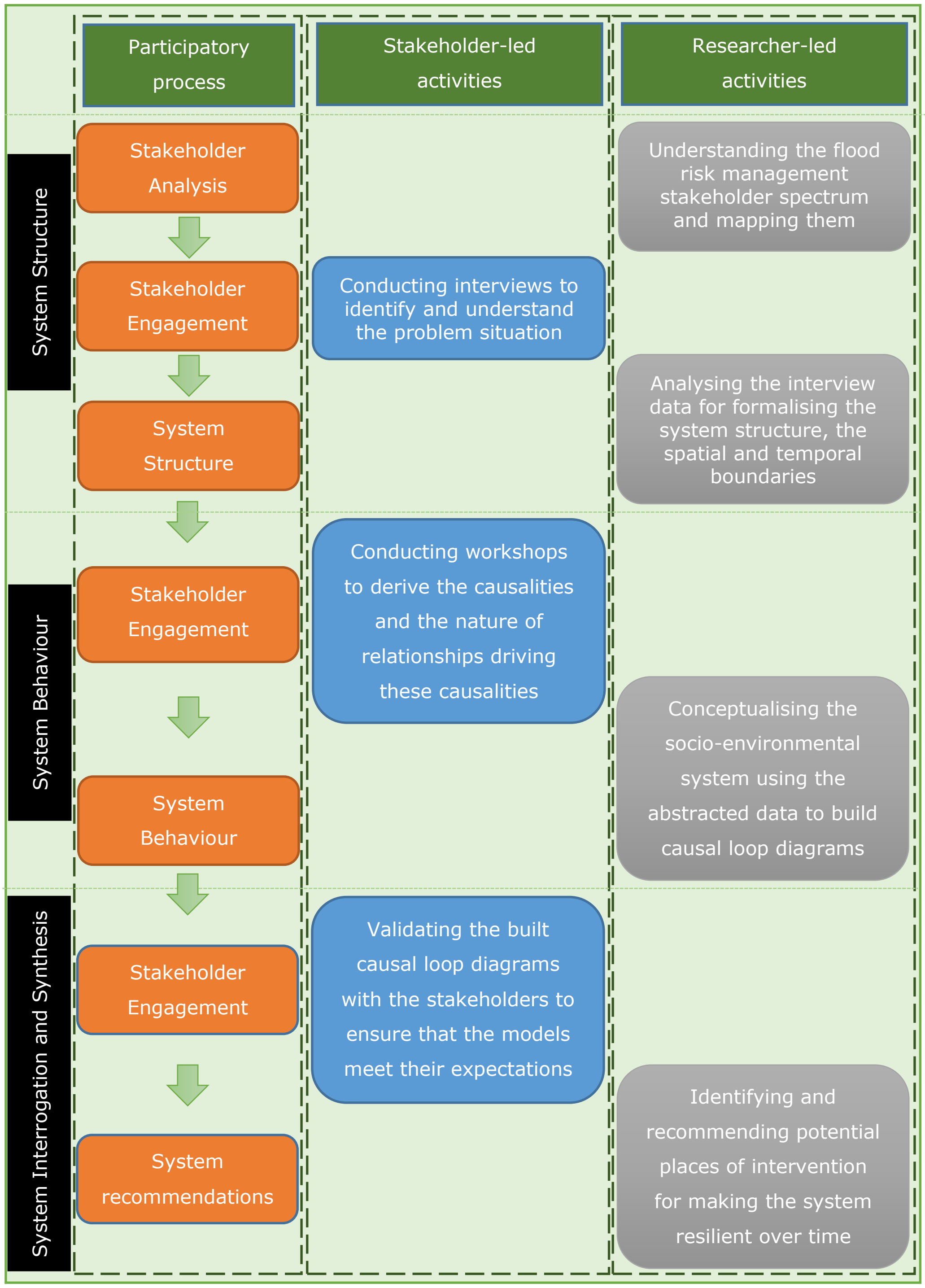


Figure 3-6 Adopted Participatory Process

3.6. Methodological tools and approaches for system conceptualisation

For conceptualising the system, in stage 4 (Figure 3-4), various techniques and tools are available to conceptualise the causal relationships of a socio-environmental system in the flood risk management field. These tools and techniques include pattern-oriented modelling (Arnold et al., 2015), agent-based modelling (Eivazy and Malek, 2019), Bayesian network modelling (Maskrey et al., 2016), system dynamics (Perrone et al., 2020), coupled component modelling (Zischg, 2018). However, the system dynamics technique is considered the best fit for the current research context.

The modelling approaches mentioned above have certain advantages and disadvantages, and selecting an approach depends on the research focus. As the research aims to develop an understanding of overall system behaviour, system dynamics was selected (Di Baldassarre et al., 2013). System dynamics is a problem-oriented modelling approach originating in the industrial field (Forrester, 1958). System dynamics has the ability to conceptualise the dynamic behaviour of a system (Forrester, 1961, Sterman, 2001). The advantage of system dynamics is its ability to develop system understanding, which makes it an explicitly used tool to model socio-environmental systems (Blair and Buytaert, 2016). Fazey et al. (2011) used local people's perceptions to understand the system behaviour in the Solomon Islands, and Mai et al. (2020) used system dynamics to understand flood risk in Roma, Australia.

The ability of system dynamics to model system feedbacks and longer-term temporal change is advantageous over alternate approaches such as Bayesian networks, which have the ability to snapshot the system at a given point in time (Maskrey et al., 2016). Kosi Basin has an annual monsoon cyclicity that produces long-term temporal changes in the system behaviour. This annual cyclicity is integral to capturing the system dynamics in Kosi Basin, and system dynamics provides the benefit of capturing longer-term temporal change. Hence, system dynamics is an appropriate technique to be used in a local setting such as Kosi Basin. Moreover, compared to agent-based modelling, system dynamic modelling focuses on understanding the system's overall behaviour, whereas the main focus of agent-based modelling is on simulating the behaviour of individual agents in a system (Cassidy et al., 2019).

However, the level of complexity involved is instrumental while using system dynamics. Very simplistic relationships can result in a failure to capture the system's complexity (Kandasamy et al., 2014) and on the contrary, including too much complexity while modelling can produce relationships that do not represent the real-world situation (Kelly et al., 2013). Therefore, system dynamics modelling requires a balance in the amount of complexity involved. In this research, the balance was achieved by being driven by the problem and incorporating local perspectives (i.e. the importance of variables and relationships are defined by actors within the system).

Therefore, system dynamics modelling provides an easy integration of disciplines, as can be seen in the works of Di

Baldassarre et al. (2013), and also works well with participatory modelling (e.g. Fazey et al. (2011)). Moreover, this modelling approach has the ability to conceptualise a system's dynamic behaviour (Forrester, 1961, Sterman, 2001). Therefore, this research adopted system dynamics in conjunction with soft system methodology to formalise the socio-environmental system.

3.7. Chapter summary

In this chapter, the soft system methodology was explored, and a methodological framework was adopted based on the soft system methodology. The details of the tools and techniques used in each stage of the methodological framework are not presented in this chapter to maintain the flow of the thesis. However, the systemic participatory approach to be adopted in this research was justified based on its normative, instrumental and substantial benefits. In the end, system dynamics modelling was chosen to be the best fit for conceptualising the system because of its ability to conceptualise system dynamics and compatibility with the participatory approach. The next chapter, i.e., Chapter 4, discusses the relevance of Kosi Basin as a socio-environmental system and how it is a perfect fit to conduct this research.

Chapter 4. Kosi Basin: A socio-environmental system

4.1. Chapter overview

This chapter presents the Kosi Basin as a socio-environmental system, according to the theoretical and methodological foundation developed in Chapter 3. Firstly, research in flood risk management worldwide is discussed (Section 4.2). This section compares flood risk management research in developed countries like the UK and the USA with a developing country like India, highlighting contrasts in flood risk management paradigms. Second, the current management and policy structure of flood risk management in India is studied (Section 4.3) which enabled exploring the current flood risk management focus and the division of roles and responsibilities between the central and state governments in the decision-making process of flood risk management.

Kosi has been selected as a study site in this research because it is a good example of the failure of hard engineering to control floods or reduce flood risk; instead, it has made the at-risk communities living in the Kosi Basin more vulnerable. Therefore, Kosi Basin and its flood risk management are presented, along with the area's current flood risk management strategies (Section 4.4). In presenting the Kosi Basin as a social-ecological system, this chapter provides an overview of the Kosi Basin's physical (along with the history of building embankments) (Section 4.5.1) and social (Section 4.5.2) dimensions. Interpretive descriptions of the system collected from participants' perceptions are presented in Chapter 5 and

Chapter 6. Moreover, in this thesis, the research scale adopted is local flood risk management. Therefore, the river system's international aspects and the upstream decision-making process are not included due to this limitation. However, a systems perspective means that some degree of connection to these broader scales is needed. Therefore, a brief overview of these topics is covered in this chapter, especially decision-making at a national scale. However, it is important to note that a 'system boundary' has been drawn at a local scale. Therefore, the national and international aspects are not interrogated in further detail.

4.2. Flood risk management around the world

4.2.1. Global flood occurrence and impact

Flooding is the most frequent natural disaster affecting more people worldwide each year than any other disaster. Since 1960, there has been a radical increase in the impact of floods worldwide. During 1960-1969, only 151 floods were observed, which increased to 1,499 floods in 2000-2009 (IFRC, 2020). From 2010 to 2019, floods constituted a total of 46% of all the disasters triggered by natural hazards, affecting a total of 673 million people around the world (EM-DAT, 2022). The trend looks to get worse in the near future as flood levels, frequencies of flooding and duration might increase because of the climatic changes. While as a result of rapid urbanisation, more than one billion people live on floodplains (Hinkel et al., 2014, Jongman et al., 2014).

Figure 4-1 provides a clear insight into the flood occurrences from 2000-2020, with each country ranked based on the total number of flood occurrences in the 21-year period. It can be observed that India and China come in the dark blue zone, with India facing 176 floods and China – 204. However, India is one of the most severely flood-affected nations worldwide, with a 2.4 times higher number of flood-related deaths in India (=29,706) than in China (=12,418) (EM-DAT, 2022). In addition, more than 12% (=0.39 million sq km) of the total geographical area of India (=3.29 million sq km) is prone to floods (NDMA, 2022). In India, on average, 16,000 lives are lost, 75,000 sq km of land is affected, and the damage to property (houses and public utilities) and crops amounts to £179 million (NDMA, 2022). These statistics show the high impact of floods in India due to the Indian meteorology (monsoons), topography (impact of Himalayas), and economy (poor populations who are more vulnerable to flood events) (NDMA, 2022).

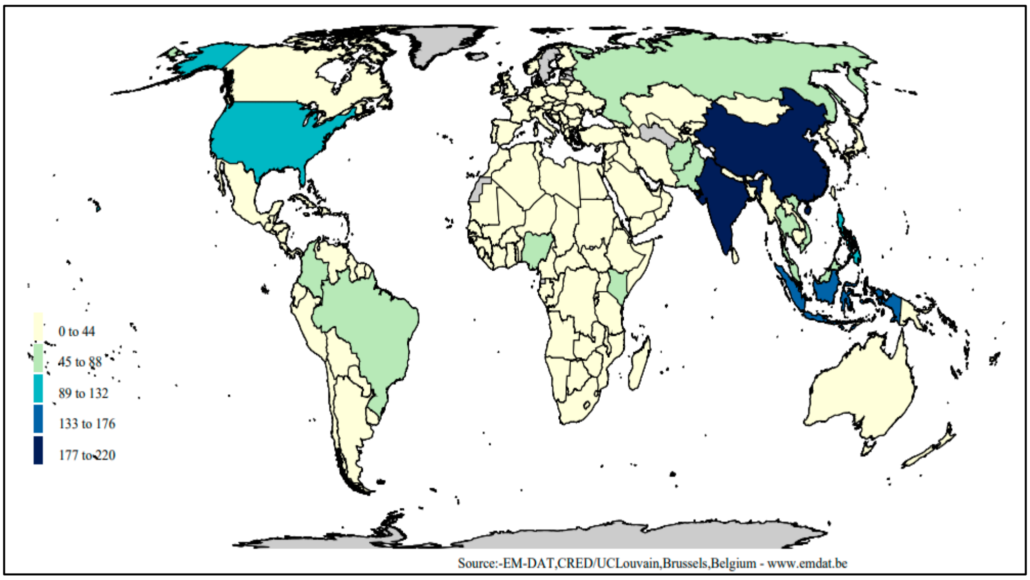


Figure 4-1 Global occurrences of flood disasters during 2000-2020 (Source: EM-DAT (2022)) Global occurrences of flood disasters during 2000-2020
(Source: EM-DAT (2022))

Furthermore, a comparison has been made between India and developed countries regarding floods and the total number of deaths (Figure 4-2). It can be seen that for the period 2000-2020, India had 176 floods with 29,706 deaths. However, in the UK, there were 26 floods with 37 deaths. The USA had 96 floods and 571 flood-related deaths. According to EM-DAT records, the Netherlands had 0 floods between 2000 and 2020. (Note: EM-DAT database consists of disasters conforming to at least one of the following criteria: 1) 10 or more people dead; 2) 100 or more people affected; 3) The declaration of a state of emergency 4) A call for international assistance) (EM-DAT, 2022)).

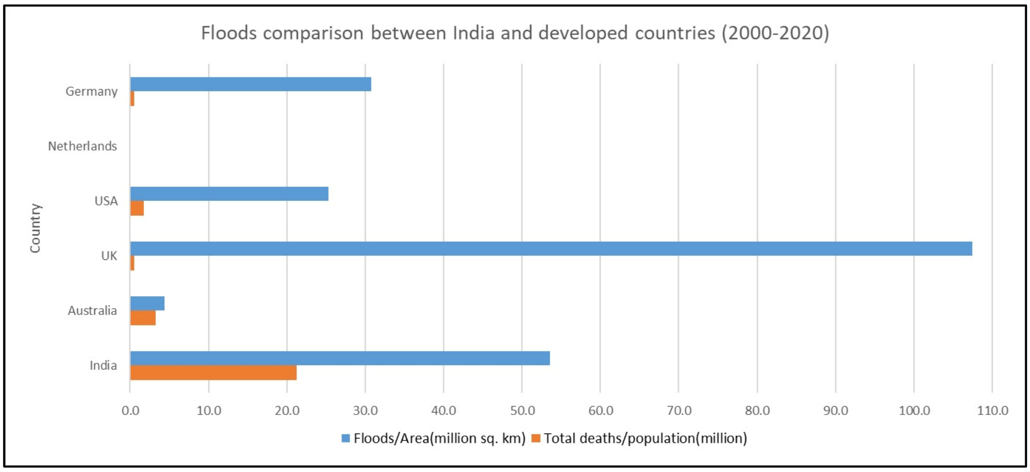


Figure 4-2 Comparison of total floods and average deaths per flood around the world (Source: EM-DAT (2022))

This dataset reflects that a developing country like India is more vulnerable to flooding than the developed world – for example, India has had 118 times more deaths per flood than the UK between 2000 and 2020. Flood vulnerability is impacted by both the physical and social systems; flood duration and frequencies are likely to increase in the future because of the increasing pressure from both systems. Extreme precipitation events will become more intense and frequent, and the likelihood of flood hazards will increase in regions like Asia, especially the south and southeast, because of climate change (IPCC, 2014). From the perspective of population growth, significant rises in people at risk in flood-prone areas are predicted, e.g. from 1970-2030 in Asia, the population at risk is expected to grow 2.6 times, increasing from 29.6 million to 77.6 million (IPCC, 2014). The future of flood risk essentially depends on how floods are managed, with both the physical and social systems putting pressure on this system of systems, a socio-environmental system of flood risk. Approaches to flood risk management will therefore have an enormous influence on vulnerable communities residing in a flood-prone areas. According to a recent definition of Disaster Risk Management by UNDDR (2020): "Disaster risk management is the application of disaster risk reduction policies and strategies to prevent new disaster risk, reduce existing disaster risk and manage residual risk, contributing to the strengthening of resilience and reduction of disaster losses." It is being understood that for managing floods, it is vital to focus on risk, and importance has been given to new data sources, involving local knowledges to understand the local context, i.e., the human-flood interactions, to understand the behaviour of the socio-environmental system to design flood risk management policies. Countries worldwide have started to recognise the importance of managing 'risk' and not only 'hazard' in flood risk management. However, each country's pace and the current situation concerning flood risk management differ from each other (Bubeck et al., 2017). Over the years, an increase in research trends for "Flood Risk Management" has been observed worldwide. In the next section, an effort has been made to understand flood risk management and the present policy focus in India.

4.3. Flood risk management in India

In post-independent India (since 1947), the government of India has been focusing on reducing the likelihood of occurrence of floods and limiting the potential consequences of flooding (Mohanty et al., 2020). The unprecedented and devastating 1954 Bihar floods were the main drive behind forming a National Program of flood management for flood prevention (Mohapatra and Singh, 2003). However, the policies were formulated based on short-term goals, and the reliance was on hard engineering for flood protection, i.e. using structural measures to control/prevent floods (Mohanty et al., 2020). The second approach adopted in India is flood preparedness, a preventive option, which attempts to avoid or limit the adverse effect of floods by focusing on flood-proofing, zoning and disaster preparedness. However, the policies predominantly focus on structural measures to reduce flood hazards (Mohanty et al., 2020). Structures like dams and reservoirs, channel improvement, drainage improvement, diversion of floodwaters, natural detention basins and embankment walls were set up in different regions of India for riverine flood protection (Kaushik and Sharma, 2012). Major embankment projects included: Brahmaputra (Assam), Kosi and Gandak (Bihar), Krishna and Godavari (Andhra Pradesh), Mahanadi (Orissa), Tapi (Gujarat), and Lower Damodar (West Bengal) (Mohapatra and Singh, 2003).

These embankment projects provided a short-term solution for flood protection in these flood-affected areas. However, in terms of long-term solutions, these structural measures were not successful, as evident from the increase in vulnerability in communities residing in flood-prone regions in the last five decades (Mohanty et al., 2020). According to a report by the Environment Agency and Defra, the effectiveness of a flood embankment can reduce over time for three main reasons (Morris et al., 2007):

(1) change in loading conditions over time relative to the original design parameters;

(2) change in their required standard of protection such as frequency of overtopping; and

(3) deterioration of materials over time, for example, due to prolonged immersion in floodwater.

Therefore, there are also significant costs associated with the maintenance of existing embankments. Several disadvantages arise from the construction of embankments. Embankments could have severe effects on the ecology of the river channel and its floodplain (Johnson et al., 2005). Embankments can restrict the natural flow of the river and prevent the creation of new side channels and wetland areas that would have otherwise occurred naturally. Due to the sturdy nature of the structure needed to create a river embankment, they act as a barrier between the river channel and the surrounding floodplain – reducing transmission loss and groundwater recharge (Johnson et al., 2005). This in turn is affecting the groundwater resources in the area, a consequence that can have both ecological and economic benefits to the community.

In 1980, the national commission on floods (Rashtriya Barh Ayog) emphasised the importance of devising a long-term strategy for flood management, including both structural and non-structural measures (Kaushik and Sharma, 2012). This commission was formed in 1976 with the aim of evaluating the flood management approach and providing future guidelines. Following this, the national and central water commission (government of India) introduced flood plain management and zoning plans to restrict potential flood damages. These non-structural measures, such as land-use planning, flood forecasting and zoning, have been mentioned in flood management policies but are only practised by some states in the country (Prasad and Mukherjee, 2014).

A major reason for embanking the rivers in India is that the policymakers, i.e., the government of India and national agencies such as the National disaster management authority, still treat disasters as a natural phenomenon as opposed to a result of community's vulnerability (Lavell and Maskrey, 2014). This assumption has made expert scientific knowledges an integral part of disaster risk management systems (Albris et al., 2020). The current structure of the flood management system in India is divided into a two-tiered hierarchy: 1) the central government and 2) the state government. The central government is responsible for formulating policies and setting up committees and task forces. The central government includes organisations like the Central Water Commission, National Disaster Management Authority, Ministry of Jal Shakti

(Ministry of Water Power), Indian Meteorological Department, National Institute of Disaster Management and National Remote Sensing Centre. However, planning and execution of the measure to be undertaken at the ground level are the responsibility of the state government (Mohapatra and Singh, 2003). The current flood management structure in India does not give the required attention to local knowledges (Mohanty et al., 2020), resulting in the exclusion of incorporating the complexity of the relationship between the hazard and at-risk communities points towards the failure of the human system to address these complex interactions (Wisner et al., 2004, Oliver-Smith and Hoffman, 2019). Therefore, there are still gaps in integrating and linking science into disaster risk reduction plans, strategies and policies (Albris et al., 2020), limiting the effectiveness of flood risk strategies in India for reducing vulnerability.

The following section discusses the flooding in Bihar and its origin. Also, focusing on the physical and social characteristics of the Kosi Basin. This is followed by a timeline of flood risk management adopted in the Kosi Basin to provide an overview of the current planning and decision-making process.

4.4. Flood risk management in Kosi Basin, Bihar

Bihar is a state in the eastern part of India bounded by 24º20'N to 27º31'N latitude and 83º20'E to 88º18'E longitude (Figure 4-3), which is simultaneously the poorest and the most chronically flood-affected (Bhatt et al., 2021). Out of the population of 104 million, 52% are multidimensionally poor (NITI_Aayog, 2021). A multidimensional poverty index is an international measure of poverty capturing the overlapping deprivations in education, health and living standards (OPHI, 2010). The annual mean rainfall of Bihar is 116.4 cm, of which 86% occurs during the monsoon (June-September) (IMD, 2011). Accordingly, most of the floods in Bihar occur during the monsoon season.

Figure 4-3 Location of Mahishi Block in Bihar
(Image source: NordNordWest - using United States National Imagery and Mapping Agency data, CC BY-SA 3.0 de, https://commons.wikimedia.org/w/index.php?curid=19910390)

The Bihar state disaster management authority is the main actor responsible for flood risk management in Bihar. The current Bihar disaster management plan describes disaster as "a catastrophe, mishap, calamity or grave occurrence in any area, arising from natural or manmade causes, or by accident or negligence which results in substantial loss of life or human suffering or damage to and destruction of, property or damage to or degradation of the environment and is of such a nature or magnitude as to be beyond the coping capacity of the community of the affected areas" (BDMA, 2014:34). In this plan, the disaster management authority recognises the importance of community as an important stakeholder in the disaster management process and mentions the importance of participation in its guiding principles (BDMA, 2014). Nevertheless, there is still a gap in implementing this paradigm shift in the thinking to ground level; therefore, the conventional flood control strategy as a response to floods is prevalent (Dixit, 2003).

In terms of floods, nearly 76% of Bihar's population and 73% of its land area are under recurring threats of floods (FMISC, 2021). Bihar has a total area of 94,000 sq km and is divided into two distinct parts: 1) north Bihar and 2) south Bihar. South Bihar has an area of 41,000 sq km, where the Ganges flows in the eastern direction primarily, covering an area of 432 km. In comparison, north Bihar has an area of 53,000 sq km with eight major basins (Ghaghra, Gandak, Burhi Gandak, Bagmati, Kamala, Kosi and Mahananda), entering India from Nepal or Tibet and draining into the main Ganges stem (Prasad and Mukherjee, 2014). This division is important because the north is primarily affected by any rainfall occurring in either Nepal or Tibet, and the present flood protection structures (i.e. embankments) result in flooding as a recurrent phenomenon in north Bihar (Prasad and Mukherjee, 2014).

Significant impacts of floods are observed in the north of Bihar due to social and physical pressures. Parameters like higher population, communities’ exposure to floods, the topography of the area, the flat terrain, higher rainfall in the upper catchment areas and high seasonal variations in the rainfall results in high flood impact (Jha and Gundimeda, 2019, Matheswaran et al., 2019, Prasad and Mukherjee, 2014). The river gradient varies from 22 cm/km (near the India-Nepal boundary) to 7.5 cm/km (at the confluence of the north Bihar River with the Ganges). During the normal rainfall years, the capacity of the river varies from 10-20 times during monsoon compared to winters, which can increase to 100 times in monsoon during intense rainfall years (Singh et al., 2009). Bihar, especially the northern region, not only suffers from riverine floods but also from waterlogging, which is a form of groundwater flooding. Waterlogging in the area has been highly intensified by human interventions. The construction of embankments, canals, railway tracks, and roads has impeded the area's natural drainage (Prasad and Mukherjee, 2014), aggravating the flooding in Kosi Basin. This surface flooding (Figure 4-4 (a)) and waterlogging (Figure 4-4 (b)) act as a barrier to the socio-economic growth of these at-risk communities living in the Kosi Basin, disrupting their livelihood (Singh et al., 2009) increasing the vulnerability of the Kosi Basin communities.

Figure 4-4 Pictures showing (a) surface water flooding (Mishra et al., 2008) and (b) groundwater flooding (Picture was taken during the field in October 2018)

Kosi Basin (Figure 4-3) presents a perfect example where the hard system solution of embanking the Kosi River has failed, and the communities residing in the Kosi Basin are put at higher risk of flooding due to the flood protection solution devised to protect them (Mishra et al., 2008, Nusser and Baghel, 2014). Three major problems have emerged as a result of embanking the Kosi River:

1) The river overspills from the embankment because of the deposition of silt/sediments in the river bed, reducing the water carrying capacity of the river (Mohanty et al., 2020).
2) Due to the silt/sediment deposits, the adjacent area outside the embankment has become low-lying, causing water seepage from the river bed into the area and creating the issue of waterlogging (Singh et al., 2009).
3) Embankment breaches have become a significant issue in the area, and a significant amount of money is spent on maintaining the embankments, which have been outlived and are poorly maintained (Sinha, 2009a).

Therefore, the north of Bihar faces floods as a recurrent event with the current flood management strategy of embanking the Kosi River (Prasad and Mukherjee, 2014). As observed in the disaster management plan of Bihar (BDMA, 2014), the importance of a flood risk perspective – one that recognises socio-economic vulnerabilities – is gaining importance, but at the ground level, India's current flood management system still lacks involvement of the social system, i.e. the communities at-risk (Prasad, 2005). Involving the at-risk communities would allow understanding of the system's behaviour by gaining insight into human-flood interactions from their years of lived experiences with floods. Understanding this socio-environmental system's behaviour at the ground level would consequently help develop sustainable flood risk management strategies for providing resilience to these vulnerable communities. A study site was selected in Bihar to understand the physical and social characteristics of the Kosi Basin socio-environmental system. These characteristics will be important to later understand the flood risk management stakeholders in the area and select research participants (Section 5.2.1).

4.5. Study site definition

For this research, a small focus area, Mahishi Block (Saharsa) (Figure 4-3), has been selected. Mahishi Block lies in the Kosi Basin and is representative of the interactions that take place between the social and physical systems in the Kosi Basin. Kosi is recognised for its unique physical properties, i.e. Kosi Basin Megafan, sediment yield and its Avulsive nature. These physical characteristics are discussed below (Section 4.5.1), along with the implications of how structural measures altered the Kosi Basin characteristics and the social characteristics of the Mahishi Block are discussed later (Section 4.5.2).

4.5.1. Kosi Megafan and embanking of Kosi River

The Kosi River is known for the devastation it has caused in the northern region of Bihar and is also named the 'sorrow of Bihar' (Mishra et al., 2008). Kosi River is a mountain-fed river (Sinha and Friend, 1994) that enters India from Chatra, Nepal. It flows for ~80 km in Nepal before entering India through the Kosi Barrage in Bhimnagar, India (Sinha, 2014). In India, Kosi enters through the plains of north Bihar, travelling further ~160 km before it joins the Ganga River in Kursela (Singh et al., 1993, Sinha, 2014).

Kosi carries a sediment yield of 0.43 Mt/yr/km^2 entering from the Himalayan Hinterland (Sinha, 2009a). This sediment yield is exceptionally high compared to some of the largest rivers in the world (Table 4-1). Although the sediment yield of Kosi (0.43 Mt/yr/km^2) is low as compared to Ganga (1.56 Mt/yr/km^2), the exceptional topographic relief in its source area makes it unique.

Table 4-1 Major Morphological and Hydrological Characteristics of Kosi (Sinha, 2009a)

Morphological and Hydrological Characteristics	**Kosi**	**Ganga**	**Amazon**
Catchment Area (10^3 km^2)	101	1,073	7,180
Total Length (km)	1,216	2,700	6,518
Average Annual Discharge (m^3/s)	2,036	15,000	480,000
Annual Sediment Load (Mt/yr)	43	1,670	1,000
Discharge/Area	20	14	25
Sediment Yield (Mt/yr/km^2)	0.43	1.56	0.14

The Kosi River enters India from a high upland (Himalayas hinterland), draining from an elevation of more than 5,500 m above mean sea level in Tibet (Sinha, 2014) into a narrow alluvial plain in the Indian Kosi Basin (Sinha and Friend, 1994). The upland to plains ratio is 5.3 (Sinha and Friend, 1994), which shows that the plains area in the Indian Basin is approximately one-fifth of the total basin area of the Kosi. Therefore, when Kosi enters the narrow alluvial channel with a high sediment yield from a high upland area, it results in an avulsive nature. The dynamics of the Kosi River, generally described as 'avulsive' shifts, have been well documented by Gole and Chitale (1966), Wells and Dorr (1987), Sinha (2014) and Latrubesse (2015). Slingerland and Smith (2004:3) define avulsion as "the process by which flow is diverted out of an established river channel into a new course on the adjacent floodplain". The Kosi records show that the river had shifted 150 km to the west in the 200 years before being embanked in the 1950s.

The accommodation of the river and its sediment in such a small alluvial plain has led to sediment aggradation in the river bed, which is further remobilised aggressively by the heavy monsoonal rainfall in parts of the catchment (Sinha and Friend, 1994). These processes lead to the formation of 'Megafan' (Figure 4-5). Megafans are "unstable avulsive fluvial systems radiating from an apex that typically transport sandy and muddy sediments in a subcritical flow regime" (Latrubesse, 2015:17). Kosi Megafan is one of the largest megafans developed at the piedmont of the Himalayas (Latrubesse, 2015), with a spread of 10^3 to 10^5 km^2 with a conical shape (80 km long and 150 km wide alluvial fan) with a convex up topology (Sinha, 2014).

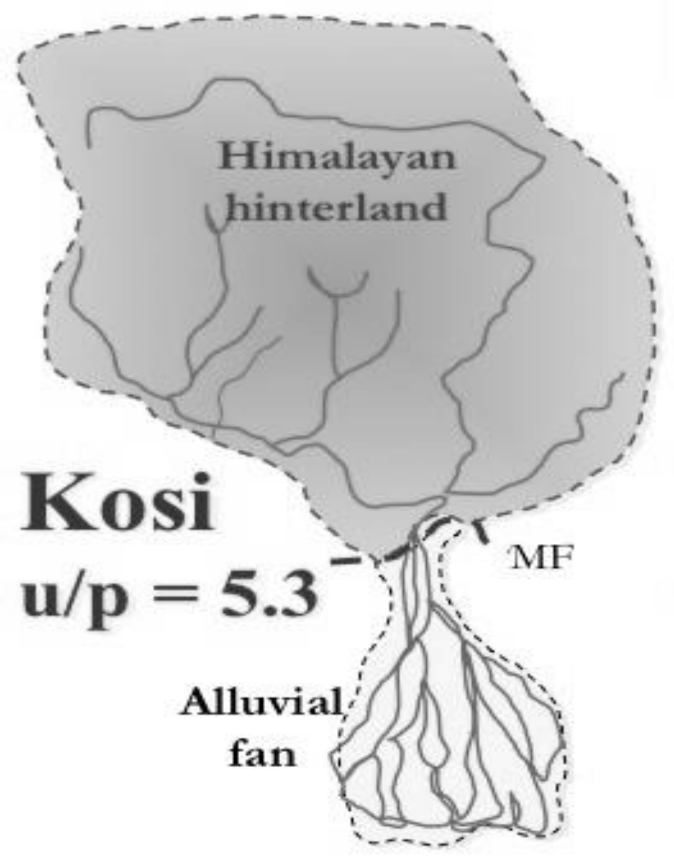


Figure 4-5 Kosi Megafan and the upland to pluvial ratio (Source: Sinha (2009a)) Kosi Megafan and the upland to pluvial ratio (Source: Sinha (2009a))

Due to this avulsive nature of Kosi, floods have always been a problem that the communities living in the Kosi Basin encountered. In 1953, the prime minister of India at the time, Jawaharlal Nehru, "was so moved by the miserable plight of the flood victims in the basin that he wanted something to be done immediately to provide succour to them" (Mishra et al., 2008:30). An immediate measure to protect the communities was using structural intervention to embank the river to separate the Kosi River from the communities. For these reasons, debates arose regarding the sustainability of embanking an avulsive river like Kosi when the plan was formalised to embank the river (for details, refer to Mishra et al., 2008, Mishra, 1997).

The construction of these embankments was a political compulsion for the government to be seen as acting in the interest of society in the post-independence period. The government wanted to be seen working for the welfare of the people by relieving them from their flood problems, and the whole project's technical viability was compromised. In the end, the Kosi River was embanked. At present, Bihar has a total of 3430 km of embankments, starting from only 160 km in 1952 (Singh et al., 2009). Floods have become a recurring event, not because of the overflowing of river water over these embankments but because the Kosi embankments have been breached repeatedly (Shah, 2013, Mohanty et al., 2020), as evident from the past Kosi embankment breaches in 1963, 1968, 1971, 1980, 1984, 1987, 1991, and 2008 (Sinha, 2009a).

According to Sinha, 2009b, during the floods of 2008, which were caused by the breach of the eastern afflux bund at Kusaha in Nepal at a location 12 km upstream of the Kosi barrage, the river completely changed its avulsion direction from the westward to eastern shift of nearly 120 km (Figure 4-6). In recent years, it can be considered one of the greatest avulsions in such a large river affecting an area of approximately 3,000 sq km, impacting more than 30 million people (Sinha, 2009a).

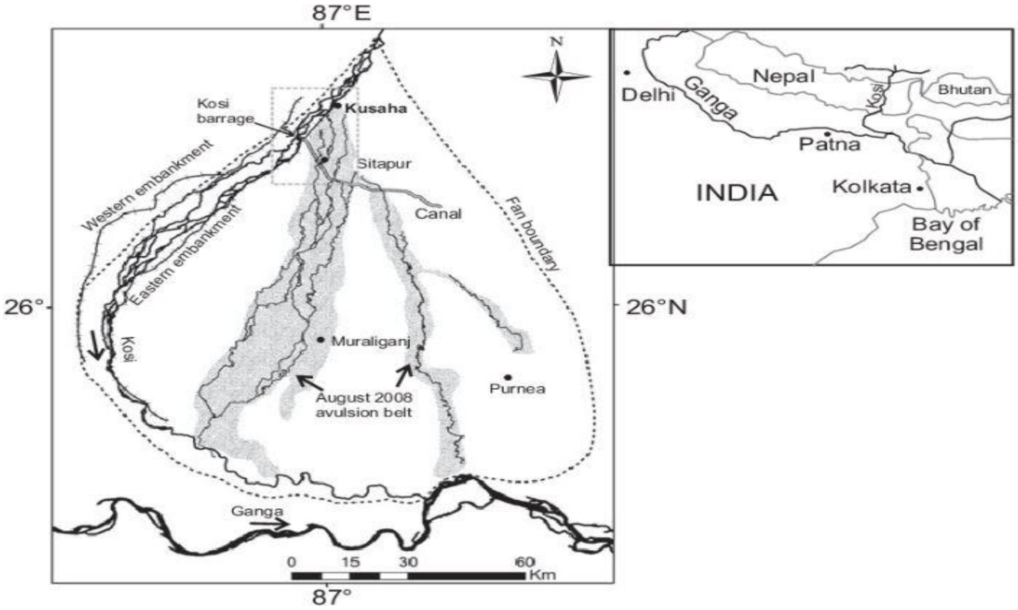


Figure 4-6 Avulsive Nature of Kosi (Source: Sinha et al. (2013))

The avulsive nature of Kosi and the embankment breaches have raised questions on the efficacy of employing rigid, hard engineering approaches (e.g., embankments, bunds) to control floods in such a complex problematic situation. Floods in this area have not been appreciably moderated even after the construction of embankments (Sinha, 2009b); instead, embankments made the lives of the people living there more difficult (Mishra et al., 2008). A brief overview of the social characteristics, including the population, literacy, livelihood data of the field area (Mahishi Block), and how the floods have impacted their livelihood, has been provided in the next section.

4.5.2. Social characteristics

Mahishi block is a rural area in the district of Saharsa, Bihar (Figure 4-3). The social characteristics provided in this section are gathered from the statistics provided by the Census of India, most recently conducted in 2011. Mahishi block is spread over 223 sq km, constituting 81 villages. The total population of the

Mahishi block is 206,774 people, 52.44% of which are men and 47.56% are women, with an average sex ratio of 907. A total of 78,399 people are literate, constituting 51,040 men and 27,359 women.

There are 39,395 households[1], out of which 70.85% are temporary households, 10.90% – semi-permanent, and only 18.07% are permanent households. This data represents how the floods have impacted the standard of living in the flood-prone area of Mahishi block.

The social structure of India consists of a caste system. In the hierarchy of this caste system, Dalits are positioned at the bottom (Raghavendra, 2020). An overview of this caste system and Dalits is provided in Box 4-1.

[1] As defined in the CENSUS, I. 2011. Census 2011. India: Indian Government.; "Permanent households refer to those houses whose walls & roofs are made of pucca materials, i.e., where burnt bricks, G.I. Sheets or other metal sheets, stone, cement, concrete is used for wall and tiles, slate, shingle, corrugated iron, zinc or other metal sheets, asbestos sheets, bricks, lime and stone and RBC/RCC concrete are used for the roof. Semi-Permanent houses refer to those houses made of other types of materials. Temporary houses refer to those houses having walls and roofs made of Kutcha materials, i.e., where grass, leaves, reeds, bamboo, mud and unburnt bricks are used for the construction of walls and grass, leaves, reeds, bamboo thatch, mud, unburnt bricks and wood etc. are used for roofs."

Box 4-1: Dalits and caste system in India

According to the ancient text 'Rigveda', the Hindu caste system has emerged from the story of Brahma (Creator of Universe in Hinduism). The caste system is divided into four main categories, namely 'varnas' dividing people based on economic and occupational lines: Brahmins (priests & teachers), Kshatriyas (warriors & rulers), Vaishyas (farmers, traders & merchants), Shudras (labourers, peasants, servants). In addition to these Varnas, there is a fifth class in Hinduism, Dalits or 'Untouchables', gaining their status from the menial jobs, generally working close to diseases in polluted areas (IHA, 2018). However, when the Indian constitution was framed in 1949, a legal framework specified emancipating untouchables and equality for all citizens. Nevertheless, in the 21st century, the condition of Dalits is degrading.

The people considered untouchables, depressed class or Harijans (a name given by Mahatma Gandhi to Untouchables meaning 'God's own children') now increasingly adopt the term Dalit (NCDHR, 2018). The word 'Dalit' is derived from Sanskrit, which means 'broken, ground-down, downtrodden or oppressed. In some cases, Dalits migration and anonymity in the urban environment has led to an upward movement in occupation, breaking the shackles of discrimination. However, the custom of discrimination still exists in rural parts of India, forcing the Dalits to menial jobs (traditional occupation).

A close link between caste and occupation can be observed, especially in rural India (Gang et al., 2017). Therefore, a tabulation has been provided in Table 4-2 to illustrate the population division. According to the Census of India conducted in 2011, Dalits, including the scheduled caste and scheduled tribes population, constitute 49,368 out of a total population of 206,774 in Mahishi Block, in which Schedule Caste constitutes 23.8% while Schedule Tribe are 0.1% of the total population (Census, 2011). These schedule caste and schedule tribes are a part of the marginalised communities residing in the Kosi Basin (discussed in more detail in Chapter 5).

Table 4-2 Mahishi Block Data (Census, 2011)

Census Data	Total	Men	Women
Population	206,774	108,437	98,337
Literacy (excluding children 0-6 years old)	48.4%	60.0%	35.6%
Scheduled Caste	49,227	25,632	23,595
Scheduled Tribe	141	65	76
Working population	75,559	50,048	25,511

The population involved in working activities is 75,559, out of which the main working category constitutes 41.6% (defined as the population who have employment and earnings for more than six months in a year). In contrast, the population involved in marginal work (population able to provide a livelihood for less than six months in a year) is 58.4% of the total population involved in working activities (excluding children). This data shows that floods, both surface water and groundwater, have reduced the period in which these communities can use the land to carry out agricultural activities. Moreover, the ratio of women to men in permanent employment is 1 to 4.3, which clearly shows that the unemployment rate for women is much higher in these areas.

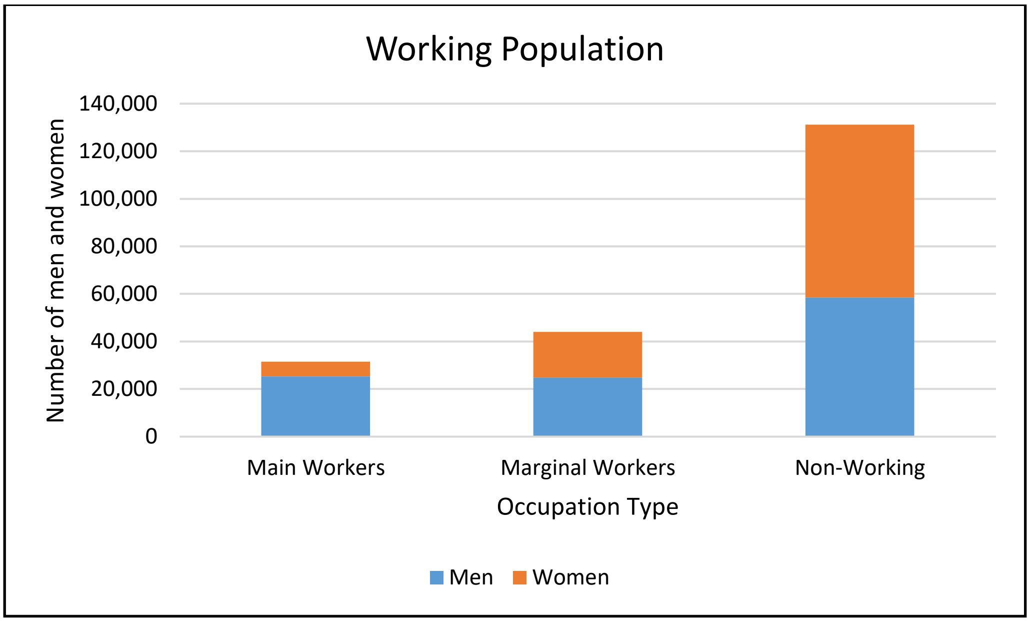


Figure 4-7 Working Population (Census, 2011)

In the main working population of 31,455, cultivators (owners or co-owners of agricultural land) constitute a population of 11,308. The ratio of women to men in the working population is low in all the different working activities; in the cultivators' category, only 14.57% are women (Table 4-3).

Table 4-3 Different activities defined in the main working population (Census, 2011)

Activities	Total	Men	Women
Cultivators (Owner or co-owner)	11,308	9,660	1,648
Agriculture Labourer	15,409	12,015	3,394
Household Industries	681	351	330
Other Workers	4,057	3,308	749

These data show that in the main working population, very few women have the opportunities to earn livelihood throughout the year.

4.6. Chapter summary

The current and previously implemented Kosi Basin flood management strategy heavily relies on structural measures that put at-risk Kosi Basin communities at high risk of flooding (Prasad and Mukherjee, 2014, Mishra et al., 2008), which has led to increased vulnerability in the area rather than providing resilience to these Kosi Basin communities. Embanking the river introduced problems such as waterlogging in the outside area adjacent to the embankments, disruption in agriculture, fisheries have declined, inaccessibility to some villages, and some are at high risk of surface water flooding (Singh et al., 2009).

These Kosi embankments are mostly viewed as a failure because a large section of communities is still at risk of flooding, with a negative effect on the socio-economic status of the entire region (Nusser and Baghel, 2014). Floods in Bihar have always been the centre of any flood debate in India, and attempts to tame the Kosi River in north Bihar have always been a challenge to engineers, who still search for a lasting solution (Mishra et al., 2008). The main reason behind this is that "policymakers often do not understand the concept of vulnerability and frequently use the term as a substitute for poverty or the state of being poor." (Singh et al., 2009: 22). However, vulnerability is inherently dynamic and heterogeneous in nature, consisting of social, physical and temporal factors, and its assessment, in a local context, requires determination of the following (after Birkmann (2006)):

- Who or what are the elements of vulnerability?
- How can we identify vulnerable social groups, and which groups would benefit from enhancing their resilience?
- What attributes or capacities do people possess to reduce vulnerability and enhance resilience?
- What are the interactions and feedback between the physical and social systems in the socio-environmental system resulting in vulnerability?

These key questions are the focus of this thesis in the context of understanding flood risk in the Kosi Basin. There is a need to involve the social system in the decision-making process of flood risk management. Conceptualising vulnerability is entirely up to the person's perspective who is doing the construction, in this research, which is through the perception of local knowledges (mentioned in the research aim (Page 11)). The local knowledges present in the Kosi Basin are explored in the next chapter, i.e., Chapter 5. In Chapter 5, these local knowledges were then elicited to understand the problems these communities face due to floods in Kosi Basin.

Chapter 5. Kosi Basin system structure

5.1. Chapter overview

This Chapter aims to elicit the system of systems structure that comprises the Kosi Basin from the perspective of the local flood risk management stakeholders. It is divided into two main components: 1) structural representation (stage 1), which contains the details of the data collection process, and 2) structural formalisation (stage 2), which consists of data analysis and structuring of the Kosi Basin system.

Structural representation (stage 1) (Section 5.2) consists of identifying participants whose perspectives and knowledge the researcher wants to include for constructing an understanding of the system. And the processes used to construct the system understanding. The first part is identifying stakeholders to be involved in the participation process to elicit the system of systems (Section 5.2.1). The first step to identifying participating stakeholders was to explore and develop an in-depth understanding of the stakeholder spectrum present in flood risk management, Kosi Basin (Section 5.2.1, 5.2.2 and 5.2.4). The identified Kosi Basin flood risk management stakeholder spectrum included communities residing in the Kosi Basin, government agencies, policymakers, and NGOs.

After acquiring a thorough understanding of the Kosi Basin stakeholder spectrum with the help of a literature review, stakeholder participation was carried out to elicit the system structure (Section 5.3). For stakeholder participation, it was vital to first scope the field site and set the spatial boundaries

(Section 5.3.1). The field site exploration was fundamental to understanding the Kosi Basin's spatial context, which can be instrumental in understanding human-flood interactions. It was found that three different at-risk communities reside in the Kosi Basin: 1) people living in the area between (within) the Kosi embankments facing Kosi River flooding in monsoon, 2) people living in the area adjacent to the (outside of) west embankment facing waterlogging in non-monsoon and river flooding in monsoon and, 3) people living permanently on the Kosi embankments, who previously resided in the waterlogged and within embankment communities who had been displaced due to flooding. These three communities are discussed and later depicted schematically in Figure 5-22. Setting the spatial boundary was informed by these three different groups of at-risk communities living in the Kosi Basin. A geographical area for the spatial boundary, including the three different community groups, was chosen based on pragmatic reasons such as the limitation of time and resources and also justified based on biophysical dynamics (Section 5.3.1).

The second crucial step undertaken prior to conducting stakeholder participation was stakeholder analysis (Section 5.3.2). Snowballing was used for traversing the stakeholder spectrum (Harrison and Qureshi, 2000) in flood risk management, Kosi Basin. Snowballing is advantageous when the stakeholders are hard to reach, and the initially identified stakeholders can assist in selecting the potential participants for the project (Naderifar et al., 2017). Then a simple stakeholder classification was carried out to identify the project participant. The Influence and Interest method used for mapping the stakeholder groups ensured minimising the sampling biases and marginalisation of different stakeholders (Reed et al., 2009). An initial group of participants was invited for the participation process (Section 5.3.3). Semi-structured interviews were selected for the process because they have the ability to capture people's perceptions about complex problem situations by allowing the participants to express their feelings and experiences openly (Åstedt-Kurki and Heikkinen, 1994). The structural formalisation was carried out following the data collection process.

Structural formalisation (Section 5.4) consists of processing the collected data and understanding what this newly generated knowledge reveals about the system. The method adopted for analysing the collected data (interview transcripts) was thematic analysis, which was carried out using the Nvivo software (Section 5.4.1). Thematic analysis is a widely used method for qualitative analysis (Roulston, 2001), which can produce detailed and rich data while maintaining the data complexity (Braun and Clarke, 2006). Quotes from the participants were used (Section 5.5) in addition to the thematic analysis to express the participants' feelings and emotions about the problem situation (Tan et al., 2018). The findings gathered by understanding the lives of these communities point out that human-flood interactions are not limited to the monsoon season and also expand to the non-monsoon season. This annual variation helped in defining the temporal boundaries of the system (Section 5.6).

The findings from the interview transcripts were then used to define the system structure (Section 5.7), specifying the spatial and temporal characteristics of the field area.

5.2. Stage 1- Structural representation of the Kosi Basin system

5.2.1. Identification of stakeholders

The first step in any stakeholder participation is understanding the stakeholder spectrum involved in the problem situation. Research question one (Page 11) is directed towards identifying the local knowledges present in a socio-environmental system. It is pertinent to understand the problem situation in the present context (i.e., the local flood risk and its management) to answer this research question. Therefore, the objective was to identify the stakeholder spectrum in flood risk management in Kosi Basin.

The concept of a stakeholder, as defined in the literature, varies depending on the aim and approach adopted for the analysis/policy area. In the traditional definition (in the business context) given by Freeman (1984:46), a stakeholder is "any group or individual who can affect or is affected by the achievement of the organisation's objectives". On the other hand, some authors emphasise that the primary stakeholders are those responsible for influencing the problem involved and do not include those affected by the problem (Crosby, 1991, Brugha and Varvasovszky, 2000).

Moreover, Hart and Sharma (2004) define the stakeholder spectrum into core and fringe categories (in a business management context). Core stakeholders represent the salient, known and influential actors who can affect the problem situation; on the other hand, the non-urgent, 'non-legitimate', and powerless stakeholders constitute the fringe stakeholders (Hart and Sharma, 2004). The core stakeholders include the competitors, non-government organisations (NGOs), suppliers, communities, employees, regulators, customers and investors, who are visible and well-established. In contrast, the fringes include the poor, weak, illiterate, disinterested, non-human, isolated, non-legitimate, adversarial and divergent stakeholders, e.g. powerless rural poor in developing countries (Hart and Sharma, 2004).

In the context of this research, the terminology has been changed to dominant (adapted from "core") and marginalised (adapted from "fringe"), as presented in Figure 5-2. This has been done in order to more accurately describe the distinction between the two communities in the context of flood risk management, as the original definitions were created in a business context.

The "dominant" stakeholders (Hart and Sharma, 2004) are the actors responsible for flood risk management, i.e., policymakers, engineers and dominant community stakeholders. In flood risk context, these communities are the resourceful and influential people residing in flood-prone areas. In contrast, marginalised stakeholders are the suppressed and powerless communities residing in the same flood-prone areas. Since both communities reside in the Kosi Basin, the terminology adopted for marginalised stakeholders is "marginalised community stakeholders" and "dominant community stakeholders" for the influential and powerful members. The researcher made sure to represent and include the marginalised community stakeholders as these stakeholders are the most vulnerable to flooding, and their inclusion was fundamental to adopting a social vulnerability perspective.

Identifying and differentiating between the marginalised and dominant community stakeholders in the communities residing in the Kosi Basin was challenging compared to the dominant stakeholders' identification. In response, a thorough literature review mainly focusing on the Kosi Basin communities was conducted to identify and distinguish the marginalised community and dominant community stakeholders existing in the Kosi Basin (Section 5.2.2). This was followed by a brief literature review to identify the marginalised sub-groups (5.2.3) and dominant stakeholders existing in the Kosi Basin (Section 5.2.4). The literature review included research papers, newspaper articles, census data, and keyword analysis of official websites of organisations (Duggan et al., 2013).

5.2.2. Dominant and marginalised community stakeholders in Kosi Basin

A natural disaster makes people socially and economically vulnerable, exposing individuals to the threats of physical, social, economic, health, cultural, personal and psychological insecurities (Ariyabandu and Fonseka, 2009). In developing countries, the significant factors influencing vulnerability are existing cultural, socio-economic, political and institutional structures and systems (Ariyabandu and Fonseka, 2009), and a complex interaction amongst these factors leads to the community's vulnerability. Therefore, the degree of vulnerability varies with the community's capacity of absorbing, responding, and recovering from the event's impact (Westgate and O'Keefe, 1976).

In a community, the consequences vary for the individuals/groups impacted by disaster and become compounded in flood-prone areas like Bihar, which are severely affected by the magnitude and intensity of recurring floods (Kumar et al., 2013). Therefore, there is a variation in the vulnerability among different community groups, pointing out that vulnerability is a heterogeneous concept and cannot be applied to the whole community homogenously:

- The elderly residing in flood-prone areas belong to the vulnerable groups due to their degrading health with age, post-flood mental problems, and relief distribution (Alam et al., 2016, Jha and Raghavan, 2008, Kar, 2009, Kar, 2006).
- Women and adolescent girls are at a significant disadvantage due to the patriarchal and social-cultural norms (Madhuri, 2016, Pritchard and Thielemans, 2014, Singh et al., 2009).
- Displaced communities face forced migration due to unfavourable circumstances and suffer from extensive socio-economic destitution, marginalisation and unjust access to land and other resources (Das et al., 2014, Mutton and Haque, 2004, Dixit, 2003, Zaman, 1991).
- The disabled community becomes more prone to natural disasters by virtue of vulnerable socio-economic and physical strata (Karagiorgos et al., 2016, Ariyabandu and

Fonseka, 2009, Hemingway and Priestley, 2006, Fielding and Burningham, 2005). A disproportionate number of disabled people suffer and die due to negligence and ignorance towards their rights and needs (UNISDR, 2014). Also, they have minor or no role to play during the decision-making process (Karagiorgos et al., 2016).

Additionally, vulnerability dynamics are hugely influenced by the caste structure in India (UNDP, 2009). The caste system in India is the main determinant of who is in the marginalised communities. The Dalits (Box 4-1) (marginalised community stakeholders) living in a disaster-prone area are more vulnerable than or compared to other community members (dominant community stakeholders) due to caste-based structural discrimination leading to marginalisation and social and economic exclusion (IDSN, 2013) of marginalised communities. Discrimination in the name of caste is still prevalent in many parts of India, especially in Bihar. Therefore, the power lies in the hands of the dominant community stakeholders belonging to the upper caste, resulting in a severely degraded quality of life for marginalised community stakeholders.

In countries like Nepal and India, people are still used to doing caste-based traditional work (Katuwal, 2008). Discrimination practices include physical and social segregation, restriction on occupation and enforcing Dalits to perform menial jobs (e.g. manual scavenging, removing human waste and dead animals, sewage disposal). Dalits often suffer from bullying as a result of caste-based violence (Ramesh, 2008, IDSN, 2013). Moreover, Dalits are often seen living in the marginal lands on the periphery of settlements (IDSN, 2013); being landless with no or little formal assets, they work as share-croppers or manual labourers ultimately to meet livelihood needs (UNDP, 2009).

Education plays a vital role in the development of a society. Hoffmann and Muttarak (2017) emphasise the importance of formal education in the context of disaster preparedness, stating that education helps people to have access to more sources and types of information available to make themselves efficient in disaster preparedness. However, education in a rural environment such as Bihar, especially for the Dalits and downtrodden residing in these flood-prone areas, is still a distant dream (Mishra et al., 2008).

According to the census of India 2011, on average, the literacy rate of India is 74.0% (82.1% men and 65.5% women). Bihar lags in literacy rate; the overall literacy rate in the state is 61.8% (71.2% men and 51.5% women). For comparison, Kerala is the most literate state in India, having a literacy rate of 94.0% (96.1% men and 92.1% women) (Census, 2011). Education plays a vital role in disaster preparedness by improving risk perception, as Hoffmann and Muttarak (2017) state, and this literacy rate suggests that being deprived of school education, the marginalised community stakeholders become more at-risk of flooding, unable to access any disaster-related information (e.g. documents on disaster policies).

During river floods, living in kaccha (mud) houses, the marginalised communities do not wait to be rescued. Instead swim through the strong currents of floodwater to make their way to camps (Jha and Raghavan, 2008) or the Kosi embankments (Mishra et al., 2008). Staying on the Kosi embankment, access to even the essential services (such as water and sanitation) is limited, ultimately exposing them to the consequences of floods with little protection against disasters (IDSN, 2013). Also, in terms of damage to lives and property, Dalits and the poor are the ones who suffer most (Jha and Raghavan, 2008).

In the case of relief aid provided during surface floods, different government bodies and NGO agencies come forward to provide relief depending on the intensity and magnitude of flooding (Mai et al., 2020), as was observed in the Kosi floods of 2008. Relief camps were set up, and relief such as food, medicine, clothes, grains, cash, and government credits was provided (UNDP, 2009). Moreover, after the surface water floods are over, the communities rely on the government to provide relief, such as food and cash for buying food, restoring livestock and also chlorine tablets for purifying the water to drink (UNDP, 2009). However, the influence of the caste-based power structure and the caste dynamics on the humanitarian aid policies and practices adopted in disaster-prone areas ultimately renders the marginalised communities unequal aid (IDSN, 2013). As a result, these Dalit communities become even more vulnerable after the flood event. In a newspaper article, Ramesh (2008) mentions that in the aftermath of flooding, the Dalits and downtrodden communities faced discrimination regarding flood relief and were also the ones to be rescued last after the upper caste people and rich had been rescued. As a result, these Dalit communities become even more vulnerable after the flood event.

IDSN (2013:12) states in their report that "…Dalit women and children were left homeless in the wake of the Bihar floods in 2007. The aid that was given was stolen by the people who were supposed to deliver it. Unless there is a comprehensive and long-term approach to addressing caste discrimination in resilience-building and development across South Asia, millions of people will continue to be at risk from preventable disasters." According to an article by DN (1988: 941), in Bihar, the caste system acts as "a dead weight holding back not merely the economic and political but also the cultural and moral development of society and even putting its imprint on the new emerging classes."

To summarise, caste discrimination results in relief discrimination (Ramesh, 2008, IDSN, 2013), illiteracy (Mishra et al., 2008), little or no land rights (IDSN, 2013, UNDP, 2009), menial jobs and bullying (Ramesh, 2008, IDSN, 2013), marginalised social position (IDSN, 2013) and, formation of the caste-based power structure and caste dynamics (IDSN, 2013) as shown in Figure 5-1.

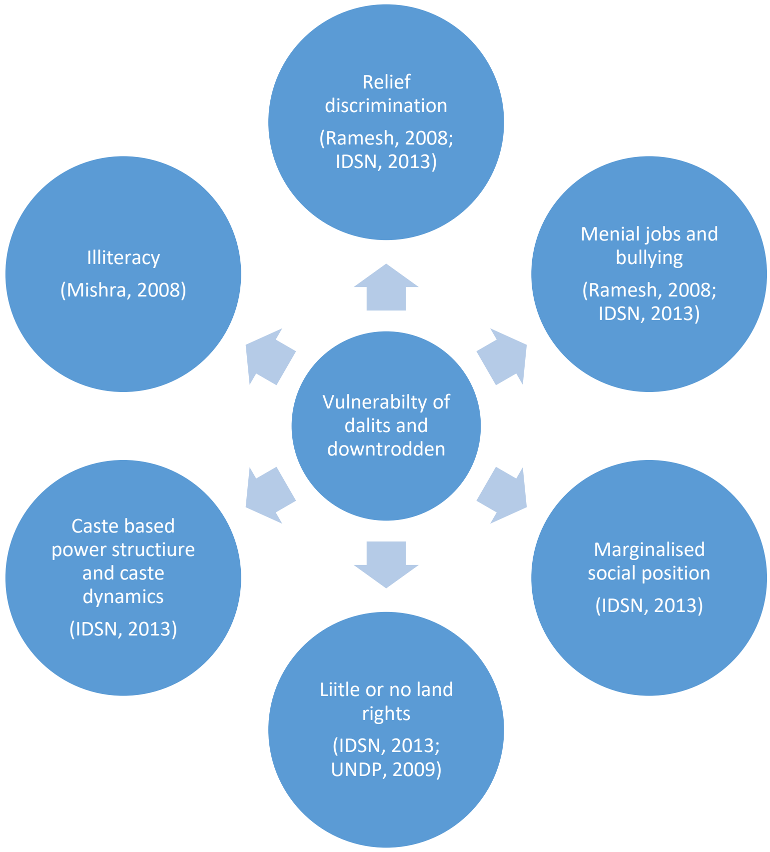


Figure 5-1 Variables leading to vulnerability of marginalised community stakeholders

Therefore, caste discrimination in the Kosi Basin results in the Dalit communities (marginalised community stakeholders) being more vulnerable than upper caste communities (dominant community stakeholders). Moreover, during floods, the effects multiply for these Dalits and downtrodden communities (Mishra et al., 2008). Even being the most vulnerable during the floods, these Dalit communities remain no more than 'the unheard voices' (Mishra et al., 2008), especially in planning and managing flood risk.

5.2.3. Marginalised sub-groups (Intersectionality)

Intersectionality is when certain groups are impacted by multiple disadvantages. Within a community, the women, the old, the poor, the young and the disabled, among other groups, are the ones facing more difficulties (whether financially, physically or psychologically) in coping with the disaster, especially during or after the flooding has occurred (Cutter and Emrich, 2006, Cutter et al., 2003, Tapsell et al., 2002, Fordham and Stevenson-Hinde, 1999). In Kosi Basin, where the caste dynamics play a significant role, the condition is far worse for the Dalit women, the disabled, and the elderly.

5.2.3.1. Dalit women

Pritchard and Thielemans (2014) emphasise cultural norms as a significant factor that makes women more disadvantaged during floods in India. Even the patriarchal norms and sociocultural factors prevalent in Bihar, especially in the lower caste, make women vulnerable to flooding (Singh et al., 2009, Madhuri, 2016). For example, men are regarded as the head of the household, and the households headed by women are discriminated against as they are often neglected and excluded from the relief programs (Madhuri, 2016).

Within the caste discrimination domain, gender discrimination is much more prevalent. Furthermore, during floods, both caste and gender discrimination makes Dalit women much more vulnerable. "The task of coping during floods magnified a set of gendered disadvantages already present in rural Indian society" (Pritchard and Thielemans, 2014: 332). Women and men perceive risk differently from one another; in light of this, gendered perspectives of flood risk (Miceli et al., 2008, Kellens et al., 2011) becomes highly important from the standpoint of flood vulnerability.

During floods, with no place else to go, the villagers take shelter on the embankment, making sanitation and defecation a grave concern. Spreading of infections such as fungal becomes common in menstruating women due to lack of sanitation (Madhuri, 2016). Findings from the studies carried out by Singh et al. (2009), and Madhuri (2016) show that the migration of men to work in other cities puts extra pressure on women, making them bear the additional responsibility of earning wages to keep the household running and having responsibility for taking care of the family. Due to gender differentiation, the wages earned by women are lower as compared to men. As pointed out by Singh et al. (2009), the agricultural wage for women comes out to be around ₹25/day to ₹30/day, approx. £0.28 to £0.33, 52-62% less than that earned by men. In these rural parts of India, the stronghold of patriarchal norms (Singh et al., 2009) with additional pressure from the caste system (Pritchard and Thielemans, 2014, Singh et al., 2009) make the condition of Dalit women far worse (IDSN, 2013). This disadvantage puts them more at risk during floods as compared to men.

5.2.3.2. Dalit Disabled

The flooding in Chennai, South India, in 2015 was a disaster that led to the loss of both lives and property. Disabled people faced more difficulties as there was no specific disaster management strategy in place to assist disabled people during a disaster (Kishore, 2015). "The results of the UNISDR survey reveal that the key reason why a disproportionate number of disabled persons suffer and die in disasters is because their needs are ignored and neglected by the official planning process in the majority of situations" (UNISDR, 2014: 12).

During their survey, UNISDR found that 85.57% of respondents from 137 countries mentioned that they have not participated in community-level disaster management and risk reduction processes that are currently in place (UNISDR, 2014). A lot can be learned from the practical experiences and knowledge of how disabled people face the problematic situation of flooding. Due to their vulnerable socio-economic and physical strata, disabled communities become more prone to natural disasters (Karagiorgos et al., 2016, Ariyabandu and Fonseka, 2009, Hemingway and Priestley, 2006, Fielding and Burningham, 2005). These variables act as a building block for making disabled communities more prone to flooding, and the impact of caste makes it worse for the Dalit disabled.

5.2.3.3. Dalit Elderly

With growing age, livelihood insecurity creeps in (Alam et al., 2016), making the elderly a liability for the family. On many accounts, there is no or inadequate transfer of resources to the elderly. Degradation of health (Alam et al., 2016) makes them prone to greater risk of the consequences of flooding. When a flood hits, thousands of people have to vacate their inundated homes. There is a sense of insecurity and uncertainty about when the help will come. During that time, sometimes, the elderly, due to their weaker physical condition, are the ones left behind when the problematic question of whom to save comes along as it becomes difficult for them to wade through the turbulent floodwater (Jha and Raghavan, 2008).

During the time of relief distribution, only the strong, able men were able to come to relief camps, and the elderly and the women and children were the ones left behind (Jha and Raghavan, 2008). After the floods, the mental health of the sufferers is a big issue. Post-traumatic stress and post-disaster psychiatric morbidity are much higher in the elderly than in other community subgroups (Kar, 2009, Kar, 2006), making them vulnerable community sub-groups.

Living with the floods all their lives, the experiences of the elderly with the floods span over a more extended period compared to other sub-groups of the community. These accumulated local knowledges of so many years make the elderly a valuable participant sub-group.

The social, political, cultural, and economic characteristics of these identified vulnerable groups were the same qualities possessed by the marginalised stakeholders, as defined by Hart and Sharma (2004). They used the term “fringe” for vulnerable groups that were divergent, adversarial, powerless, isolated, illiterate, weak and poor. Hence, the Kosi Basin's Dalit communities (especially the sub-groups, including the elderly, women, and disabled) are defined as marginalised stakeholders.

5.2.4. Dominant stakeholders

Applying the definition of Hart and Sharma (2004) to flood risk management, the dominant stakeholders are the ones who have the power to influence the flood risk management decisions and are involved in the process at a certain level. In Kosi Basin, the dominant stakeholders identified are a) dominant community stakeholders, b) the water utility agencies and government agencies and c) NGOs.

The first category is the dominant community members. However, all communities residing in the Kosi Basin are at risk of flooding; the dominant community stakeholders are the influential and powerful community members who can manage flood risk better than the marginalised communities. Moreover, they have better resources which prepares them better for floods.

The second category of dominant stakeholders is the government agencies and water utility agencies. These government agencies include the engineers and policymakers involved in flood risk management (Table 5-1).

Table 5-1 Government agencies and water utility agencies working in flood risk management

Government Agencies	Level	Description
Ministry of Jal Shakti	Water utilities	Development and regulation of the country's water resources
India Meteorological Department	Water utilities	The principal government agency in all matters relating to meteorology and allied subjects
Central Water Commission	Water utilities	Promotes integrated and sustainable development and management of India's water resources
National Disaster Management Authority	Central government (National level)	Assigning policies, plans and guidelines for Disaster Management.

Government Agencies	Level	Description
Bihar state disaster management authority	Local government (State level)	Focuses on disaster mitigation and risk reduction in Bihar state
Water Resources Department, Bihar	Local government (State level)	Protects the right of the State to share Water of Inter-State Rivers/Basins
District Disaster Management Committee	Local government (District level)	Focuses on disaster mitigation and risk reduction at the district level
Block Development Officer	Local government (Block level)	Planning and Development of block

The third category of dominant stakeholders is NGOs. NGOs are private organisations that perform activities to promote the interest of the poor, relieve suffering, protect the environment, undertake community development, or deliver basic social services (WorldBank, 1989). These organisations play a vital role in the training and capacity building of the communities residing in disaster-prone areas (Mondal et al., 2015). NGOs operating within the Mahishi Block and working to improve the quality of life of the communities at risk of flooding, identified through a web search, are presented in Table 5-2.

Table 5-2 NGOs identified in Mahishi Block

NGO	Level	Action focus	Background
SEEDS India	Central (National level)	Building Resilient Communities	Established in 1994, SEEDS aims to transform the vulnerable into resilient and thriving communities by equipping the most vulnerable with appropriate tools and technologies, sharing knowledge and skills and promoting linkages among stakeholders.
Indian Red Cross Society	Central (National level)	Delivering emergency relief during disasters	Medical and humanitarian organisation, founded in 1920. There are more than 700 branches throughout India.
Sahbhagi Shikshan Kendra	Central (State level)	Centre for Participatory Learning and Action	Founded in 1990, this organisation facilitates training programmes and workshops. It operates in Uttar Pradesh, Bihar, and Jharkhand.
Megh Pyne Abhiyan	Central (State level)	Water quality and Sanitation	Formed in 2005 as a campaign and functional network, this organisation works on water-based resilience and adaptability measures in Bihar, West Bengal, and Jharkhand
Kosi Seva Sadan	Local	Flood action group	This is a non-profit organisation, working in Bihar since 1981 and

NGO	Level	Action focus	Background
			focusing on rehabilitation of victims of natural calamities.

The literature review helped create an essential structure for understanding the flood risk management stakeholder spectrum existing in Kosi Basin and is presented in Figure 5-2.

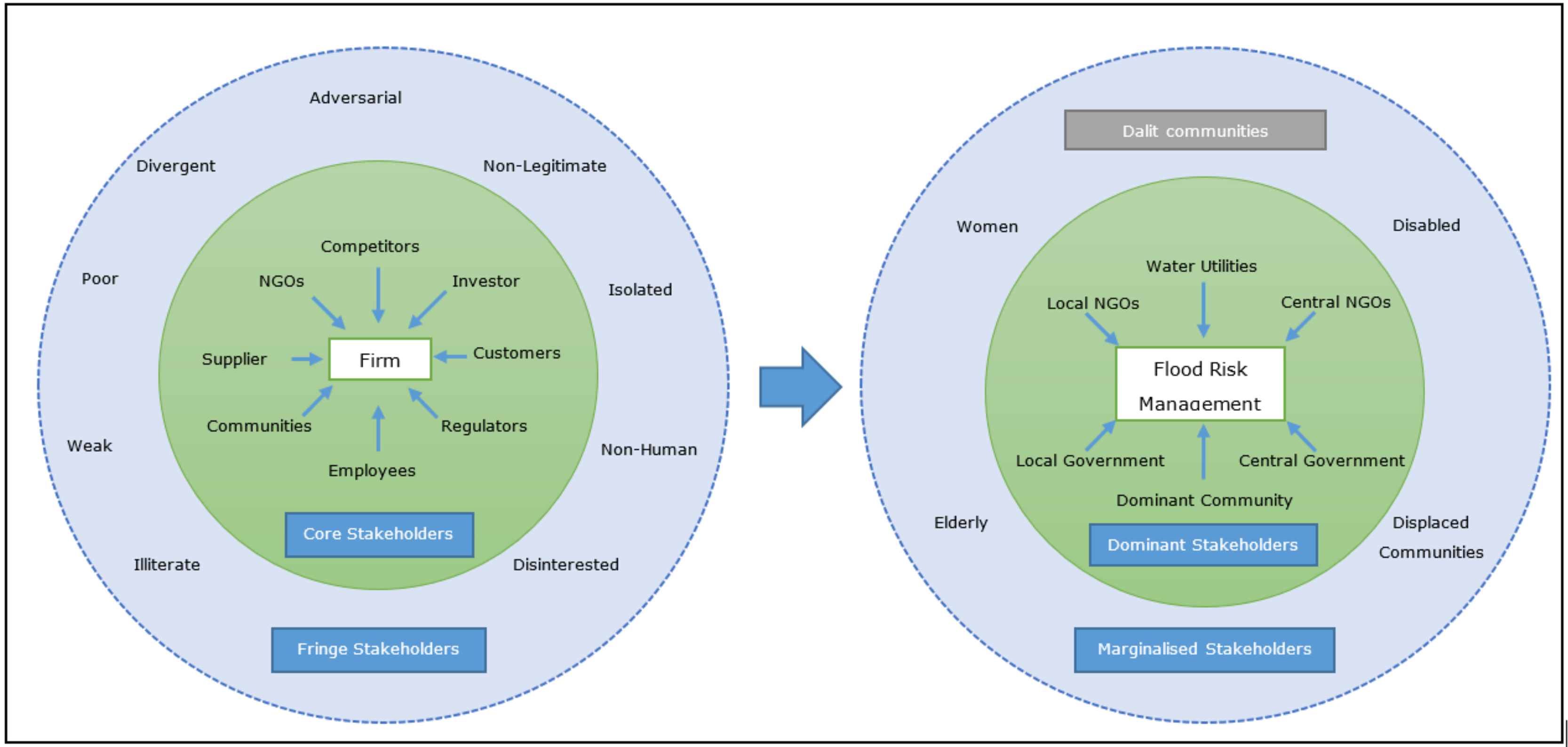


Figure 5-2 Flood risk management stakeholder spectrum existing in Kosi Basin (modified after Hart and Sharma (2004) – shown on the left)

5.3. Stakeholder participation for eliciting system structure

The second research question (Page 11) was directed towards identifying tools and techniques to elicit local knowledges based on the socio-demographics of a local context. In this section, an evaluation of tools and techniques was carried out to identify the most appropriate one suitable for the socio-demographics of the Kosi Basin. The basis for participation modelling lies in the inclusion of the stakeholders, reflecting their knowledge and experience. Their understanding of the system inevitably impacts the outcome of the participatory process. A systematic approach is critical for analysing the stakeholders and identifying those with diversity and breadth of situated knowledge required to fulfil participation goals (Reed et al., 2009, Bryson, 2004). There was a lack of pre-existing relationships with the Kosi Basin flood risk management stakeholders in this project. Gatekeepers (Professor Rajiv Sinha from the Indian Institute of Technology, Kanpur, and Sahbhagi Shikshan Kendra (SSK) NGO), who work in the area, were approached through email to bridge this gap in the relationship.

Professor Rajiv Sinha had been working on Kosi Basin and had completed several projects on hydrology, flood risks and sediment transport of the Kosi River. While working on the projects, he developed relationships with the government official responsible for managing floods in the Kosi Basin. Furthermore, Sahbhagi Shikshan Kendra (SSK) NGO worked in flood-affected villages in Mahishi Block, Saharsa district, Bihar, at that time. The NGO worked with the livelihood needs and sanitation problems of poor and vulnerable communities affected by the Kosi River floods. They employed community members as part of their team for their work. A significant advantage of working with the SSK NGO was that the field personnel lived in the field area and had situated local knowledge about the field area. Moreover, working with the communities in the area, they had established support and trust in the communities.

Stakeholder identification for participation was carried out by scoping the field area and traversing local networks of stakeholders. Scoping the field area was required to provide spatial context about the at-risk communities (Brugha and Varvasovszky, 2000), and traversing the local networks was essential for mapping the flood risk management stakeholder spectrum (Maskrey et al., 2016).

5.3.1. Scoping the field site and setting spatial boundaries

SSK NGO personnel helped the researcher in scoping the field site, and as a result, a cartographic map of Mahishi Block, Bihar (25°51′40″ N, 86°24′52″ E) is presented in Figure 5-3. The map represents a basic layout of the area with physical features like embankments, rivers and major roads. During the field investigation, it was established that the communities living in the Kosi Basin are divided into three groups. This grouping was based on the spatial location of their residence:

- Section 1 (cross-sectional width ~ 2 km) cross-sectional area from the east Kamla Balan embankment to the Kosi west embankment marks the waterlogged communities. These communities are named waterlogged communities because these communities also face groundwater flooding during the non-monsoon time in addition to river flooding during monsoon.

- Section 2 (cross-sectional width ~ 9-10 km) is composed of communities residing within the west and east embankments of Kosi, named within embankment communities. These are the communities facing the direct impact of the Kosi River flooding during monsoon time.
- Section 3 (cross-sectional width of embankment = 3 m) consists of communities residing on the Kosi west embankment, named embankment communities. These communities are landless people who have lost their homes to groundwater or river flooding. So, these communities consist of people who were a part of waterlogged communities or within embankment communities once.
- Section 4 is beyond the eastern Kosi embankment and is also affected by waterlogging like Section 1.
- Section 5 is the east Kosi embankment area; landless communities from the waterlogged and within embankments area live there, same as Section 3.

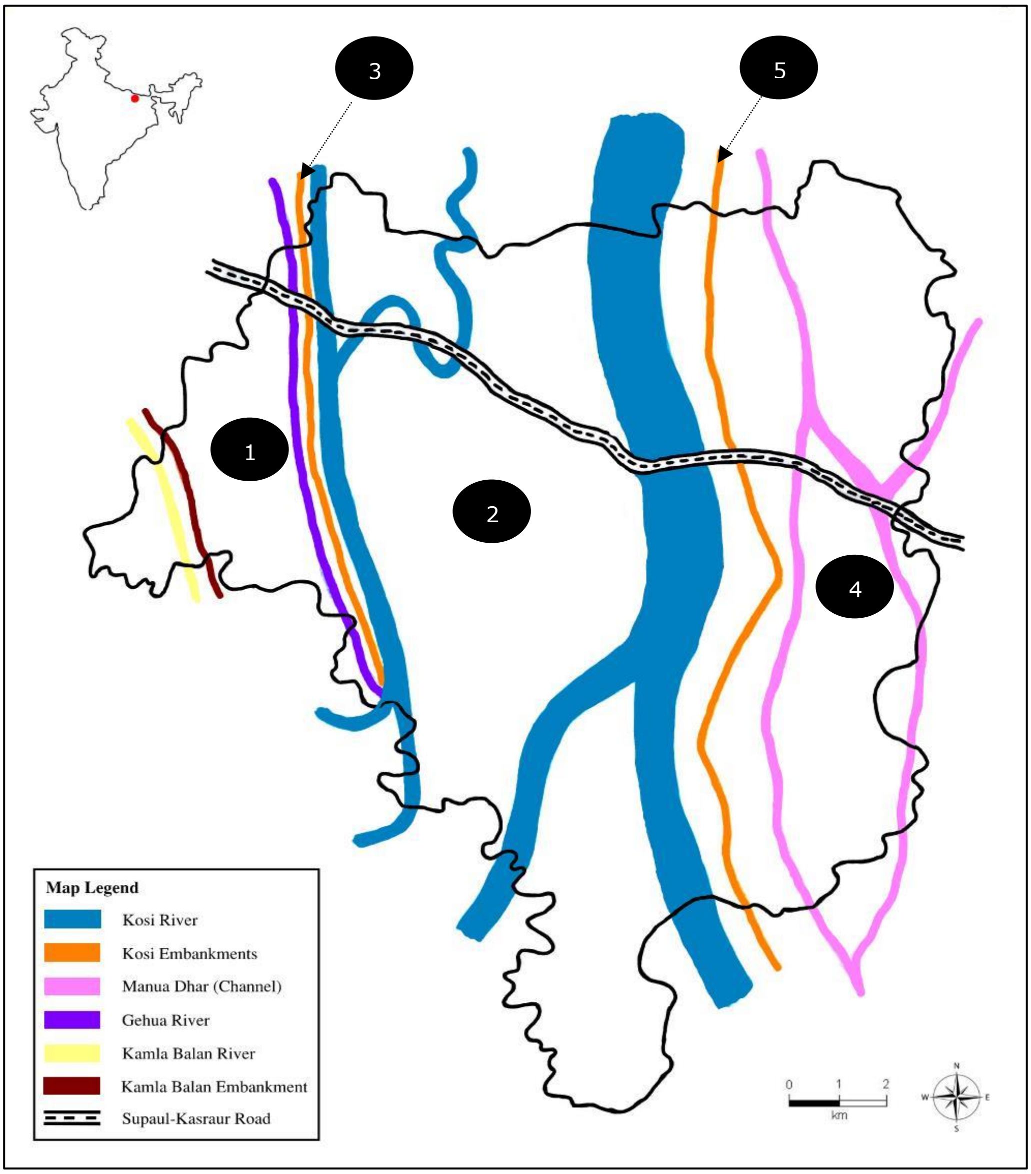


Figure 5-3 Mahishi Block Map

For conceptualising the Kosi Basin system, it was essential to explore whether these groups of communities residing in the waterlogged area, on the embankments and within the Kosi embankments are distinct from each other and whether they behave differently concerning the human-flood interactions. Hence it was fundamental to the research to understand whether:

1. The Kosi Basin system consists of spatial communities (waterlogged, within embankments, and on the embankment) independent of each other, or

2. All the communities are dependent on each other and have the same human-flood interactions. These interactions may have different scales within different communities.

Therefore, including these three different groups of communities in the participation process was deemed crucial for understanding the whole Kosi Basin socio-environmental system. However, the areas included in the present study were specifically set due to pragmatic reasons such as the limitation of time and resources and also justified based on biophysical dynamics:

1. **Waterlogged area (Section 1):** The waterlogged area is impacted by both river flooding and groundwater flooding. This groundwater flooding is a result of the Kosi River. Therefore, this area was included to understand the impacts of Kosi groundwater and river flooding on the communities. Section 1 and Section 4 are both affected by waterlogging. Furthermore, Section 1 is enclosed from both sides, from the east by Kosi west embankment and from the west by east Kamla Balan embankment; in comparison, Section 4 is enclosed from one side only. After discussions with the SSK NGO personnel, it was understood that the same issues are faced in both Section 1 and Section 4. Therefore, it was considered pragmatic (time and resource constraints) to focus on just one

community i.e. Section 1 as it is broadly representative of the challenges faced by others in those similar situations.

2. **Within Kosi embankments area (Section 2):** Section 2 was included in the study to understand the impacts of direct Kosi River flooding on the communities residing within the communities.

3. **West embankment area (Section 3):** This area became home to many landless families impacted by waterlogging or river flooding. Hence, including the communities living on the embankments would provide information about the worst impacts of flooding in the Kosi Basin. Since Sections 3 and 5 share the same characteristics, including one section out of the two was considered pragmatic. Hence, Section 3 was selected for the present study.

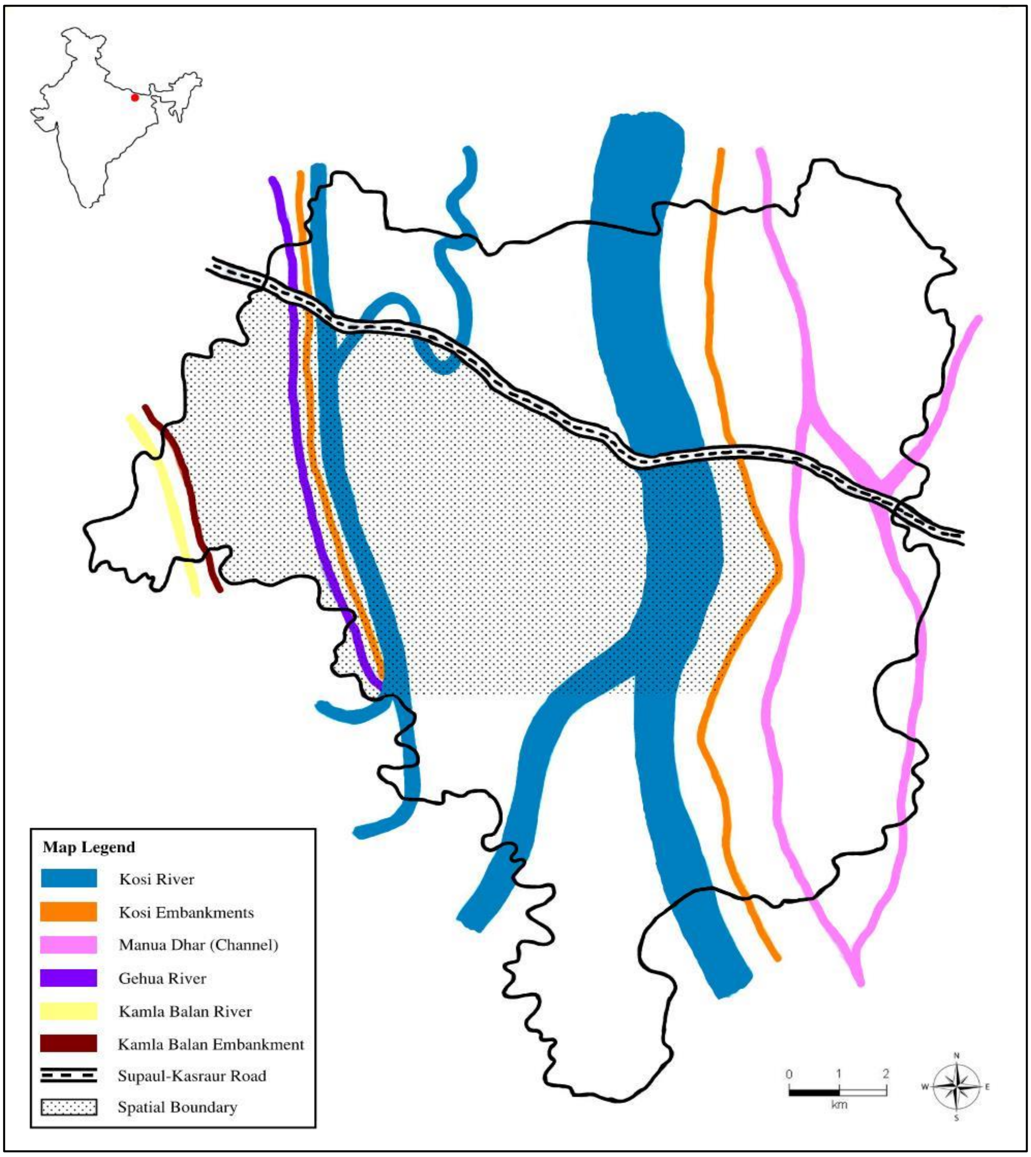


Figure 5-4 Spatial boundaries

In conclusion, the present study's spatial boundaries (Figure 5-4) were set as follows: 1) Cross-section (east to west) → from the eastern Kosi embankment to the east Kamla Balan River Embankment and, 2) Longitudinally (north to south) → from Supaul-Kasraur road to the end of the west Kosi Basin embankment. A smaller area from the whole Mahishi block area was selected because this area is representative of the human-flood interactions that happen in all three groups of communities, i.e., waterlogged communities, within embankments communities and west embankment communities.

5.3.2. Stakeholder analysis

After the scoping study and selecting the spatial boundaries for the present study, the next step was to traverse the entire flood risk management stakeholder spectrum. The SSK NGO helped access the different villages' leaders (local government), dominant community and marginalised community stakeholders and government authorities at the block level. Also, Professor Rajiv Sinha from the Indian Institute of Technology, Kanpur, helped gain access to the state-level government agencies.

Following that, a top-down iterative methodology (Dougill et al., 2006, Prell et al., 2008, Maskrey et al., 2016), also known as 'referral sampling' or 'snowballing' (Harrison and Qureshi, 2000, Hair et al., 2000) was used to identify potential participants. This sampling technique is used when the potential participants are hard to reach (Siddiqui et al., 2016, Sadler et al., 2010). So, the already identified participants help recruit future participants among their social networks (Naderifar et al., 2017). The descriptions of stakeholders who were approached using the snowballing technique are presented in Table 5-3.

Table 5-3 Stakeholders approached using the snowballing technique

Stakeholder sub-category	Stakeholders	Description
Stakeholder category- Marginalised stakeholders		
Marginalised community	Dalit and downtrodden communities residing in Mahishi Block	Divergent, adversarial, powerless, isolated, illiterate, weak and poor communities
Stakeholder category- Dominant stakeholders		
Dominant community	Zamindars (Landowners)/ upper caste communities residing in Mahishi Block	Powerful, resourceful communities with a strong socio-economic status
Local governance	Sarpanch (Village head)	Village decision-maker elected by village level constitutional body of local self-government (gram sabha)
	District Magistrate of Saharsa	Chief Executive of the district responsible for running and administration of the district
	Block development officer	Planning and Development of block
	Rural Development Department	Implementation of programs for alleviating poverty
Regional NGOs	Sahbhagi Seva Sadan	Center for Participatory Learning and Action
	Indian Red Cross Society	Delivering emergency relief during disasters

Stakeholder sub-category	Stakeholders	Description
	Seeds India	Building Resilient Communities
Local NGOs	Kosi Seva Sadan	Flood action group
	Megh Pyne Abhiyan	Water quality and Sanitation
Water Utilities	Bihar Disaster management authority	Focuses on disaster mitigation and risk reduction in Bihar state
	Water resources department	Protects the right of State in sharing Water of Inter-State Rivers/Basins
	Flood control and drainage, Birpur, Bihar	Construction and maintenance of Kosi embankments and drainage of waterlogged areas

To ensure the minimisation of the sampling biases and marginalisation of different groups of stakeholders (Reed et al., 2009, Ananda and Herath, 2003); Maskrey et al. (2016) suggest the usage of the Influence and Interest method (Figure 5-5). This method provides a simpler stakeholder classification of context setters, key players, subjects and the crowd (Ackermann and Eden, 2011, De Lopez, 2001). This classification helped structure the wide range of stakeholders identified based on their local flood interest, experiences and expertise (Maskrey et al., 2016).

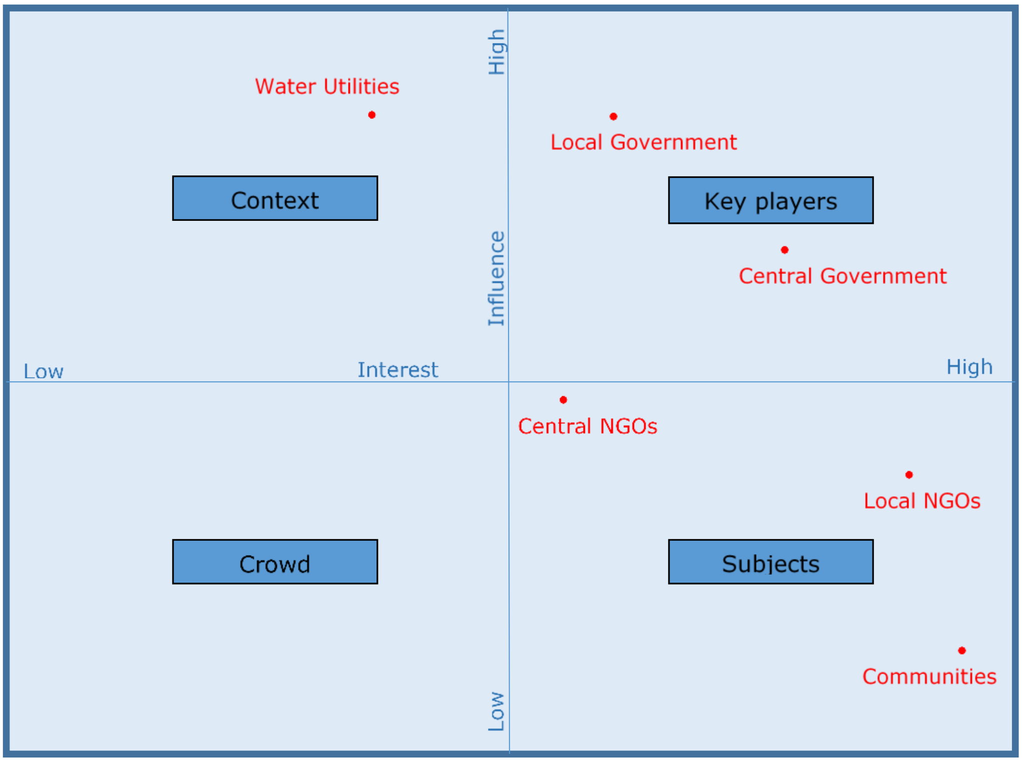


Figure 5-5 Stakeholder mapping (after Ackermann and Eden, 2011, De Lopez, 2001, Maskrey et al., 2016)

However, co-production of knowledge for improving existing flood risk management strategies, involving both local and scientific expert knowledges, is considered problematic because of a substantial difference in their elementary value system (Thaler and Levin-Keitel, 2016, Klinke and Renn, 2002) and interest (Thaler and Levin-Keitel, 2016), resulting in the absence of shared understanding (Kuhlicke et al., 2016) to conceptualise the system.

Therefore, the stakeholders with local knowledges mapped to the quadrants overlapping the high-interest and high-influence regions were invited as an initiation group to participate in the project. These comprise stakeholder groups covering a wide range of situated local knowledges: 1) dominant and marginalised community stakeholders, 3) stakeholders from local government, and 3) regional and local NGOs. The selection of these stakeholder groups was instrumental in constructing a conceptual model of the Kosi Basin system, henceforth acknowledging the need to integrate local knowledges into local flood risk management (Edelenbos et al., 2017).

5.3.3. Interview process

Compared to quantitative methods, qualitative approaches for system representation provide more opportunities to engage with the stakeholders, especially the marginalised sub-groups, in holistic research (Denzin et al., 2008, Dennis and Horn, 2011). The roots of qualitative research lie in generating knowledge elicited from human experiences (Sandelowski, 2004). However, the data collection process for complex problem situations like Kosi Basin needs to be rigorous and fundamentally affects the research findings (Kallio et al., 2016), influencing the trustworthiness and quality of results (Kitto et al., 2008). Therefore, selecting an appropriate data collecting method is vital and depends on the research question 3 (Kallio et al., 2016), i.e. what systems of causality exist within the flood-prone Kosi Basin?

Semi-structured interviews, the most frequently used method for data collection in qualitative research, were selected for the data collection process (DiCicco-Bloom and Crabtree, 2006). The selection of the method was based on its suitability for studying people's perceptions involving emotionally sensitive (Åstedt-Kurki and Heikkinen, 1994, Barriball and While, 1994) and complex issues (Barriball and While, 1994) like flood problems in Kosi Basin. Also, compared to structured and unstructured interviews, semi-structured interviews are structured to an extent yet provide freedom for the participants to share their perceptions freely. Moreover, the open-ended questions in the semi-structured interview process introduce a degree of flexibility in the data collection process (Guest et al., 2013).

Twenty-four face-to-face semi-structured interviews were conducted. Out of these twenty-four interviews, twenty-one were conducted within the spatial bounds of the field site (Figure 5-6). These interviews included the dominant community members, the marginalised community members and the local governance personnel residing in the area. Three more interviews were conducted with the NGO personnel but are not plotted on the map because these participants do not reside within the bounds of the field area.

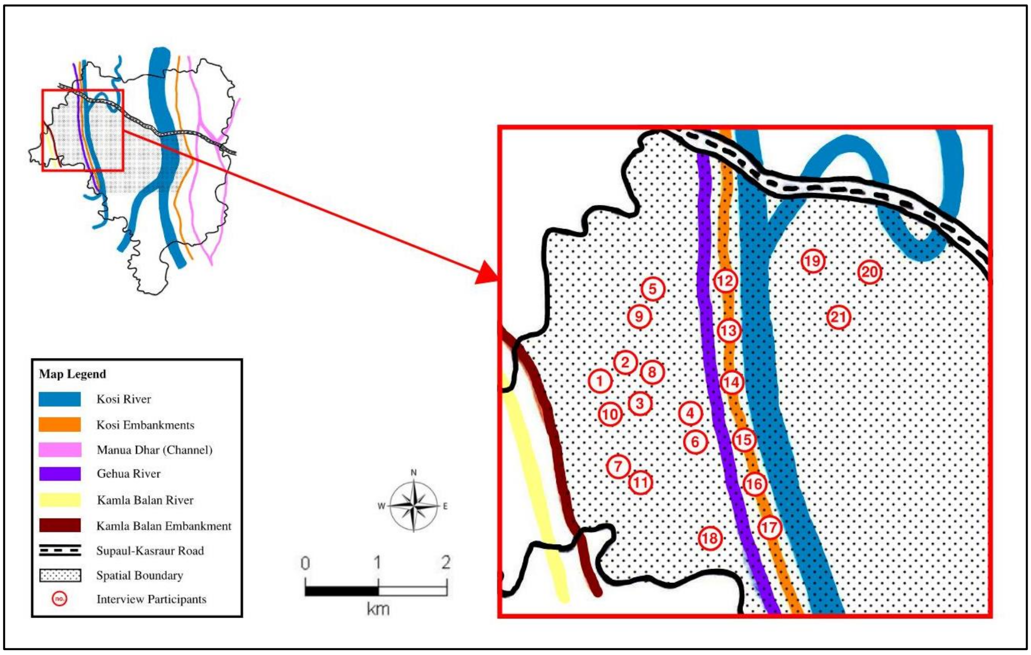


Figure 5-6 Spatial location of community participants

Moreover, a detailed description of all the twenty-four participants is provided in Table 5-4. To maintain the anonymity of the participants interviewed, they were coded based on their gender and area where they live (or stakeholder group) as follows:

1. Community members and local government personnel
   Code → <gender><number><area where they live>

Where,

gender= M for male, F for female

Number = 1 to N, N=1, 2, 3…with respect to area

Area where they live, i.e. WL= Waterlogged area, E= West Embankment and, WE= Within Embankments

E.g. First male participant living in the waterlogged area interviewed → M1WL

2. NGOs
   Code → <gender><number>NGO;

Where,

gender= M for male, F for female

Number = 1 to N, N=1, 2, 3…

E.g. First male NGO personnel interviewed → M1NGO

Semi-structured interviews provide an opportunity to include diverse perceptions, making it possible to focus on issues and problems meaningful to the different groups of participants (Cridland et al., 2015). According to Mishra et al. (2008:8), "it is not possible for others to narrate the stories of floods, erosion, sand casting and the resulting house collapses, loss of crops, starvation, unemployment, medical emergencies, indebtedness, extortion by money-lenders and migration that the people of the area have endured for long”. Therefore, the interviews aimed to derive particular knowledge from their lived experience in the context of their daily lives (Pritchard and Thielemans, 2014). Understanding the human-flood interaction of the at-risk communities would help understand the long and short-term effects of flooding on their lives.

However, involving only the community members would have introduced the likelihood of biases centred on their particular experience of recent flood events. Yet, many NGOs and local government participants had no first-hand experience of flooding and were not at substantial risk of flooding. The inclusion of these different stakeholder groups was favourable in minimising the participants' biases to an extent (Maskrey et al., 2016).

The inclusion of the gendered dimension in the participatory process allowed women to share gender-based problems arising due to floods. Women and adolescent girls are among the most vulnerable groups, being suppressed by patriarchal norms and socio-cultural practices (Madhuri, 2016). Moreover, they are in charge of the daily household responsibilities, taking care of the children and working as unskilled labourers (Mishra et al., 2008). The inclusion of women allowed gathering information about their experiences living in the Kosi Basin with floods which can provide vital insights that can be used for local flood risk management planning. The interview process also allowed the segregation of women from men, which was essential because of existing societal patriarchal norms. The power dynamics favour the men, resulting in subjugation and segregation of women, especially in rural India (Madhuri, 2016). These societal issues result in lean or no women's representation in society. However, the interview process allowed them to speak more freely about their problems. Also, having a woman researcher and a woman translator (SSK NGO personnel) was an added advantage (Singh et al., 2009). The interview process provided an opportunity to understand the lives of these women and the problems they face.

Table 5-4 Detail of meetings and interviews

S.no.	Date	Participant code	Stakeholder group	Participant characteristic	Age	(Village) Area	Moved From	Occupation
1	10/10/18	W1WL	Marginalised community	Woman	30	(Bhanti) Waterlogged Area	-	Unskilled Labour (Agriculture)
2	10/10/18	W2WL	Dominant community	Woman	26	(Bhanti) Waterlogged Area	-	Tailor
3	10/10/18	W3WL	Marginalised community	Woman (Disabled)	24	(Bhanti) Waterlogged Area	-	Homemaker
4	10/10/18	W4WL	Marginalised community	Woman (Disabled)	27	(Samani) Waterlogged Area	-	Homemaker
5	11/10/18	M1WL	Dominant community	Elderly Man	60	(Piparpati) Waterlogged Area	-	Farmer and Landowner
6	11/10/18	M2WL	Dominant community	Elderly Man	62	(Samani) Waterlogged Area	-	Farmer and Landowner
7	12/10/18	M3WL	Dominant - Local government	Elderly Man	58	(Pachminda) Waterlogged Area	-	Sarpanch
8	12/10/18	W5WL	Marginalised community	Adolescent girl	18	(Bhanti) Waterlogged Area	-	-

S.no.	Date	Participant code	Stakeholder group	Participant characteristic	Age	(Village) Area	Moved From	Occupation
9	12/10/18	M4WL	Dominant community	Elderly Man	64	(Piparpati) Waterlogged Area	-	Landowner/Farmer
10	12/10/18	M5WL	Marginalised community	Elderly Man	59	(Bhanti) Waterlogged Area	-	Unskilled Labour (Agriculture)
11	12/10/18	M6WL	Marginalised community	Elderly Man	61	(Pachminda) Waterlogged Area	-	Unskilled Labour (Agriculture)
12	13/10/18	W1E	Marginalised community	Elderly Woman	59	West Embankment	(Dhama Tola) Waterlogged Area	Small Business (Bamboo weaving)
13	13/10/18	M1E	Marginalised community	Man	33	West Embankment	(Dhama Tola) Waterlogged Area	Seasonal Migrant
14	13/10/18	M2E	Marginalised community	Man	37	West Embankment	(Dhama Tola) Waterlogged Area	Unskilled Labour (Agriculture)
15	13/10/18	M3E	Marginalised community	Man	31	West Embankment	(Dhama Tola) Waterlogged Area	Unskilled Labour (Agriculture)
16	15/10/18	M4E	Marginalised community	Man	30	West Embankment	(Baghwa) Within Embankments	Small Business (Bamboo weaving)
17	15/10/18	M5E	Marginalised community	Elderly Man	40	West Embankment	Darbhanga District, Bihar	Unskilled Labour (Agriculture)

S.no.	Date	Participant code	Stakeholder group	Participant characteristic	Age	(Village) Area	Moved From	Occupation
18	15/10/18	M7WL	Marginalised community	Man	36	(Ghonghepur) Waterlogged Area	-	Fisher
19	16/10/18	M1WE	Dominant - Local government	Elderly Man	56	(Bhagwa) Within Embankments	-	Sarpanch
20	16/10/18	M2WE	Dominant community	Elderly Man	59	(Bhagwa) Within Embankment	-	Farmer and Landowner
21	16/10/18	M3WE	Marginalised community	Man	40	(Bhagwa) Within Embankments	-	Unskilled Labour (Agriculture)
22	17/10/18	M1NGO	Dominant - NGO	Elderly Man	70	-	-	NGO
23	17/10/18	M2NGO	Dominant - NGO	Man	41	-	-	NGO
24	18/10/18	M3NGO	Dominant - NGO	Man	37	-	-	NGO

Furthermore, interviewing men and women engaged in different livelihoods such as fishing, agriculture, and seasonal migration workers provided an opportunity to understand the impact of floods on these communities' livelihood. In the context of flood risk management, assessing the problems that different livelihoods face in these areas can help understand the system's economic impact on these communities.

Therefore, the inclusion of a diverse group of stakeholders facilitated elicitation of local knowledges ranging from different experiences with floods: 1) living with floods (communities), 2) providing aid (NGOs), and 3) local governance (Sarpanch).

The conceptual base for the semi-structured interviews was informed by critically appraising the previous knowledge (Åstedt-Kurki and Heikkinen, 1994) before the data was collected (Turner, 2010, Barriball and While, 1994). This previous knowledge was collected through an extensive literature review (Barriball and While, 1994, Krauss et al., 2009) about the problem situation in Chapter 4: Kosi-Basin: A socio-environmental system.

Therefore, focusing on the purpose of the research (Krauss et al., 2009), the preliminary semi-structured interview guide was formulated. It is pertinent to form interview questions in a way that will help to explore all the relevant dimensions of the lives of people living in flood-prone areas.

The structure of the questions was participant-oriented (Barriball and While, 1994); being mindful of the social or cultural contexts of the questions would make the participants feel comfortable. Also, the questions were well-formulated and not leading (Turner, 2010) to avoid biases, and the style was open-ended (Krauss et al., 2009, Turner, 2010) and concise. The structure aimed to generate the richest possible data/answers (Turner, 2010), which were in-depth, spontaneous (Baumbusch, 2010, Dearnley, 2005), vivid (Dearnley, 2005), reflecting the personal feelings (Whiting, 2008) and stories (Rabionet, 2011) of the participants.

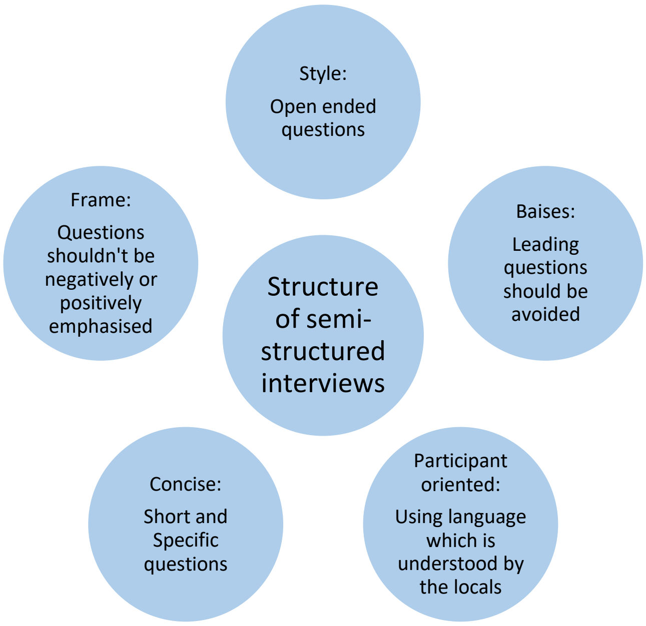


Figure 5-7 Structure for semi-structured

The semi-structured interviews (Figure 5-8) consist of two levels: central theme and follow-up questions (Kallio et al., 2016). The opening question was: "What would you say are the most concerning issues you face due to river flooding?" Descriptive answers were encouraged by starting follow-up questions with what, who, where, when, how (Chenail, 2011), and sometimes why (Turner, 2010). E.g. when the participant mentioned that agriculture is being affected by floods, then to know in detail the question: "how does the flood affect agricultural activities?" was asked.

Figure 5-8 Interviewing (a) an elderly and (b) local government personnel

However, a considerable challenge that the researcher realised was that a portion of participants, primarily women, spoke the Maithili language, which is the local language of the area. The rest of the interviewees were able to communicate in Hindi, which is the researcher's native language. Due to fewer educational opportunities in the area, the area's literacy rate is low. Also, these people are less exposed to the outside world, resulting in this language barrier. However, SSK NGO personnel helped with the translation from Maithili to Hindi, which was instrumental in minimising the data loss in the whole process and aided in obtaining a clear picture of the problems these communities face.

5.4. Stage 2- Kosi Basin structural formalisation

5.4.1. Thematic analysis of interview transcripts

The goal of the semi-structured interviews was to explore the interaction processes, behaviour, meanings, values and experiences of the purposefully selected participants in their 'natural' context (Liamputtong and Ezzy, 2005, Malterud, 2001). The original language of the interviews was kept, i.e. Hindi. Although it meant that only the researcher would be able to read the transcripts, it also ensured that the transcripts captured the richness of experiences shared by the participants (van Nes et al., 2010).

The data abstraction technique used to elicit primary qualitative data was thematic analysis (Ryan and Bernard, 2003, Holloway and Todres, 2003). Thematic analysis is a method used for identifying, analysing, organising, describing and reporting themes found within the collected data set (Braun and Clarke, 2006). The software used for coding the transcripts to draw out themes was Nvivo 12.0 (Figure 5-9).

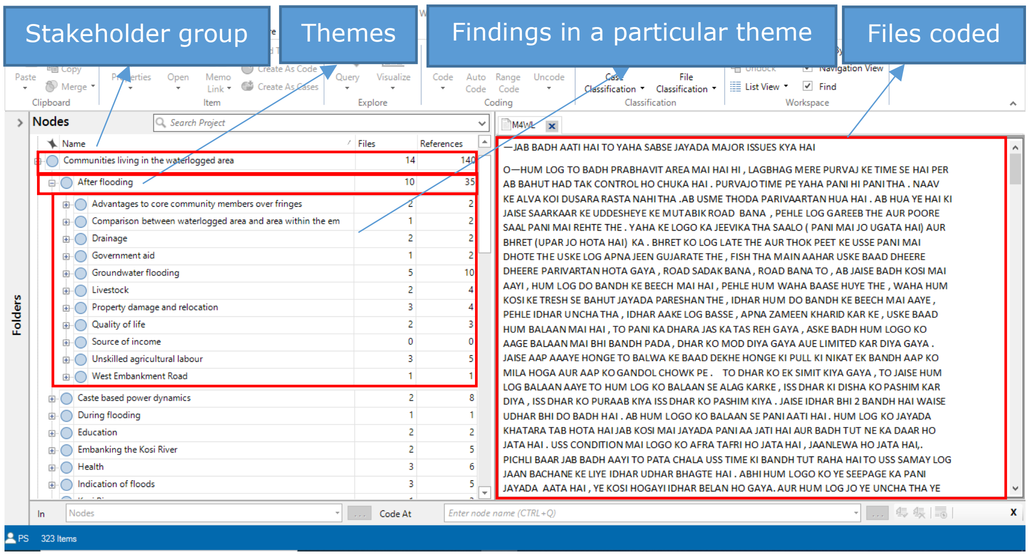


Figure 5-9 Nvivo 12 coding for analysing transcripts for waterlogged area

As shown in Table 5-5, the themes drawn out from the interview transcripts helped comprehensively understand the context and content of the problem situation. In Table 5-5, the syntax of findings was: X (number of transcripts, references).

Where,

X = Finding

number of transcripts = the total number of transcripts in which references are present

References = the total number of times the participants mentioned a particular finding

It was evident from the findings that the participants recognised connections between different activities, events, places and expressed the relationships and interactions taking place in the Kosi Basin system. E.g., the finding 'Government policy for building toilets is challenging to implement in flood-prone areas (1,1)' mentioned by the stakeholder group 'Communities living in the waterlogged area' under the theme 'Sanitation facilities' suggests a connection between the central government policy and its implementation in a flood-prone area.

The interview transcripts from different stakeholder groups were coded separately to understand if different spatial communities have different interactions with floods in the Kosi Basin system.

5.4.2. Thematic analysis findings

It was evident from the findings (Table 5-5) that during non-monsoon, waterlogged communities suffer because of waterlogging. Their source of income is impacted as they are unable to do agriculture. The west embankment communities face problems due to landlessness and can be moved anytime by the government or the Zamindars. However, the within embankments communities have better conditions because they have better agricultural opportunities than the other two spatial communities. Under the theme 'After river flooding (non-monsoon)' in Table 5-5 for stakeholder group 'Communities living in the waterlogged area', 'Communities living on the Kosi west embankment' and 'Communities living within Kosi embankments' for details.

However, these communities are not independent of each other. During the monsoon, the waterlogged communities and the within embankment communities temporary reside on the Kosi west embankment with the embankment communities to be safe from floods. Under the theme 'During river flooding (monsoon)’ in Table 5-5 under stakeholder group ‘Communities living in the waterlogged area’ and ‘Communities living within Kosi embankments’ for details.

A detailed description of the lives of the communities residing in the waterlogged area, within the embankments and on the west embankment is provided in the next section, i.e. Section 5.5. This description provides an insight into the lives of these communities and the short term and long-term impacts of flooding.

Table 5-5 Themes and findings for the Kosi Basin system

Themes	Findings (number of transcripts, references)
Stakeholder group: Communities living in the waterlogged area	
After river flooding (Non-monsoon)	**Quality of life:** Waterlogging in the area (1,1), Cleaning the house from insects (1,2) **Government aid:** Government Aid is given (1,2) **West embankment road:** The poor condition of the west embankment road (1,1) **Unskilled agricultural labour:** Batai (working on Zamindar's land) (3,3), If no crop yield, then no labour is paid (1,1), Zamindar keeps the crop damage compensation given by the government (1,1) **Property damage and relocation:** Flooding of the house (1,2), Relocation to a new place (2,2) **Groundwater flooding:** Waterlogging (5,10) **Livestock:** Livestock mortality (1,1), Livestock drinking stagnant contaminated water (1,1), Feeding on water hyacinth (2,2) **Source of income:** • **Agriculture:** Reduction in agriculture (6,12), Only able to grow green gram lentils, Maize (1,1), Limited agricultural period (Feb to May) (2,2), Nearly 30% land available for agriculture (1,2), Only Rabi season (1,1), Seeds spoil due to rain and storm (1,1), Taking private loans for doing agriculture (1,1), Removing water hyacinth and ploughing the agricultural fields (1,1) • **Fishing:** The quality of fish is better in the Kosi River as compared to the waterlogged area (1,1)

Themes	Findings (number of transcripts, references)
	Drainage: Improper Drainage (2,2)
Comparison between waterlogged area and area within the embankments	Water quality is poor than from the communities living within the embankments during non-monsoon due to waterlogging (1,1), Fewer agricultural opportunities as compared to communities living within the embankments (1,1)
Learnings from river flooding experiences	**Preparations:** Preparation for floods (2,2), Selecting high grounds (1,2), Preparing food in advance (1,1), Making community groups (1,1), Learning to swim and rowing boats since they were children (1,1), Arranging boats (2,2)
Caste-based power dynamics and corruption	**Education:** Unfair distribution of stipend and scholarship money at school (1,1), Corruption in the distribution of daily meals at school (1,1) **Relief:** Corruption in flood relief given by government (1,2) **Boat distribution:** Discrepancy in boat distribution (1,2)
During river flooding (Monsoon)	**Temporary relocation to the west embankment to be safe from river flooding (July to September)** • **Transportation and rescue:** Transportation problems (4,5), Dependency on boats (2,2), If no access to boats, then goes through the floodwater walking (1,1)

Themes	Findings (number of transcripts, references)
	• **Living arrangement:** Temporary relocation to the west embankment (3,3), Make huts from plastic sheets and live there for the flooding period (1,1), Lack of safety (1,1) • **Women and adolescent girls:** Walking in flood water makes them prone to diseases (1,1), Using dirty cotton clothes (washed in flood water) as sanitary napkins (1,2), Lack of money for treatment of infections (1,1), Being in flood water cause tetanus (1,1) • **Snake and other insects:** Snakebites (2,2), Snakes and insects come over to the embankment (1,1), Human mortality from a snake bite (1,1) • **Sanitation:** Lack of toilets (4,6), Open defecation (1,1) • **Livestock:** Take livestock, if possible, otherwise, leave them in floodwater (2,2), Drowning of livestock (1,2) • **Healthcare facilities:** Lack of healthcare (1,1) • **Drinking water:** Lack of clean drinking water (1,1) • **Electricity:** Lack of electricity (1,1) • **Government:** Lack of government support (1,1) **High places for temporary relocation during river floods provided by the government:** Poor condition of the high places (1,1), Lack of toilets (1,1), Lack of food (1,1), Lack of clean drinking water (1,1) **Condition of the waterlogged area where they live:** Danger to life and personal belongings in the waterlogged area (2,4)
Education	**Physical constraint:** School surrounded by waterlogging (1,1)

Themes	Findings (number of transcripts, references)
	Facilities: Lack of teachers (1,1)
Embanking the Kosi River	**Groundwater flooding:** Seepage in areas outside the Kosi Embankments (2,2), Waterlogging due to seepage and improper drainage planning (1,1) **Community participation in flood risk management planning**: No participation of communities in flood risk management projects (1,1) **Agriculture:** Lack of agricultural opportunities due to waterlogging (1,1)
Health	Spread of diseases like Cholera, Diarrhoea, TB and Asthma (3,5), Lack of health facilities (1,1)
Indication of river floods	**Early warning system:** No early warning system (1,1), If warning given that the water from the barrage is being released, then there will be less loss to life and property (1,1) **Experienced Judgement:** Increasing water level (2,2), Move to the embankment when the water starts rising (1,1)
Kosi River	**Physical properties:** Scouring (1,1), Playful river (1,1), Back flows into the waterlogged area through the end of the west embankment (1,1)
Male seasonal migration	**Migration:** Migrating to other cities for unskilled labour (6,8) **Reason for male seasonal migration:** Lack of source of income (3,4), Family responsibility (3,3) **Duration:** From 6 months to 1 year (1,1)

Themes	Findings (number of transcripts, references)
Stakeholder interventions	**NGOs:** NGOs providing boats (1,1) **Government:** Improvement in health and transportation facilities (2,2) **Community:** Community efforts (2,5)
Reasons for flooding	**Groundwater flooding:** Seepage leading to waterlogging (2,2) **Surface water flooding:** River water released from Kosi barrage (2,2), Embankment failure (2,2)
Sanitation facilities	Make toilets from bamboo (1,1), Government policy for building toilets challenging to implement in flood-prone areas (1,1)
Socio-economic status of communities	Poverty (1,2), 90% communities come in marginalised class (1,1)
The advantage to dominant community members over marginalised community members	People with better socio-economic status raise their land (2,2)
Water Quality	Limited hand pumps (1,1), Excess iron content in water (1,1), Reduction in quality and quantity of fish (1,2), Most hand pumps are not deep enough to pump clean drinking water (1,1)

Themes	Findings (number of transcripts, references)
Why living there?	Emotional attachment (5,6), Personal assets (3,3), Community support (2,2), Cheaper to live there than the city (1,2), Cultural attachment (1,1), The relocation land given by the government is less, they will not be able to do agriculture (2,2), Used to living in floods (1,1)
Women	Gender inequality in wage distribution (1,1), Lack of toilets (1,1)
Problems for Disabled people	Difficult to walk in the waterlogged area (2,2), Difficult to get on a boat without help (2,2)
Stakeholder group: Communities living on the Kosi west embankment	
Why living there?	**Reasons for permanent movement from waterlogged area to Kosi west embankment** **Groundwater flooding and water hyacinth:** Surrounded by water for 12 months (3,3), No place to keep livestock (1,2), Low crop yield (1,3), Long commute time from the waterlogged area (1,1), Spread of water hyacinth (1,1), Difficulty in reaching their home even by boats (2,2), Permanent resettlement to west embankment (4,4)

Themes	Findings (number of transcripts, references)
	Reasons for permanent movement from the area within the embankment to the Kosi west embankment **River flooding:** House got submerged during river flooding (1,1) **Power Dynamics:** Cannot go back to their land once it is levelled because it is captured by Zamindars now (1,2) **Government Compensation:** No compensation given by the government (1,1)
After river flooding (Non-monsoon)	**Sense of security:** • **Zamindar**: Forcefully removed Zamindars as they claim it is their land (1,1) • **Government**: Lack of security while living on the embankment as the government can move them at any time (3,4), People feel hopeless as no action taken on the forceful land acquisition complaints filed by the people (1,2)
Stakeholder group: Communities living within the Kosi embankments	
Why living there?	Do not want to leave the place and live somewhere else (1,1)
Socio-economic status of communities	10% rich population (1,1)
Water quality	Hand pumps need to be 110 ft. (1,1), Low boring leads to high iron content (1,1), Poor people are unable to bore 110 ft., leaving boring height only 40-45 ft. (1,1)

Themes	Findings (number of transcripts, references)
The advantage to dominant community members over marginalised community members	People with better socio-economic status raise their land (2,2), People who raised their lands do not come to the embankment during low floods (2,3),
Rehabilitation	Did not rehabilitate because the land was given outside the embankments in the waterlogged area, the land was not suitable for agriculture (2,2)
Reasons for river flooding	Heavy rains in Nepal (1,1)
Learnings from river flooding experiences	**Preparation:** Preparing food in advance (2,3), Self-reliant for facing floods (1,1) **Agricultural opportunity:** Grows rice to utilise river flood water for irrigation (2,2)
Indication of river floods	**Flood warning:** Sometimes government vehicle warns through announcing about water being released from the barrage (1,1), If someone hears the announcement, then they inform other people in the community (1,1) **Experienced judgement:** Increasing river water level (1,1)
Health	Spread of diseases like diarrhoea, skin diseases (1,1)
Education	Poor quality of education and corruption in distributing daily meals (1,1)

Themes	Findings (number of transcripts, references)
During river flooding (Monsoon)	**Condition of the area within the embankments where they live:** Water level increases in the river (1,1), Submergence of houses and villages (2,3) **Temporary relocation to the west embankment to be safe from river flooding (July to September)** • **Transportation and rescue:** Dependency on boats (1,1), Use boats to go to the embankment (1,1) • **Living arrangement:** Temporary relocation to the west embankment (2,2), Make huts from plastic sheets and live there for the flooding period (1,1) • **Livestock:** Livestock eat hay and not water hyacinth like the livestock in the waterlogged area (1,2) • **Snake and other insects:** Snakes come over to the embankment (1,1), Use sticks for protection (1,1), Human mortality from snake bites (1,1)
Comparison between waterlogged area and area within the embankments	Good agricultural opportunities before and after river flooding (1,2), Suffer for 1-3 months (July to September) till the time floods last (2,2), When the embankments were built, the situation of the waterlogged area was better than the area within the embankments (1,1)

Themes	Findings (number of transcripts, references)
After Flooding (Non-monsoon)	**Flood relief and compensation:** If half house flooded then food grains, one quintal (100kgs) wheat and plastic sheet is given as relief (1,1), If the house falls in the river, compensation= ₹2000 (~£20) (2,2), More compensation is given in case of fire (1,1), Rehabilitated land given by the government in other villages (1,1) **Quality of life:** After flooding, do not face any problem as such (1,1), do not make houses with bricks because they live in the earthquake zone (1,1) **Source of income:** Male seasonal migration (1,1), Unskilled labour or Agriculture (1,1)
Stakeholder group: NGOs	
Before embankments	Communities were in better condition (1,1), Floods used to come, and within 2-4 days things were back to normal (1,1), River water used to bring good agricultural soil (1,1), People from other states used to do seasonal migration here for agricultural labour (1,1), There was a flood coping system (1,1), There was no male seasonal migration (1,1)
After embankments	Work for constructing embankments started in 1955 (1,1), 13 blocks (380 villages) are trapped inside the embankments (1,1), Embankments are the reason for our hardships, male seasonal migration (1,1), Nearly 80% of people do seasonal migration (1,1), Mostly elderly population live here (1,1), Waterlogging (started nearly 20-25 years ago) (1,2), Waterlogging destroyed the fertile land (1,2), Major issues to farmers living outside the embankment within 2-3 km distance (1,1), The agricultural activities have decreased (1,1)

Themes	Findings (number of transcripts, references)
Reason for flooding	**River flooding:** Embankment damage (1,1), Embankment has been broken due to floods eight times (1,1), Man-made flood (1,1) **Groundwater flooding:** The outside area became low land due to siltation in the river (1,1)
Government	**High platforms:** Provides platforms for safety from floods (1,1), Platforms are made of silt which gets flooded during floods (1,1), These platforms are not sufficient (1,1)
Health	Snake bites cause death (1,1), During delivery time, sometimes pregnant women die during transportation to the city (1,1)
Life of people in the waterlogged area	Waterlogging due to improper drainage (1,1)
Life of people inside the embankments	**During floods:** • **Fertile soil:** River water brings fertile soil for agriculture (1,1) • **Education:** Children can drown in the river water if they try to go to school (1,1), Education ceases (1,1) • **Livestock:** Difficulty in taking livestock to high places during floods (1,1) • **Transportation problems:** Difficulty in commute (1,1) **After floods:** • **Education:** Teachers do not go to school because of a lack of transportation facilities (1,1)

Themes	Findings (number of transcripts, references)
Comparison between waterlogged area and area within the embankments	The current agricultural situation of people within the embankments is better than people living outside the embankments (1,1)
NGO work	**During floods:** • **Relief:** Provide survival packets (food, plastic sheets) to families during river floods (1,1) **After floods:** • **Awareness:** Spreading awareness about floods (1,1), Spread awareness about how to clean their house and surroundings (1,2) • **Education:** Helping in school admissions (1,1) • **Relief:** Spread Lime powder (1,1), Distribute livestock and medicines (1,1)
Stakeholder interventions	**Transportation:** The condition of transportation is getting better (1,1)
Rehabilitation	Some people did not rehabilitate in the beginning because they had their agricultural lands within the embankments (1,1), Some of the rehabilitation lands are also waterlogged (1,1),

5.5. The lives of communities living in the Kosi Basin

In this section, quotes are used to help to justify the themes and findings presented in the Table 5-5. These quotes from the participants explicitly represent the emotions and beliefs about the content and context of the problem situation (Tan et al., 2018), and were also instrumental in demonstrating the participants' systems view.

During the interviews, the participants pointed that the problems began after the Kosi embankments were built (Box 5-1). The beginning of the problems indicates the time when the three different spatial communities originated. Before the embankments, all the communities used to be impacted by river floods during the monsoon.

Box 5-1: M3WL - "The problems of Kosi in this area are since the construction of this (Kosi) embankment, east and west embankment… We are influenced by this a lot. It has impacted our culture. When flooding happened during the time of our ancestors (before the building of embankments), it used to bring 3-4 feet of water, and it would stay for 3-4 days maximum. It would bring soil which will help in increasing the fertility of the land. The crops were able to produce a good yield without even using fertilizers. However, since the day these Kosi embankments were built, we face a lot of seepage from the Kosi River."

5.5.1. Lives of waterlogged communities during non-monsoon

Communities residing in the waterlogged area are affected by river flooding during monsoon and groundwater flooding during non-monsoon. In Kosi Basin, the flood embankments affect drainage connections between the river and the floodplains, causing waterlogging.

During non-monsoon, waterlogged communities interact with groundwater flooding. However, groundwater flooding is not as severe as river flooding, but it has prolonged effects because it lasts longer. Although, during the initial years, the water drained out with time, and the communities would go back to their agricultural activities.

After the construction of Balan embankments to the west to the communities living adjacent to the Kosi west embankment, the situation got worse (Box 5-2). The construction of the Balan embankment slowed down the area's drainage, and now the area remains waterlogged for 6-12 months every year. Therefore, these communities remain waterlogged during most of the non-monsoon period.

Box 5-2: M3WL- "Constructing the embankments would not solve the (flood) problem. On both sides, embankments have been constructed; the seepage would increase. From here (the end of Kosi west embankment), the Kosi River water backflows, and from there (Kamla Balan east embankment), the Balan River water also enters (through the sluice gate) in the waterlogged area."

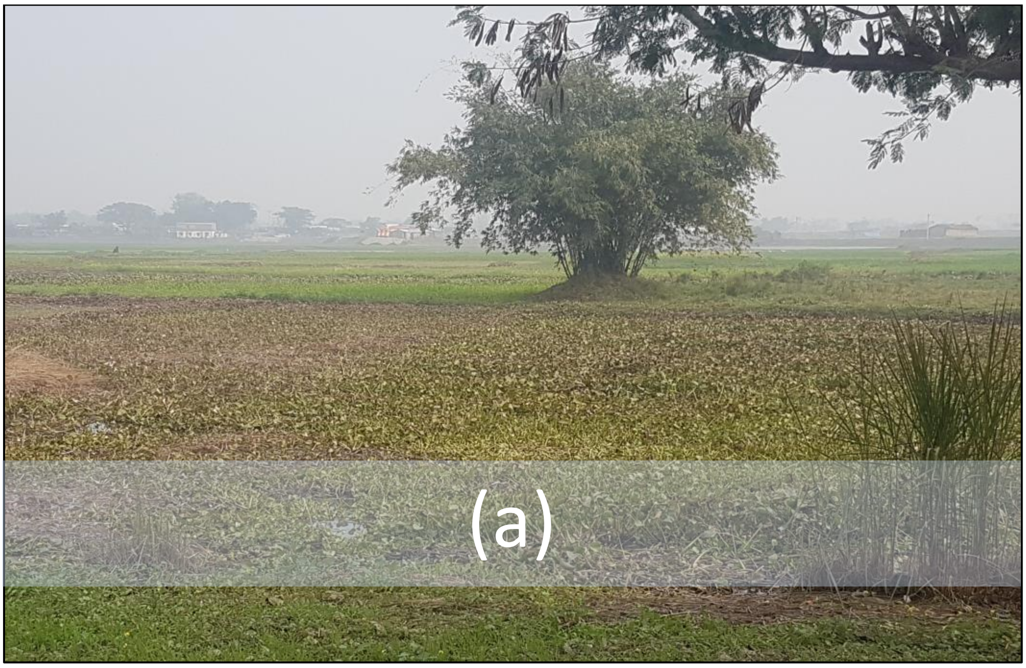
Also, the varying depth of waterlogging in the waterlogged area creates a problematic situation for the people residing in some areas, impeding their agricultural activities (Box 5-3).

Box 5-3: M4WL – "This area has become waterlogged, the waterlogging stays for 6-7 months and these other areas (pointing towards Ghonghepur and parts of Pachminda villages) with lower elevation remain waterlogged year around. We are not able to do agriculture there."

Pictures (Figure 5-10) were taken in the field site to compare the contrasting situation observed in Pachminda Village. From the images in Figure 5-10(a) and Figure 5-10(b), which were taken from the road to Pachminda Village (nearly 500m) from the west embankment, it can be observed that the south side (Figure 5-10(a)) is still affected by water hyacinth. Water hyacinth is an invasive species that has multiplied itself in the waterlogged area, making most of the land not suitable for agriculture even when it is dry. On the other hand, the north side, shown in Figure 5-10(b), is free from waterlogging and is being used for agriculture (Box 5-3). Agriculture being the backbone of this area renders people without livelihood forcing them to do seasonal migration (Box 5-4), which has become a common practice in the communities to fulfil livelihood needs of their families.

Box 5-4: M3WL- "We are unable to do agriculture here, so the villagers (males) seasonally migrate to other cities"

M1NGO- "Before the embankments, we were quite content. People from other states used to seasonally migrate here for their livelihood needs, especially for agricultural labour…but today, the condition is such that 80% of people (males) seasonally migrate."



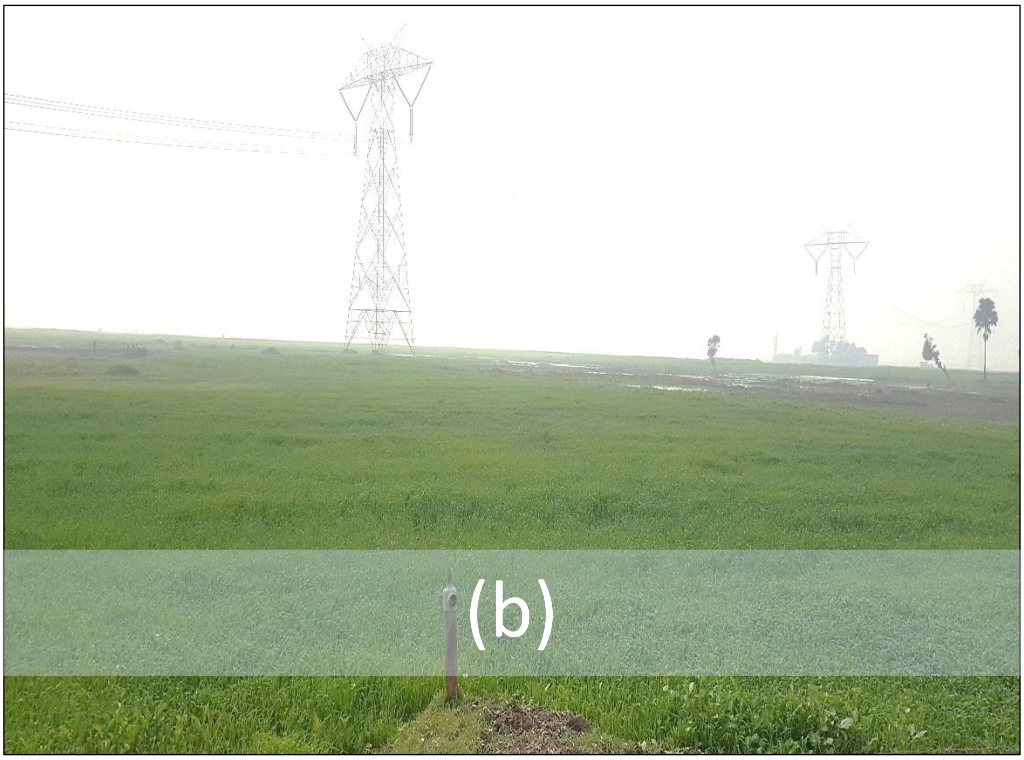


Figure 5-10 Contrasting images showing variable waterlogging (a) South side and (b) North side of the Pachminda village road (facing the Kosi west embankment)
(Pictures were taken during the field visit in October 2018)

Several farmers mentioned (Box 5-5) that water hyacinth is used as fodder for livestock (Figure 5-11); because of the low agricultural opportunities in the area, people are unable to grow crops that can be used as fodder.

Box 5-5: M1WL- "We are unable to do agriculture because it gets waterlogged here. The water becomes black and gets polluted. Because of this, animals also die…Villagers feed water hyacinth and water grass to the livestock"

Feeding water hyacinth to the animals makes them sick. Also, the spread of infections in livestock is high because of the stagnant, polluted water in the waterlogged area. These situations ultimately lead to high animal mortality. However, this has become a common practice for these communities due to no or fewer agricultural opportunities.

Figure 5-11 Children collecting water hyacinth for feeding livestock (Picture was taken during the field visit in October 2018)

Figure 5-12 depicts an example of an adaptation technique, which demonstrates how the people in the waterlogged area have used water hyacinth to catch fish in the area. These people capture the fish when fish come under the shadow provided by water hyacinth.

Figure 5-12 Water hyacinth being used as a means to catch fish
(Picture was taken during the field visit in February 2020)

The spread of water hyacinth in the area worsens the situation by obstructing transportation in the waterlogged area. It makes the commute by boat challenging and time-consuming. Even education suffers because of waterlogging (Box 5-6) (Figure 5-13). Due to waterlogging, it becomes difficult for children to reach school.

Box 5-6: M2E- "The water hyacinth is spread everywhere. There is no means for the commute, not even with a boat. If we go, we put the bamboo stick (used as an oar) over the water hyacinth and commute slowly…The children go to school when the water depth is low. We do not have enough money to send them to a convent school (private education), so they go to government school… The problem is that the school is completely surrounded by waterlogging. It is difficult to reach there."

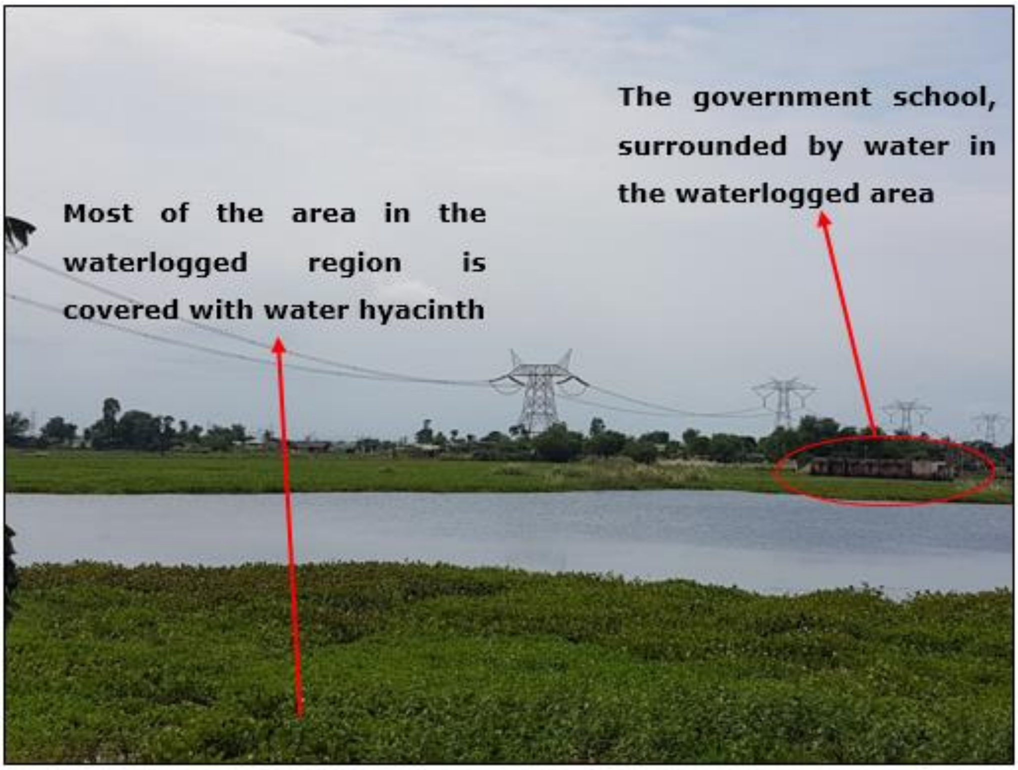


Figure 5-13 Waterlogged area in Pachminda Village, Mahishi Block
(Picture was taken during the field visit in October 2018)

When the water depth is low, the waterlogged communities cannot even use the boats for transport (Box 5-6) (Figure 5-14(a)). However, the government has built a cement road

(Figure 5-14(b)) to provide connectivity to several villages (Box 5-7), including Pachminda, but some villages still suffer from improper connectivity (Figure 5-14(c)).

> *Box 5-7: NGO1 – "Transportation facilities are getting better. Some roads and the bridge on the Kosi River have been constructed."*

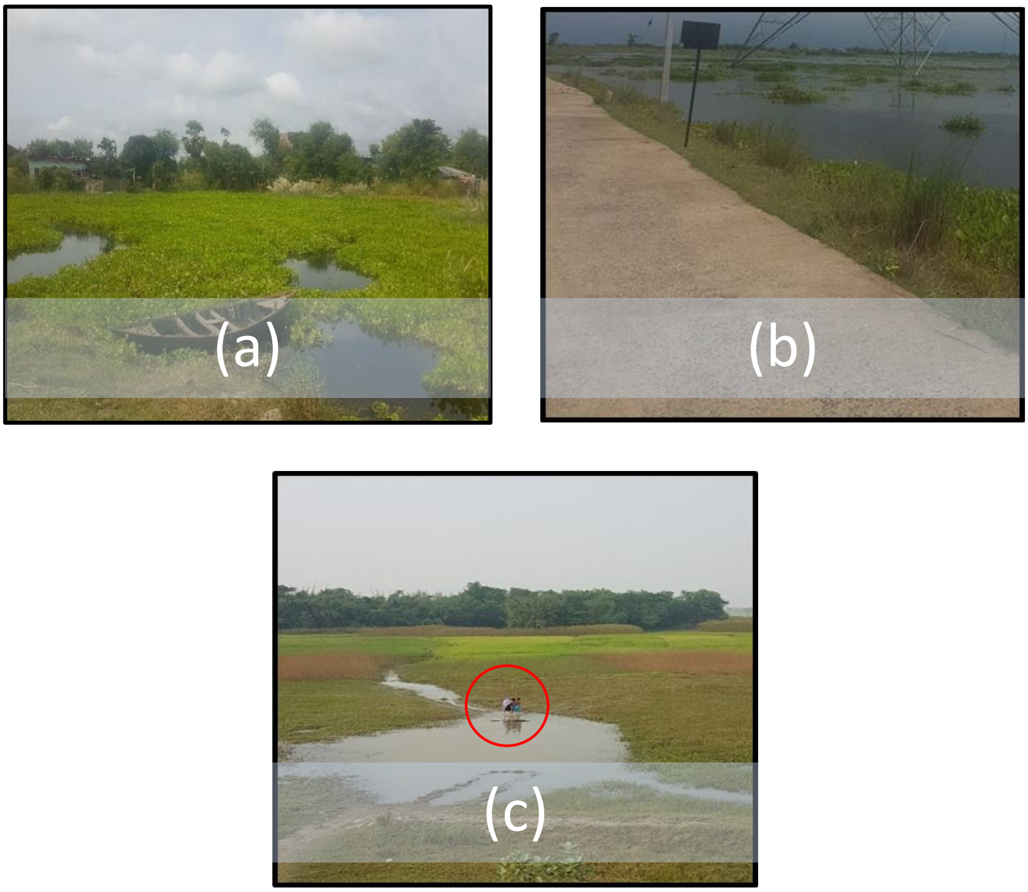


Figure 5-14 Condition of transportation in the waterlogged area during the low water period a) Boats used in Pachminda village, b) road in Pachminda village and c) way to Bharampur village (Pictures were taken during the field visit in October 2018)

In the waterlogged area, the dominant community stakeholders raise their land/home with soil to become resilient from groundwater flooding and low river floods (Box 5-8). However, the marginalised community stakeholders suffer more from waterlogging due to their inability to raise land.

Box 5-8: W2WL: "When the floodwater enters the courtyard (raised land), then we go to the (west) embankment. If the floodwater does not reach the courtyard, then we stay here only."

W1WL: "Some people put (extra) soil to raise their land every year. One trolley of soil is £4."

The families let the children swim in the waterlogged areas and practice rowing boats (Figure 5-15) as a means of preparing them for recurring monsoon flood events. However, this prevalent practice results in skin infections/diseases in children as a result of poor water quality (Box 5-9).

Box 5-9: M2WE- "This water has become black (polluted). When kids swim in it, they get skin diseases."

Figure 5-15 Children rowing boat and swimming in the waterlogged area (Picture was taken during the field visit in October 2018)

Furthermore, the water quality in both the waterlogged and within embankments areas is different. The spread of diseases is much higher in the waterlogged area due to polluted stagnant water (Box 5-10).

Box 5-10: M2WL- "There is a difference in the water in both the areas (waterlogged and within embankments). The Kosi River water is clean, and this water in the waterlogged area has no flow and become stagnant which causes diseases."

During the interviews with women (Box 5-11), it was also found that the commercial sanitary napkin is also a luxury. Due to the prevalent poverty and detachment of the area from the city, the sanitation standards are low. Due to shyness, women and girls do not communicate to the men regarding their needs; instead, they use napkins made out of old cotton clothes. However, flooding worsens the situation as there is limited access to clean water to wash the used cloth and dry it, increasing women's infection rate during floods.

Box 5-11: W5WL- "We are unable to go in the water. However, in an emergency, we have to go, which causes diseases. We do not have enough money to get treatment. Because of this, we do not go in the water if not required. If the sanitary cloth gets wet, then we re-use that same dirty cloth."

The conditions are much more severe in the trapped and unprotected villages. Due to the remoteness and lack of health facilities, many fatalities during pregnancy and childbirth occur in these areas (Box 5-12).

Box 5-12: M1NGO- "If a pregnant woman is due to deliver her baby, they (her family) have to take her to Mahishi or Saharsa city. During this commute, pregnant women have died."

The toilets, typically used by the community are temporary and made of bamboo (Figure 5-16 (a)). It was discovered that NGOs like SSK had had provided toilets in the villages. Making these toilets cost-efficient, initially, the constructed toilets only had one chamber (Figure 5-16 (b)). During the interview, women pointed out that most women cannot use the toilets as they feel shy to go in the same toilets as men. Afterwards, the NGO redefined the model to two chambers to facilitate separate toilets for men and women, resolving the issue to an extent.

Figure 5-16 (a) Bamboo toilets and (b) One chamber toilets provided by the SSK NGO
(SSK NGO provided the picture during the field visit in October 2018)

The waterlogging problem in Mahishi Block also worsens due to an opening (Figure 5-17) in the end on the west embankment connecting the area back to the Kosi River, initially helping to drain the water back to the river. So, when the discharge in the river increases, water flows back in the villages through that opening. This backflow was one more issue mentioned by participants during the interviews (Box 5-13).

Box 5-13: M3WL- "From this side (the end of Kosi west embankment), Kosi river water backflows into the (waterlogged) area."

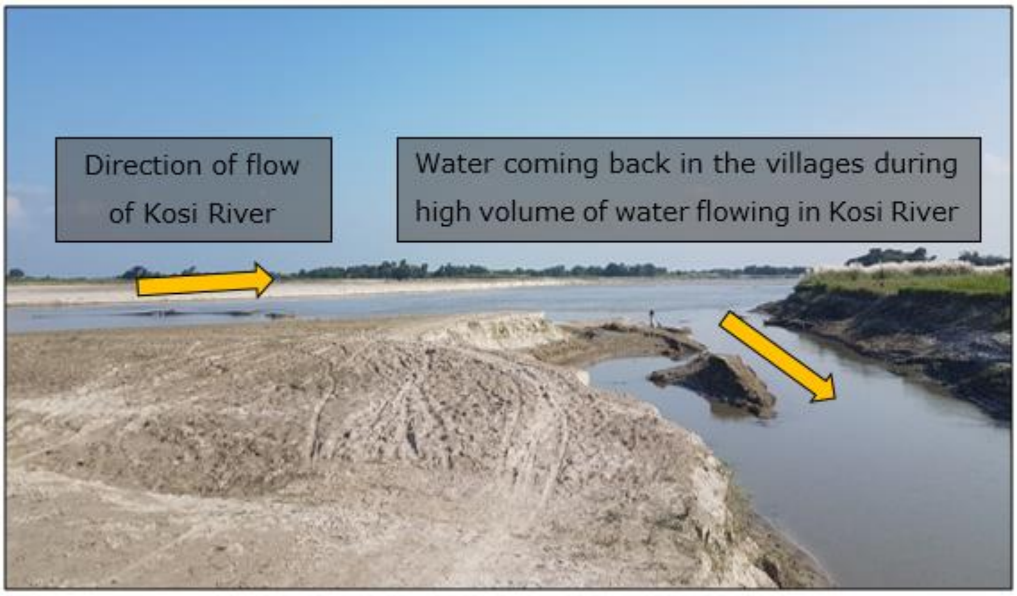


Figure 5-17 The opening at the end of the west embankment
(Picture was taken during the field visit in October 2018)

Furthermore, the communities living in the waterlogged area, facing all these agricultural, transportation, livestock, sanitation and water pollution issues, reside there. The participants mentioned that very few want to leave their ancestral land i.e. there are only a few people who want to move. Further, even if these people decide to move, they would not be able to do agriculture in the rehabilitation land because the rehabilitation land given to them is smaller than where they live now (Box 5-14). In the context of this study, rehabilitation land refers to the land given by the government to flood-affected people.

Box 5-14: M1WL- "Every person has a cultural base. We like living here. Going to Delhi, Punjab does not feel good. This land is our birthplace, the land of our ancestors. Why will we go leaving it behind… if the government gives us rehabilitation land, how much will it be? The land will be about 2-5 decimal (~0.02-0.05 acres), not more than this. However, with this much area, how will we earn our livelihoods? Here (waterlogged area), everyone has agricultural land. I have 10 acres of land. If we calculate by 30%, then 3 acres is viable for agriculture... if there are no floods, then we will also progress upward. On 30% land, 10 maund (~370 kg) of crop is grown. If the additional 70% of the agricultural land is also utilised, then the total crop yield will be 33 maund (~1232 kg)."

This section provided a summary of the lives of the waterlogged communities during the non-monsoon period. The details of their lives during the monsoon period are covered later in Section 5.5.4.

5.5.2. Lives of within the embankments communities during non-monsoon

During the non-monsoon season, the communities living within the embankments have good agricultural opportunities; even during the floods, they utilise the floodwater for growing rice (Box 5-15).

Box 5-15: M1WE: "(Before river floods), we do not face any problem as such… During floods, rice plants are sown in paddy fields using tractors. From July, we start sowing rice plants… if there is a lot of water during the (river) flood, the rice fields will be flooded away; otherwise, it will be safe. Without water, rice cannot be grown. After floods, we grow corn, wheat, cucumber, peas and red lentils."

When the embankments were constructed, the government gave rehabilitation land to the communities within the embankments. Most of the rehabilitation land was adjacent to the Kosi west embankment. Some people took the opportunity and relocated from the area within the Kosi embankments to live in the areas adjacent to the Kosi embankments. However, that area became waterlogged with time, and when given the option to rehabilitate there at present times, the within embankment people do not want to rehabilitate in the waterlogged area (Box 5-16).

Box 5-16: M1WE- "Where the rehabilitation land was given (by the government), it was just near the Kosi embankment. The land was not suitable for agriculture. It was low land covered in water. The government gave the land which they had."

The participants mentioned that while they live in the area between the embankments facing the direct impact of Kosi, they still feel that they are in a better situation and have better agricultural opportunities than those living outside the embankments in the waterlogged area. The people who moved from within the Kosi embankments shortly after these were built made fun of the people still living in the area within the Kosi embankments (Box 5-17). These communities residing within the Kosi embankments were facing the direct impact of the Kosi River during the monsoon. During the monsoon, these communities living within the embankments would go to the Kosi west embankment to be safeguarded from floods. However, the situation started changing with time, as mentioned by the communities living within the embankments.

Box 5-17: M3WE - "People living there (in the waterlogged area) used to laugh at us when they would come to the embankment (during river flooding). They laughed and said that everything (of the people living within the Kosi embankments) has flooded. They were happy to see that people (from within the embankments) were coming to stay here (on the Kosi west embankment). After the construction of the Balan embankments, the drainage of the waterlogged area has slowed down. It will drain out but rather slowly."

Slowly the area adjacent to the Kosi west embankment started getting waterlogged. Waterlogging began because the Kosi riverbed started rising due to silt deposition (Box 5-18). This rising bed started causing seepage from the area within the embankments to the low-lying adjacent areas.

Box 5-18: M3WL– "The Kosi embankments were deep. However, nearly 14 feet of siltation has happened since the Kosi embankments were constructed. Every time at least some siltation occurs. When the flood hits, the floodwater leaves silt here on its way."

Therefore, during non-monsoon, the communities residing within the Kosi embankments have no waterlogging in the area, yielding better agricultural opportunities than the waterlogged communities.

5.5.3. Lives of west embankment communities during non-monsoon

The Kosi west embankment communities (Figure 5-18) are formed by the permanent movement of the people residing either in the waterlogged or within the embankments area.

Figure 5-18 Communities residing on the Kosi west embankment (Picture was taken during the field visit in October 2018)

This permanent relocation occurs during the non-monsoon period due to severe impacts to river and groundwater flooding. One participant living on the west embankment pointed that they moved permanently to live on the west embankment from the waterlogged area (Box 5-19).

Box 5-19: M2WL - "It has been three years since we came to live here (Kosi west embankment). We came here (Kosi west embankment) during the floods. We faced a lot of problems there (waterlogged area) due to waterlogging. We didn't have any road to go to our house, and if ever we wanted to go, we needed boats. Even with boats, , it used to take nearly the whole working day to commute because of the water hyacinth, so we stopped going there."

Another participant moved on the Kosi west embankment from within the embankments (Box 5-20). During the monsoon, the lands get scoured people lose their agricultural lands, making them economically unstable. Even their houses get washed away by the high currents of the river, rendering them landless.

Box 5-20: M2WE- "When the river (flood) came, everything started to sink. Because of that, we somehow took our home (a small hut from the area within the embankments) and started living here (on the embankment). We came here 30 years ago."

These communities have a low sense of security living on the government land, i.e. Kosi west embankment. Being landless, they have no authority on the land. Zamindars threaten the landless people to move away somewhere else, sometimes forcefully putting mud over these peoples' houses (Figure 5-19), claiming that the land belongs to them (Box 5-21). Even after complaining to the government officials, the issue is not resolved. Therefore, these communities can be moved whenever the Zamindar wants or during embankment repair works.

Box 5-21: M4E- "There is also pressure here (living on the west embankment). Zamindar tells us to move our house to somewhere else. We do not know anything. If we complain to government officials, they say that you live in a good location. We do not have any support from anyone…Zamindar says that it is his land. He tells us to move from his place or else he will burn the hut."

Figure 5-19 Zamindars forcefully put mud on the west embankment houses

The permanent relocation of people from within embankments and waterlogged areas established that the west embankment communities have become a permanent part of the Kosi Basin. The permanent movement of people is due to them facing the worst flood effects living either in the waterlogged or within embankments areas. Therefore, waterlogged communities and within embankment communities are not the only communities residing in the Kosi Basin. However, the west embankment communities' situation is different from the waterlogged and within embankments communities because these people are landless with a low sense of security.

5.5.4. Lives of waterlogged, within embankments and west embankment communities during monsoon

As gathered from the interviews, the human-flood interaction changes with the monsoon and non-monsoon periods. During monsoon, when the river flood strikes, people from the waterlogged and within embankment communities temporary settle on the west embankment and live with the west embankment communities (Box 5-22).

Box 5-22: W2WL - "When the floodwater enters our house, we move to the embankment."

However, the movement of these communities depends on the flood intensity and not all people temporarily settle on the west embankment. If the flood intensity is low, some dominant community members who have houses on the higher ground stay in their houses (Box 5-23).

Box 5-23: M1WE- "During floods, we go there (west embankment) with prepared foods… but not everyone comes. Poor people come, but those who have houses in a higher place do not… nearly 10% of the total population (have houses on higher ground)."

During the rescue, sometimes casualties occur. While moving towards the embankment, swimming or in a boat, people drown because of the heavy current of Kosi River water (Box 5-24).

Box 5-24: M1WL- "There is a danger to life and assets (when river flood strikes). Many livestock drown, many kids drown and die. People who do not know how to swim and if they are on the boat (going to the west embankment), suddenly the boat drowns, the flood water is 20 feet deep. Last year, two girls drowned. Sometimes, even the people who know how to swim (they also) drown."

However, the communities are able to safeguard themselves from floods by temporarily settling to the Kosi west embankment; their assets are being flooded in the waterlogged or within embankments areas where they live. Communities residing within the embankment are significantly affected during the monsoon season facing the high currents of the Kosi River (Box 5-25). An example of the Kosi River scouring is provided in Figure 5-20.

Box 5-25: M2WE- "The (River) flood begins due to heavy rainfall in Nepal. For example, if it rained for ten days, then the water stored in the Kosi Barrage gets full. Therefore, the Bihar and Central government open the barrage gates full-time (for the flood duration)."

Figure 5-20 Kosi River scouring
(Picture was taken during the field visit in October 2018)

Figure 5-21 shows how some communities live under the bridge in the Bhagwa village, which can have catastrophic effects during the monsoon season (Box 5-26). Because of living within the embankment, these communities are impacted by the Kosi River flood directly.

Box 5-26: M1WE- "There (within the embankments), water reaches high depths. It enters in houses… (Flooding lasts for) three months from July to September. After floods, the flood water recedes."

Figure 5-21 People living within the Kosi embankments in Bhagwa village (Picture was taken during the field visit in October 2018)

5.6. Temporal boundary

Temporal boundaries were set when the different spatial communities formed and, according to the change in the lives of the communities in the waterlogged area, area within the embankments, and Kosi west embankment during the non-monsoon and monsoon periods. Therefore, the temporal boundaries are:

- In this research, the system structure has been studied since after the Kosi embankments were built in the late 1950s,
- Annual variation in the behaviour of the systems to be considered, non-monsoon and monsoon.

It is critical to consider the variation in the lives of these communities during the entire annual cycle to understand the impacts of groundwater flooding and surface water flooding on these communities. A conceptual cross-sectional view of the area is presented in Figure 5-22 to understand the Kosi Basin socio-environmental system. It shows the placement of the three spatial communities, i.e., communities living within the Kosi embankments area, in the waterlogged area and on the Kosi west embankment. This cross-sectional view also demonstrates the connections between the communities and the area's physical characteristics gathered from the thematic analysis of the interview transcripts. The physical characteristics are mentioned as follows:

1. Seepage: Seepage path of the river water from the higher riverbed to the low flood plains through the Kosi embankment,
2. Groundwater flooding: The seepage water causing waterlogging in the area adjacent to the Kosi embankments,
3. Surface water flooding: River water scouring the land within the embankment during the high flood season.

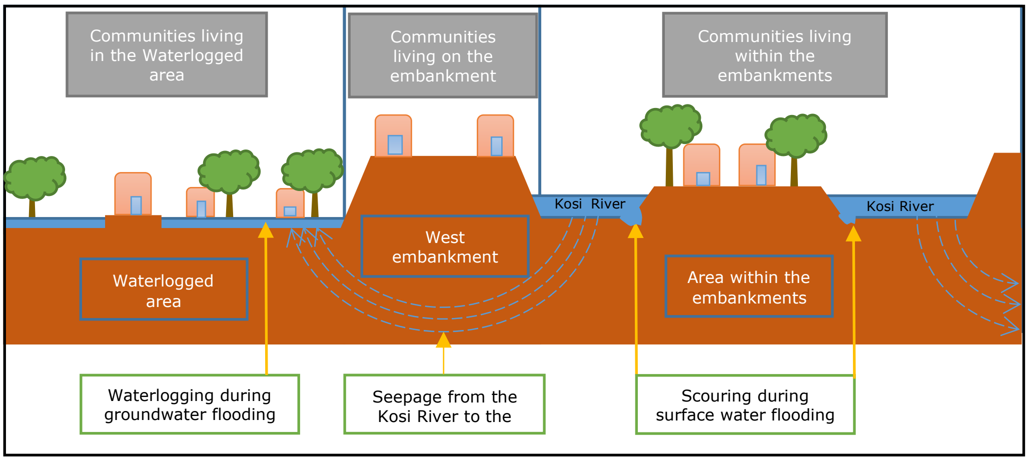


Figure 5-22 Conceptual cross-sectional view of the areas affected by flooding in Kosi Basin

5.7. System structure

Understanding the impact of floods on these communities' lives facilitated gathering basic information about the Kosi Basin system's structure. The system structure formalises the system boundaries and recognises that the socio-environmental system is intertwined, and optimising components of a system in isolation is inadequate to deal with the real-world dynamic complexity (Walker and Salt, 2006). This case study is a perfect example of the complexities and subjectivities of the real-world dynamic complexity as represented in the human-flood interactions elicited from the communities residing in the Kosi Basin. The thematic analysis of the interview transcripts and the participants' quotations used in summarising the findings state that the three areas, i.e., waterlogged area, area within embankments and west embankment area, are crucial parts of the Kosi Basin system and are instrumental in getting the whole Kosi Basin system and analysing the dynamic complexity of the system.

The communities selected for studying the behaviour of Kosi Basin are the waterlogged communities, within embankment communities and west embankment communities, i.e. spatial communities. The fourth selected community is a transient community that is formed on the west embankment during river flooding. The inclusion of these four communities was fundamental to capture the human-flood interactions occurring during monsoon and non-monsoon seasons. The impact of floods on the lives of the three spatial communities is year-round and cannot be secluded only for the flooding period.

It was evident that the communities residing in the Kosi Basin have different interactions with floods during non-monsoon based on their spatial location. However, during monsoon, the waterlogged communities and within embankment communities, temporary settle on the west embankment, and the interactions are common for all three spatial communities, although the overall impact is different. The overall impact on communities depends on the area where they reside because even though they temporarily settle on the west embankment, their assets are still in danger of river flooding.

5.8. Sub-system boundaries

Identifying and understanding the problem situation with the help of semi-structured interviews helped gain a better picture of the human-flood interaction system: the areas, the communities and the temporal element. The defined spatial and temporal characteristics assisted in defining the sub-system boundaries existing in the Kosi Basin. It is worth emphasising that taking a systems perspective in this case study recognises both social and physical dimensions and that there are spatially distinct but connected sub-systems. All these dimensions vary over time. Moreover, defining what constitutes a 'system' is partly a pragmatic decision based on the research aim, i.e., to understand flood risk by analysing complex human-flood interactions and feedbacks through a socio-environmental systems lens using local knowledge. Therefore, the researcher defined the Kosi Basin socio-environmental system into three different human-flood sub-systems are:

1. Waterlogged sub-system: It defines the human-flood interactions taking place in the waterlogged area. It has two essential components:
    a) Non-monsoon waterlogged sub-system: human-flood interactions in the waterlogged area during non-monsoon, and
    b) Monsoon waterlogged sub-system: human-flood interactions in the waterlogged area during monsoon.
2. Within Embankment sub-system: It defines the human-flood interactions taking place in the area within the embankments. It also has two components:
    a) Non-monsoon within embankments sub-system: human-flood interactions in the area within the embankments during non-monsoon, and
    b) Monsoon within embankments sub-system: human-flood interactions in the area within the embankments during monsoon.

3. Embankment sub-system: It is representative of the embankment human-flood interactions taking place on the Kosi west embankment. It has two components:
    a) Non-monsoon embankment sub-system: it covers the human-flood interactions during non-monsoon.
    b) Monsoon embankment sub-system: This sub-system is formed during river flooding when the waterlogged and within embankment communities temporarily settled on the west embankment with the embankment communities.

The human-flood interaction sub-systems mentioned above form the 'system of systems' Kosi Basin system, constituting the relationships between the social and physical systems. The classes of variables that inform hydrological dimensions of the socio-environmental system are presented below:

1. Groundwater class of variables: The variables related to waterlogging during the non-monsoon season.
2. Surface water class of variables: The variables related to river flooding during the monsoon season.

Class of variables in both groundwater and surface water are part of the Kosi Basin's hydraulic system that influences the communities residing in the Kosi Basin. It is worth mentioning that the thematic analysis of the semi-structured interview transcripts showed the importance of considering both physical and social systems to get the whole picture of the system and its behaviour, covered in Chapter 6.

5.8.1. Non-monsoon period

During non-monsoon, the communities living on the embankment and within the embankments have no interaction with the groundwater flooding. However, the behaviour of embankment and within embankment sub-systems change. This behaviour change is because of the interaction of these systems with surface water flooding during the monsoon (Table 5-6).

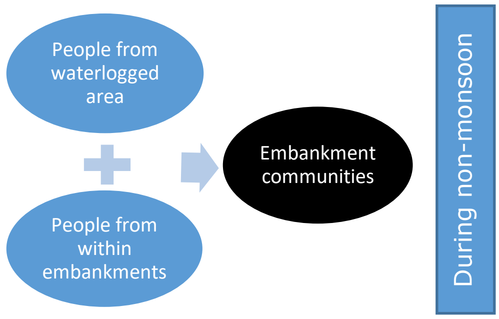
Table 5-6 Interaction of area with Hydraulic system during non-monsoon

Area	Part of the hydraulic system interacting with the area during non-monsoon	Resultant sub-system
Waterlogged area	Groundwater flooding	Non-monsoon waterlogged sub-system
Embankment area	None	Non-monsoon embankment sub-system
Within embankments area	None	Non-monsoon within embankments sub-system

In addition, the problems for the embankment communities arise due to living on government land. The west embankment communities can be moved anytime from the embankment because they have no land rights. This system belongs to permanently relocated people who have lost their homes/land in the waterlogged or within the embankments area. However, the communities in the waterlogged area interact with groundwater flooding during non-monsoon, and the waterlogged sub-system represents these interactions and the impacts of surface-water flooding.

During non-monsoon, the system behaviour is not merely a result of the interaction of groundwater flooding but is also influenced by surface water flooding. Both waterlogged and within embankments areas witness a permanent movement of some people belonging to these communities to the west embankment. The people move to the Kosi west embankment after facing the adverse effects of flooding (Table 5-7).

Table 5-7 Formation of communities permanently living on the Kosi west embankment

Communities	**Interaction with the hydraulic system**	**Formation of communities permanently living on the Kosi west embankment**
Waterlogged communities	Surface water and groundwater flooding	
Within embankment communities	Surface water flooding	

The people have permanently moved away from the within embankments area because their houses flooded during surface water flooding rendering them homeless/landless. Similar adverse effects are faced by some people belonging to waterlogged communities. These communities face the impacts of groundwater flooding during non-monsoon and surface water flooding during monsoon. The people move from the waterlogged area to permanently live on the Kosi west embankment due to their house/village getting waterlogged for almost the entire year. This situation leaves them surrounded by water hyacinth with no agricultural opportunities during non-monsoon, and monsoon only worsens the situation. So, these people facing the impact of groundwater and/or surface water flooding permanently move from the waterlogged area to live on the Kosi west embankment. A conceptual diagram of non-monsoon is presented in Figure 5-23.

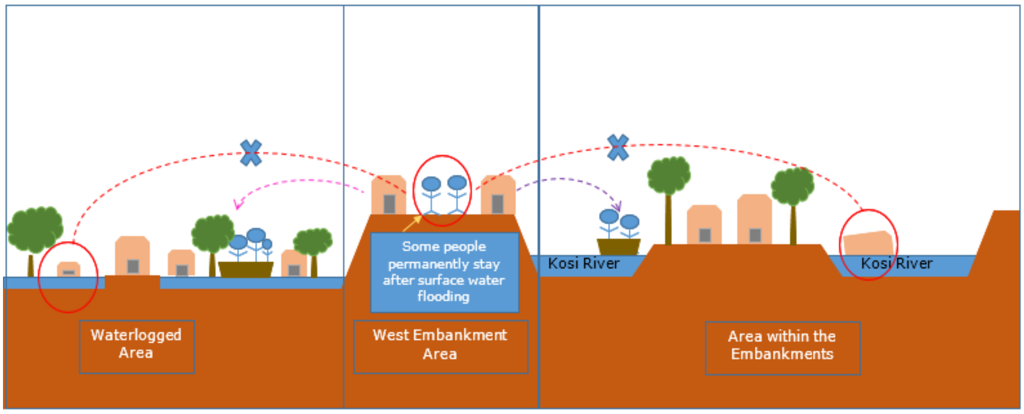


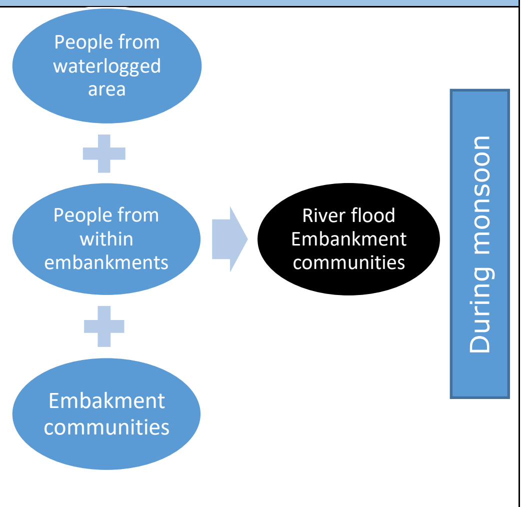
Figure 5-23 Conceptual cross-sectional view of the areas during the non-monsoon period

5.8.2. Monsoon period

With the onset of monsoon, both the waterlogged and within embankments areas are flooded with Kosi River water. During this time, the Kosi west embankment becomes the safest option for these communities. The height of the Kosi embankment ensures that the flood water will not reach the top of the embankment. Understanding this aspect of the Kosi embankment, the people from waterlogged and within embankments communities' start moving to temporarily settle on the Kosi west embankment to be safe from floods.

The total number of people moving from the waterlogged area and area within the embankments to the west Kosi embankment depends on the severity of floods. This temporary settlement creates a new transient community for river floods, defined as river flood embankment communities (Table 5-8). The river flood embankment communities stay on the west embankment for the entire duration of river floods. This sub-system of human-flood interaction for the period of surface water flooding is named as monsoon embankment sub-system.

Table 5-8 Formation of communities temporary living on the Kosi west embankment

Communities	Interaction with components of Hydraulic system	Formation of communities temporary living on the Kosi west Embankment
Waterlogged communities	Surface water flooding	
Within embankment communities	Surface water flooding	
Embankment communities	Surface water flooding	

However, the people from the waterlogged and within embankments areas move to the Kosi west embankment during surface water flooding; the communities sustain losses due to flooding in their residing area (Table 5-9).

Table 5-9 Interaction of areas with sub-systems of hydraulic system during monsoon

Area	Part of the hydraulic system interacting with the area during non-monsoon	Resultant sub-system
Waterlogged area	Surface water flooding	Monsoon waterlogged sub-system
Embankment area	Surface water flooding	Monsoon embankment sub-system
Within embankments area	Surface water flooding	Monsoon within embankments sub-system

The conceptual cross-sectional view of the areas during monsoon is presented in Figure 5-24. The backwater flow from the opening at the end of the Kosi west embankment majorly contributes to the impact of floodwater in the waterlogged area.

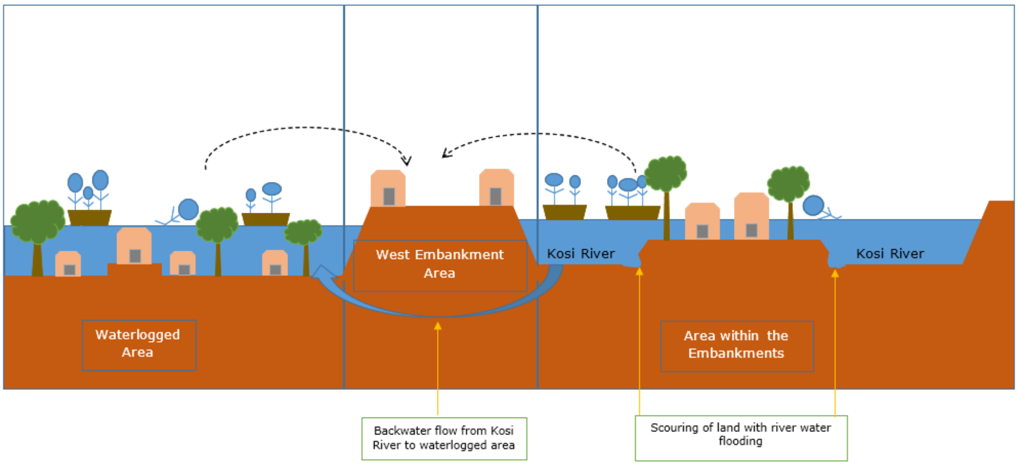


Figure 5-24 Conceptual cross-sectional view of the areas during the monsoon period

The waterlogged communities have their assets in the waterlogged area which are being flooded. Moreover, the area within the embankments faces the Kosi River's direct impact during surface water flooding, destroying the crops and damaging the houses. Sometimes, their homes get washed away by the floodwater.

The annual cycle of floods is instrumental in formalising a complete understanding of the impacts of flooding on the Kosi Basin communities. Table 5-10 presents essential aspects of the Kosi Basin system, which are described below:

1. For the waterlogged area, it becomes vital to understand the impacts of floods on the waterlogged area during monsoon and non-monsoon and the temporary settlement of waterlogged communities on the embankment.
2. For the communities living within the embankments, the critical sub-systems included in the study are the within embankment sub-system (monsoon and non-monsoon) and the temporary settlement of the communities living within the embankments on the west embankment.
3. For embankment communities, both monsoon and non-monsoon behaviour are included. The embankment communities face land ownership problems during non-monsoon and sharing space on the west embankment with the communities from the waterlogged and within embankments during monsoon.

Table 5-10 Annual human-flood interactions of communities

Annual cycle / **Communities**	**Non-monsoon (Oct-June)**	**Monsoon (July-Sept)**
Waterlogged communities	Permanent movement of severely flood-affected waterlogged people to the west embankment + Groundwater flooding	Temporary movement of people from waterlogged communities to the embankment + Flooding of assets in the waterlogged area
Within embankment communities	Permanent movement of severely flood-affected people from within the embankments to the west embankment + Agricultural opportunities	Temporary movement of people from the area within the embankments to the west embankment + Flooding of assets in the area within the embankments
Embankment communities	Low sense of security due to displacement from their ancestral land	Living with the within embankments and waterlogged communities on the west embankment

5.9. Chapter summary

To summarise, flood risk management stakeholders were identified and interviewed in this chapter to define the boundaries of dynamically complex structure of Kosi Basin system. The human-flood sub-systems defined were: 1) waterlogged sub-system, 2) within embankments sub-system and 3) embankment sub-system. The system boundaries elicited in this chapter consist of the following characteristics:

- Three spatial areas: 1) Area within the Kosi embankments, 2) Kosi west embankment, and 3) waterlogged area adjacent to the Kosi west embankment.
- Four communities: 1) waterlogged communities, 2) communities residing within Kosi embankments, 3) west embankment communities and 4) transient communities (river flood embankment communities) formed on the west embankment due to surface water flooding during monsoon.
- Annual temporal cycle: 1) monsoon (surface water flooding) and 2) non-monsoon (groundwater flooding) temporal variations are included in the study.

It is worth mentioning that system boundaries and Kosi Basin sub-systems are delineated differently in Chapter 6 depending on the emphasis on temporal dynamics and spatial locations. Moreover, the findings from the semi-structured interview process also provides with an opportunity to emphasise the importance of considering hydrological factors alongside social and economic ones. It is important to consider both physical and social systems to get the whole picture of the system and its behaviour. The behavioural representation and formalisation are covered in the next chapter, i.e., Chapter 6.

Chapter 6. Kosi Basin system behaviour

6.1. Chapter overview

This chapter aims to formalise the behaviour of sub-systems in the Kosi Basin, namely the complex interactions and feedbacks within and between elements of the social and physical systems. This formalisation involved understanding the monsoon and non-monsoon behaviour of the three spatial human-flood interacting sub-systems (i.e., the waterlogged sub-system, within embankments sub-system and embankment sub-system). Formalising system behaviour consists of assessing past and present experiences of stakeholders, building causal loop diagrams, and analysing interactions between system elements to understand broader system dynamics. Interrogating the system behaviour to understand the current system dynamics and predict the future behaviour is covered in Chapter 7.

The two crucial aspects of this chapter are 1) behavioural representation (stage 3), which consists of the behavioural data collection process, and 2) behavioural formalisation (stage 4), which consists of data abstraction and Kosi Basin system behavioural conceptualisation. Behavioural representation (Section 6.2) consists of systematically designing the workshop group structure (Section 6.2.1). The first step in behavioural representation was systematically designing the workshop group structure to acquire an in-depth understanding of the Kosi system behaviour from participants' perceptions. The participating workshop groups formed were 1) communities living in the waterlogged area, 2) communities living on the Kosi west embankment, 3) communities living in the area within the Kosi embankments, and 4) NGOs.

The second step was to gather data through the workshops to understand the behaviour of the Kosi Basin's human-flood interacting sub-systems (waterlogged sub-system, within embankments sub-system and embankment sub-system identified in Chapter 5). The 'Rich picture' technique was used in the workshops (Section 6.2.2), a tool in soft system methodology. Rich pictures represent a visual understanding of a complex situation, typically presented in an abstract drawing, which helps identify relevant themes in the problem situation (Checkland, 1981). After the participants drew their rich pictures, their explanations were video recorded. This audio-visual technique allowed the participants to explain their rich pictures, helping them draw out the relationship between different elements they drew. The strategy to video record the explanations was instrumental in ensuring the richness of the gathered data by minimising viewer bias (Bell et al., 2016).

The next stage is the behavioural formalisation (Section 6.3), which included the abstraction of workshop data and analysing the results to understand the system behaviour. During abstraction of data, the first step was deriving a rich picture of the Kosi Basin system by combining the participants' rich pictures. The researcher produced a rich picture derived from the participants' rich pictures as a visual aid to conceptualise how the researcher defined the sub-systems in the Kosi Basin (Figure 6-4). The second step was transcribing, abstracting and refining the acquired rich picture data to extract rich data about the system behaviour. The findings included defining the sub-system groups (Section 6.4.1), which only include the participating groups directly related to the sub-system. The sub-systems were defined for ease of data abstraction by including only the sub-system groups for analysing their respective sub-system. The data abstraction included identifying themes (Section 6.4.2) and the variables (Section 6.4.3) in these themes in the human-flood interacting sub-systems. The theme refers to the broad category of change in the sub-system, whereas the variable defines the item (either from the physical or social system) changing in the sub-system. Also, the relationships between the items changing in a human-flood interacting sub-system were elicited (Section 6.4.4). These relationships were defined as the interactions and feedback occurring in the sub-system.

The abstracted data, i.e., the elicited variable relationships, were plotted to derive the causal loop diagrams (Section 6.5). The concept of the causal loop diagram was first introduced in the sixties by Forrester (1961), and its primary function is to map out the dynamic behaviour of a system (Haraldsson, 2004). Causal loop diagrams helped understand the Kosi Basin system dynamics by drawing out the connections and feedback occurring in and amongst the different formalised human-flood interacting sub-systems. The interactions and feedbacks occurring amongst the sub-systems also shed light on the cross-interactions between the sub-systems. Analysing these sub-systems would provide an understanding of the overall behaviour of the Kosi Basin socio-environmental system, identifying the key interactions and feedback where sustainable changes can be applied to provide resilience to these flood-prone communities (Chapter 7).

6.2. Stage 3 - Behaviour representation of Kosi Basin system

6.2.1. Workshop and workshop group structure

The first step to understanding the behaviour of the Kosi Basin system from the participants' perceptions was to organise the workshops and design the workshop group structure. The venue selected for conducting workshops was a school on the premises of the field area. The school was chosen for its easy accessibility, facilities, capacity and convenience of the community participants (Moore et al., 2021). The participants for the workshops were identified in parallel with the semi-structured interviews conducted to build the system structure in Chapter 5. The referral-based technique was used to identify the potential unknown community stakeholders living in the waterlogged area, on the west embankment, and within the Kosi embankments of the Mahishi Block. The purpose of identifying the potential unknown community stakeholders was to engage the stakeholders in this phase of the study, i.e., determining the behaviour of the Kosi Basin System. The referral-based technique (Harrison and Qureshi, 2000, Hair et al., 2000) helped maximise the efficiency of identifying potential stakeholders.

Figure 6-1 shows the approximate spatial location of the school where the workshops were conducted and the areas from where the 19 participating groups belonged. Nine participating groups were from the waterlogged area (groups 1-9), four from the west embankment area (groups 10-13), five from the community living within the Kosi embankments (groups 14-18), and one group of NGOs (group 19). However, the last workshop (workshop number 7) carried out with the NGO group (group 19) was conducted at the premises of Kosi Seva Sadan, which is located outside the bounds of the field site. Hence, group 19 was not plotted on the map.

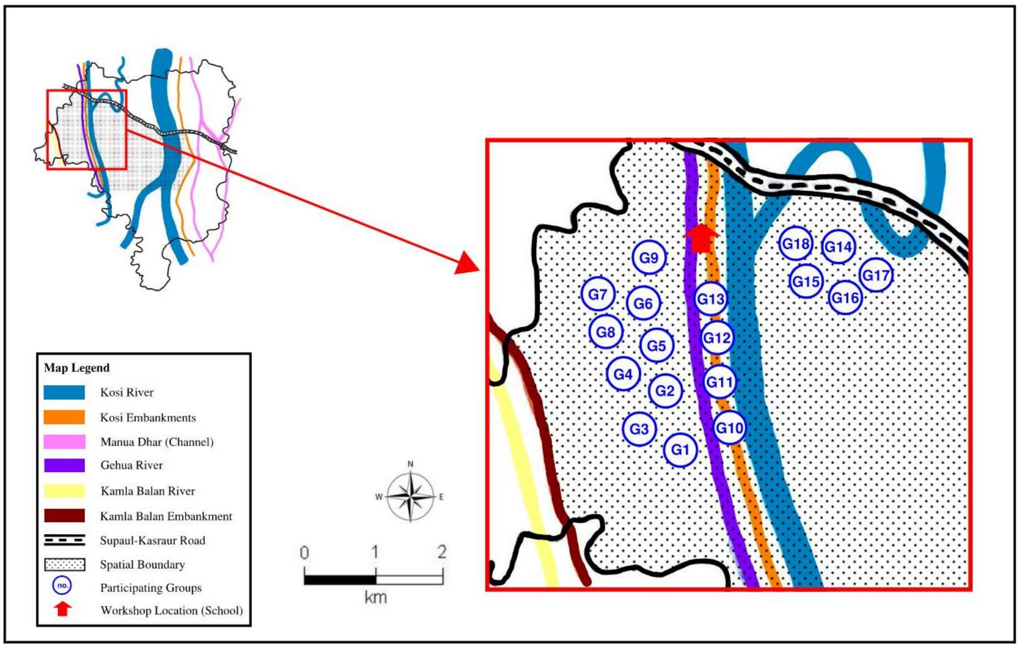


Figure 6-1 Spatial location of participating groups and workshops conducted

A total of seven workshops were conducted in four days and a summary of participating groups is presented in Table 6-1. There were a total of 19 workshop groups constituting a total of 82 participants, 74.4% marginalised community stakeholders and 25.6% dominant stakeholders. A detailed description (age, gender, occupation and village) of the workshop participants is presented in Appendix A (Table A - 1).

Table 6-1 Workshop details

Stakeholders	Gender	Workshop groups	Stakeholder category		Total participants
			Marginalised	Dominant	
Waterlogged community	Men	5	100%	0 %	20
	Women	4	86.7%	13.3%	15
West embankment community	Men	3	100%	0 %	14
	Women	1	100%	0 %	6
Within embankment community	Men	3	33.3%	66.7%	12
	Women	2	36.4%	63.6%	11
NGO	Men	1	-	100%	4
	Women	-	-	-	-
		19	**74.4%**	**25.6%**	**82**

The workshop group structure was informed by the system structure generated in Chapter 5. The system structure was instrumental in understanding that the three spatial communities in the Kosi Basin have different experiences of flooding based on the temporal (monsoon and non-monsoon) and spatial (area of residence - waterlogged, west embankment or within embankments) factors. Furthermore, the flood experiences differed for men and women in a particular community. These characteristics contributed to dividing the invited participants into workshop groups to maximise workshop efficiency. It would also be instrumental in minimising sample biases and marginalisation of different groups of participating stakeholders (Ananda and Herath, 2003, Reed et al., 2009). The criteria for forming workshop groups were as follows:

- **Spatial location:** The data gathered through semi-structured interviews (Chapter 5) concluded that for extracting rich raw data from the communities living in these flood-affected areas of Mahishi Block, the identified participants needed to be divided into workshop groups based on their spatial location. Therefore, the workshop groups were divided based on the spatial location of residence, i.e., waterlogged community workshop group, within embankments community workshop group and embankment community workshop group. This division ensured that every community from these three spatial communities was given equal opportunity to share their experiences freely without being overpowered by any other spatial communities.

- **Gender:** Another factor taken into account for dividing the participants was gender. There were primarily two groups in a community workshop group, i.e., Men and Women. This segregation assured that the data from both genders is gathered without bias, and women could also raise their issues openly. In the rural part of India, the women do not speak up due to the century's long practice of patriarchy in Indian society. Therefore, men and women were put in separate workshop groups for promoting effective social participation by minimising the impacts of deep-rooted gendered social norms (Ziegler, 2012).
- **Power dynamics:** The findings from the structural formalisation primarily emphasised the inclusion of marginalised community stakeholders to understand social and political standing in the Kosi Basin system. The marginalised community stakeholders were defined by caste. Power dynamics (Thaler and Levin-Keitel, 2016, Juntti et al., 2009) based on the caste system prevalent

in Kosi Basin can lead some powerful groups to actively pursue their self-interests during the participation process (Kuhlicke et al., 2016, Taylor and Bhasme, 2021). The stronghold of the caste-based power structure within the at-risk communities of Kosi Basin (IDSN, 2013) can ultimately result in a biased participation process suppressing the voices of the marginalised communities (Mishra et al., 2008). Also, some stakeholders might feel that their inputs are not treated with seriousness, leading them to feel frustrated that their opinions have no effect or impact (Monnikhof and Edelenbos, 2001). This biased participation might result in an inaccurate formalisation of the system. It is vital to critically re-analyse the participatory approaches to avoid power and political considerations as a whole and shift towards the desirability of empowerment (Cleaver, 2001). Therefore, a substantial proportion (74.7%) of participants invited to participate in the workshop belonged to the marginalised community. This step was taken to ensure that the marginalised communities were not marginalised during the workshop.

- **Occupation:** The invited participants included main workers, marginal workers and non-working populations residing in the flood-prone areas. However, it was challenging to segregate different occupational groups, given the diversity of household occupations. Therefore, the occupation was not selected as a criterion for the division of workshop groups.

The critical finding of the Kosi Basin's sub-systems structure was instrumental in designing the community workshop group structure. The workshop structure ensured that the participants from the same human-flood interactions sub-system in the same community workshop group, and also the gendered perspective was taken into account.

6.2.2. Rich picture technique

The second research question (Page 11) was directed towards identifying tools and techniques to elicit local knowledges based on the socio-demographics of a local context. Similarly to tools and techniques evaluated in Chapter 5, this section also presents an appropriate technique used for collecting data, suitable for the socio-demographics of the Kosi Basin. The technique used to collect the data during the workshop was 'rich picture'. In a remote setting such as Kosi Basin, the advantage of using the rich picture technique is that it does not require any expert knowledges, prior training or literacy and can be used by any group of stakeholders (Bell et al., 2016). Moreover, it provides creative problem identification by visualisation (Bronte-Stewart, 1999), enabling the participants to illustrate their flood experiences working in small groups.

At the beginning of the workshops, the project details were presented separately to each group verbally (details in Appendix B). This step was taken to ensure everyone understood the aims of the project and the workshop, as illiteracy played a significant role in the field area. Moreover, a literate participant was placed in every group to ensure the groups' ability to draw. If there were not enough literate participants, the workshop organising team helped the groups write and draw. The team members were briefed not to provide their inputs and only assisted in the drawing if the participants struggled. This step ensured that the integrity of the data was maintained. The team had five members, including the researcher, three members of SSK NGO: one woman and two men and the researcher's brother. Only the women team members assisted the women participants if required during the workshops, which was instrumental in easing the comfort level of women participants, making them speak freely (Singh et al., 2009) about their lives through rich pictures.

The rich picture technique helped the researcher visualise the system in detail through the participants' eyes. However, the problem with visual methods is the interpretation, but involving a number of groups aids in minimising the biases (Bell et al., 2019). It provides the participants with an opportunity to negotiate and work on a shared understanding of an entire system, providing their perspectives and, as a result, generating social learning (Bell et al., 2019, Conte and Davidson, 2020). While drawing their rich picture, each participant in a group communicated well and worked together as a team (Figure 6-2). Moreover, the rich picture technique provided a good and easy way for the participants to explain their situation, ensuring rich data could be elicited.

Figure 6-2 Groups of (a) Men and (b) Women from within Kosi embankments building Rich Pictures

The rich picture technique facilitates expressing the problem situation, it however fails to capture the system dynamics and critical feedbacks. Also, the interpretation of rich pictures is subjective because the viewers can interpret the rich pictures in different ways (Bell et al., 2016). Therefore, after preparing rich pictures, group representatives for each group were taken outside the room one at a time to explain their group's rich picture (Figure 6-3), and the explanations were video recorded. Separate video recording sessions were instrumental in ensuring that one group's rich picture explanation did not influence other groups' pictures/explanations. This process ensured that each group's perspective was captured as authentically and accurately as possible.

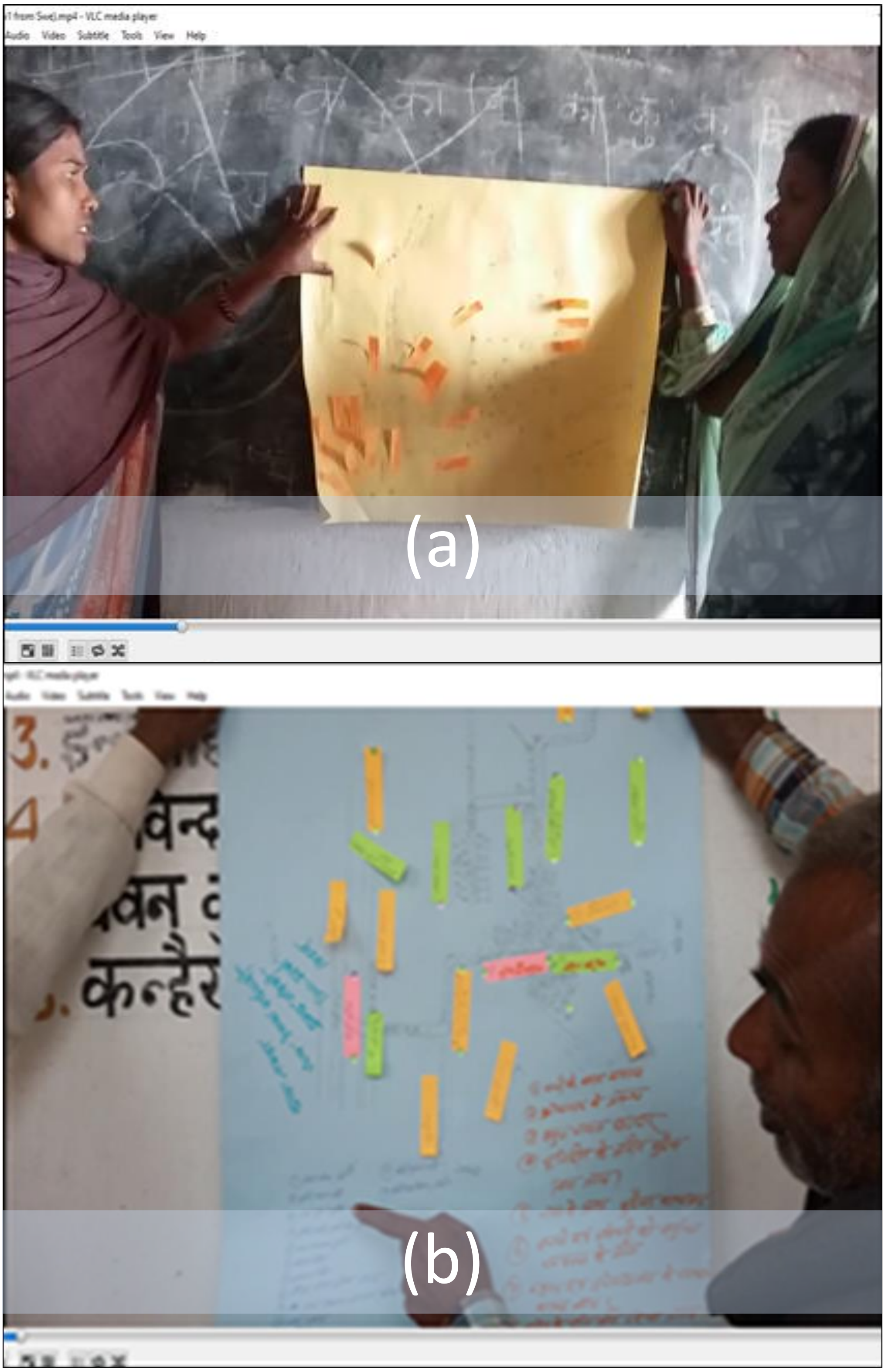


Figure 6-3 Participants explaining their Rich Pictures (a) women (Kosi west embankment), (b) men (waterlogged area)

Video recording the explanations allowed the participants to share their perception regarding the crucial aspects of the Kosi Basin system, including the system dynamics (interactions and feedbacks) in their words (Warren, 2005, Loizos, 2000). This step played a key role in minimising viewer bias (Warren, 2005), ensuring that the integrity of participants' viewpoint was maintained through their rich picture narration.

6.3. Stage 4- Behavioural formalisation of Kosi Basin system

6.3.1. Data abstraction from the rich pictures

The rich pictures drawn by the participants were vital in exploring the sub-systems existing in Kosi Basin in depth. The visual representation of the sub-systems gathered during the workshops aided in understanding the processes and connections within and among the Kosi Basin sub-systems. A rich picture derived from the combination of the rich pictures obtained from the workshops was drawn by the researcher and is presented in Figure 6-4 to provide a conceptual understanding of the Kosi Basin system. This abstracted rich picture was not validated by the participants due to the travel restrictions as a result of Covid-19.

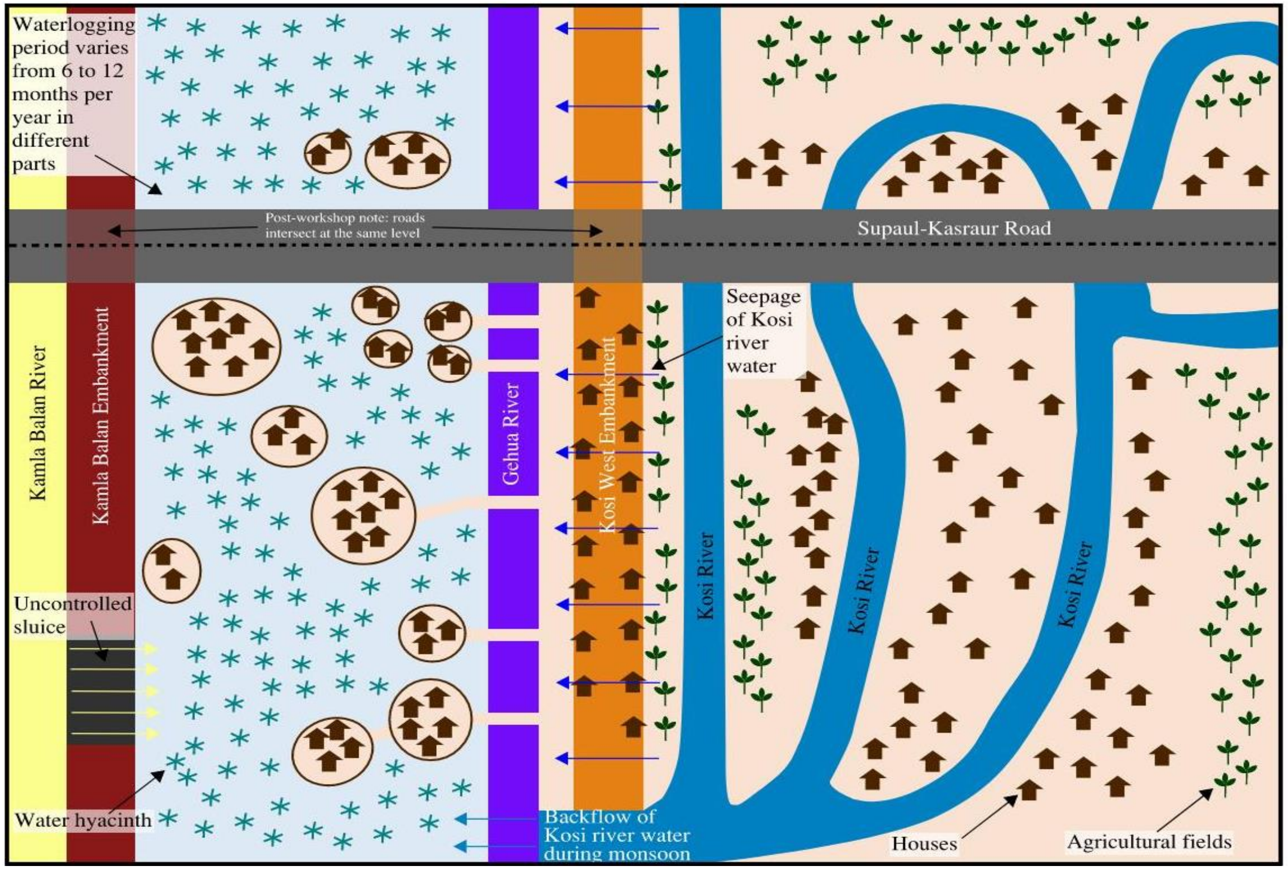


Figure 6-4 Rich picture derived from the workshop rich pictures

For abstracting the variables and relationships between the variables from the rich picture data, the method adopted for current research is based on the works of Fazey et al. (2011). This work involved understanding the trajectories of change in Makira, Solomon Islands. Trajectories of change were defined as dynamic processes resulting from human activity, i.e., individuals, community groups, and societal responses emerged as effects of changes in a socio-environmental system, which creates system feedbacks. Therefore, the feedbacks and the interactions reflect the aggregated characteristics of these dynamic processes (Fazey et al., 2011). Themes and variables were two critical aspects in understanding the trajectories of change as defined by Fazey et al. (2011). In this research, the theme was defined as a broad category that determines the general nature of change in the Kosi Basin socio-environmental system, whereas variable was an entity changing due to the human-flood interactions in the sub-system/system.

Analysing these themes and variables is fundamental in providing a root definition: a core description of the purposeful activity (Flood and Carson, 1988). In the scope of this research, a purposeful activity was defined as the system's (social or physical) activities or interactions between these systems. These purposeful activities would act as a building block to develop the causal loop diagrams for different human-flood interacting sub-systems identified in Kosi Basin.

For deriving the purposeful activities, the root definition and CATWOE analysis was carried forward by the researcher. Details of CATWOE and root definitions are presented on Page 69. The CATWOE analysis is as follows:

- C = Customers → Marginalised community stakeholders
- A = Actors → Flood risk practitioners and policymakers
- T = Transformation process → There is a need for local perspectives to be well established as vital to the future of flood risk research and practice.
- W = Worldview → Floods are a complex system of interconnected physical and social systems and human actions are integral to nature.
- O = Owner → Policymakers
- E = Environmental constraints → Spatial, social and political constraints.

The customers are the marginalised community stakeholders as they are the victims and beneficiaries of the system, and the causal loop diagram represents their viewpoint. However, the participants also included NGOs and dominant community stakeholders. The data from the NGOs was used to understand the overall state of the Kosi Basin area, including the physical characteristics and the data from the dominant community stakeholders was used to understand how the lives of the dominant community stakeholders differ from marginalised community stakeholders.

The root definition was derived from the viewpoint of the marginalised community stakeholders. A root definition is typically illustrated as 'A system to do X, by means of Y, in order to achieve Z'. Therefore, for Kosi Basin, the root definition is:

A system to determine the human flood interactions (X), by means of local perspectives (Y), in order to determine deep leverage heuristics of flood vulnerabilities existing in Kosi Basin.

Therefore, analysing the workshop data to identify the themes and variables and eliciting the relationships amongst the variables was instrumental to deriving the causal loop diagrams for different human-flood interacting sub-systems identified in Kosi Basin. The workshop data included the audio-video data from Rich Pictures' video explanations and written/drawn data that the participants mentioned on the Rich Picture diagrams (Figure 6-3). This raw data gathered from the workshops were converted into written transcripts in Microsoft word using the video recordings and respective rich picture.

A total of 19 transcriptions were generated for the 19 participating groups, and the original language, i.e. Hindi, was kept to ensure no data loss during converting data from audio to written form (van Nes et al., 2010). The rich pictures were instrumental while transcribing video recordings because they provided a ‘map’ of the system (Conte and Davidson, 2020). The map defines the spatial and temporal context of the identified human-flood interacting sub-system in question. Furthermore, the video recordings enabled capturing the interactions and feedback amongst the physical and social systems concerning the identified sub-system context through the perspective and experiences of the participating groups. The rich picture tool's advantage was to allow ‘sense-making’ (Checkland, 2000), which refers to reflecting upon deeply held views via conversations to reveal new insights (Conte and Davidson, 2020). Therefore, sense-making via video recordings would ultimately deliver rich data about the system dynamics in the spatial and temporal context of the sub-system in question.

6.3.1.1. Data analysis process

The data analysis for the transcripts was done using Nvivo 12 Pro software. Transcribed files of the participating groups were imported to Nvivo with the same group number provided in Appendix A (Table A - 1). A three-level hierarchy of nodes was used for naming 1) variables (node 1), 2) theme (node 2) and 3) the sub-system (node 3) (Figure 6-5). The advantage of Nvivo is that it provides flexibility for data coding into nodes (Eker and Zimmermann, 2016), i.e., the nodes can be reorganised by moving, renaming, and copying them. All nodes were colour-coded to efficiently arrange the nodes in the identified sub-systems. The pink colour was used for waterlogged sub-system, purple for within embankments sub-system, peach for monsoon embankment sub-system, green for non-monsoon embankment sub-system and blue for surface water and groundwater class of variables. The coding was refined with iteration to ensure that all nodes were placed correctly, and the transcripts were thoroughly coded (the process of code refining is mentioned in Section 6.3.2). For the coded nodes, the column 'Files' specify the total transcript files in which a node has been identified, and 'References' indicate the number of times that particular node was referred to in those files.

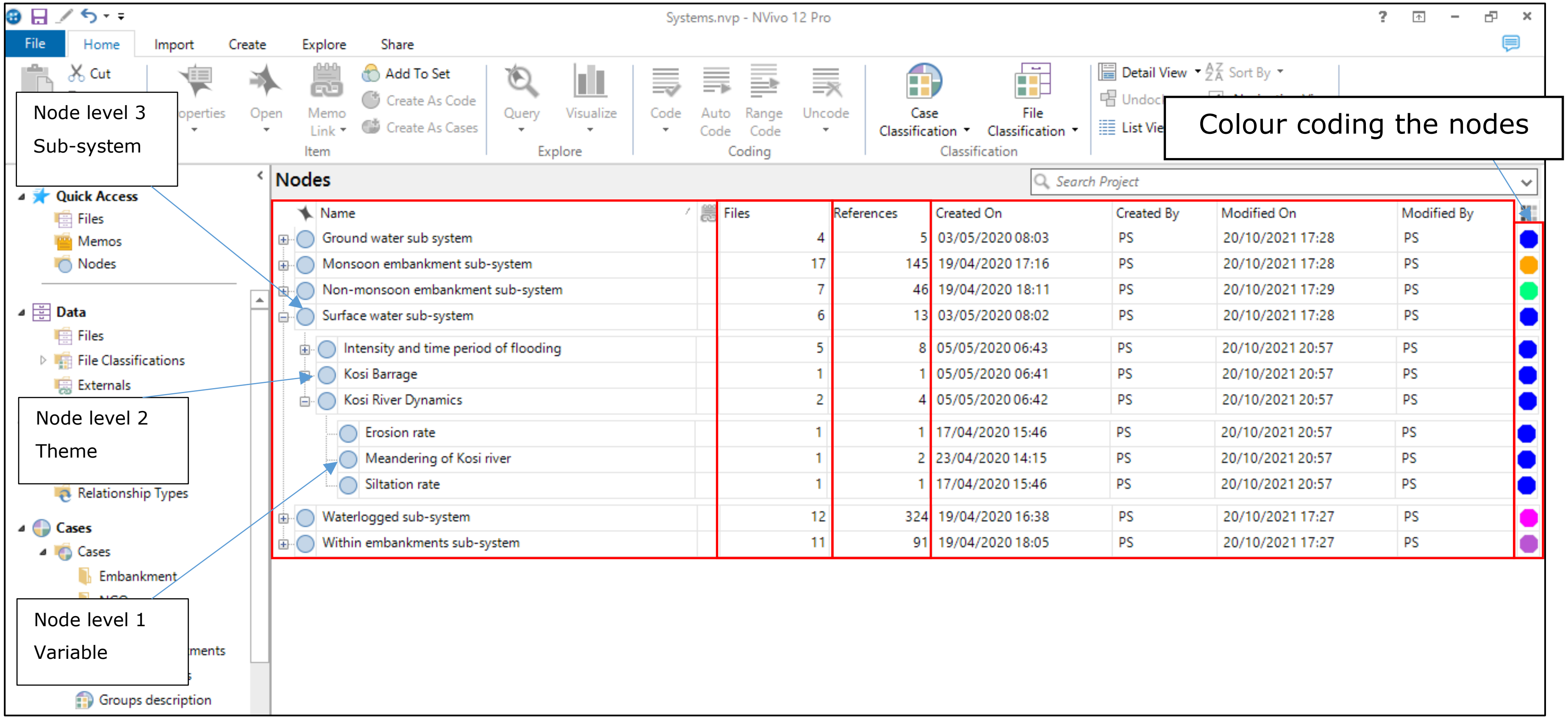


Figure 6-5 Creating node hierarchy and child nodes in Nvivo

After defining and refining and colour coding the nodes, the <variable> relationships defined in the transcripts were coded using the relationship function. Some <variables> were renamed while drawing out the relationships, which assisted in accurately defining the relationships. Coding the relationship would also help examine if these variables cross boundaries and interact with variables from another human-flood interacting sub-system. Moreover, if a relationship was present in N different sub-systems, it was duplicated for those sub-systems. While relating the items, three types of relationships were identified and defined:

- Positive relation: As the value of item X increases/decreases, the value of item Y tends to increase/decrease.
- Negative relation: As the value of item X increases/decreases, the value of item Y tends to decrease/increase.

Relationship colour coding: The identified relationships were also colour-coded according to their respective sub-system. This step ensured that all the relationships for a particular sub-system were easy to identify and arrange while drawing the causal loop diagrams for different sub-systems.

This approach was advantageous in defining the relationships between 1) variables in a sub-system and 2) sub-systems in the Kosi Basin system. However, there was a limitation to this approach concerning the degree of change in a relationship. The researcher was not able to measure the degree of change in the identified relationships, or the theme (linear, exponential, delay, threshold etc). Therefore, it was only possible to provide the change's directionality (positive, negative).

6.3.2. Refining of codes

The refining of codes of variables and their relationships was a fundamental step in analysing and defining the behaviour of the Kosi Basin system. The iterative nature of refining ensured that the information extracted from the transcripts was to the maximum capacity of the researcher. Refining codes was a two-step process, a) internal refining and b) external refining, adopted by the researcher (Figure 6-6):

- **Internal refining:** Identifying nodes in the files was a dynamic process, and it kept on evolving with each file until all the files were analysed. It was established in Chapter 5 that the three spatial communities (waterlogged, within embankments and west embankment communities) were connected to more than one human-flood interacting sub-system. E.g. the waterlogged community was not only connected to the waterlogged sub-system but also the transient monsoon embankment and non-monsoon embankment sub-systems. These connections resulted from the annual cycle of flooding, resulting in permanent and temporary settlement of the west embankment. These connections of a spatial community to different sub-systems made it challenging to place a <variable> in a particular sub-system. It was because a particular <variable> can belong to N different sub-systems. Therefore, internal refining was carried out to establish the location of a <variable> in different sub-systems.

- **External refining:** All the 19 files were assessed again after finalising the first draft of codes. This step was necessary to ensure all the data had been analysed to a maximum extent, and no mention of the participants' human-flood interaction was left without coding.

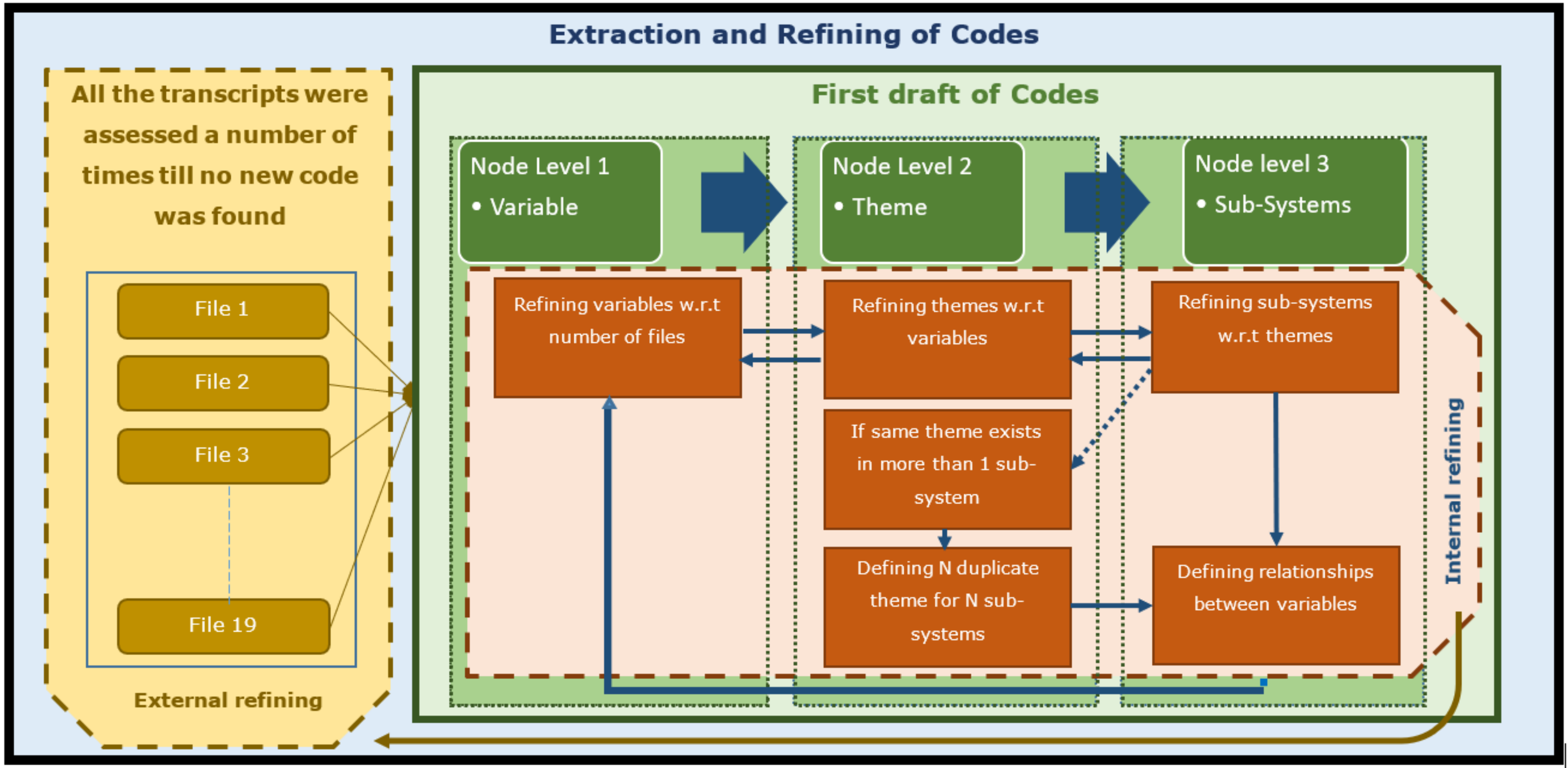


Figure 6-6 Process of extracting and refining nodes adopted by the researcher (where dark blue arrows represent internal refining and brown arrow represents external refining)

6.4. Findings

6.4.1. Defining sub-system groups

The results gathered from the analysis helped calculate all workshop groups' contributions. The contribution of a workshop group (Equation 6-1) is defined as the percentage coding references made by that workshop's participating groups concerning a particular sub-system. The contribution of workshop groups was worth reporting to showcase the knowledges of the workshop groups towards defining different sub-system. These sub-systems included either human-flood interacting sub-systems (waterlogged, within embankments, non-monsoon embankment or transient monsoon embankment) or hydraulic sub-systems (groundwater or surface water). The contribution of a workshop group can be expressed as:

$$\text{Contribution of a workshop group} = \frac{\text{Coding references made by that workshop group about a sub} - \text{system}}{\text{Coding references made by all the workshop groups about that sub} - \text{system}} \times 100 \qquad \text{6-1}$$

The contribution of the workshop group (Figure 6-7) served as a basis to analyse the degree of importance a particular community/NGO gives to a sub-system. The 'matrix coding' function in Nvivo 12 pro was used to draw the participating groups' coding references for the sub-systems. Matrix coding shows the coding intersection between two lists of items. Those values were then exported to Microsoft Excel, and the participating groups were combined into their respective workshops. From Figure 6-7, it can be seen that the community workshop groups focused more on the sub-systems that exist in the area they live or the transient sub-system (monsoon embankment sub-system) that forms during the monsoon.

The waterlogged community workshop group contributed 90.2% towards defining the waterlogged sub-system, 100.0% towards the groundwater class of variables, and 52.6% towards the transient monsoon embankment sub-system. In contrast, within embankments community focused more on the within embankments and surface water sub-systems with a contribution of 67.2% and 69.2%, respectively. However, the embankment community focused predominantly on the non-monsoon embankment sub-system with a contribution of 91.2%. Furthermore, the NGO workshop group contributed more towards the surface water sub-system, i.e., 15.4%, followed by 6.1% and 3.4% contribution to waterlogged and within embankments sub-systems. Furthermore, the within embankments and west embankment communities showed 0% interest in groundwater class of variables as these communities are not impacted by groundwater flooding. However, the total contribution of a workshop group (Equation 6-2) is defined as the percentage contribution of that workshop group towards defining all the sub-systems:

$$\begin{aligned} &\textit{Total contribution of a workshop group} \\ &= \frac{\textit{Coding references made by that workshop group about all the sub} - \textit{systems}}{\textit{Coding references made by all the workshop groups about all the sub} - \textit{systems}} \\ &\times 100 \end{aligned} \qquad \text{6-2}$$

From Figure 6-7, it can be observed that the waterlogged communities contributed 55.8% as compared to 3.8% contribution from the NGO workshop group. Moreover, the communities living within the embankments and on the west embankment contributed 21.1% and 19.2%, respectively. It was observed that the communities primarily focused on the sub-systems they are a part of and rarely mentioned the other sub-systems. This helped understand that the spatial communities have in-depth knowledge about their sub-system but do not mention much about other sub-systems.

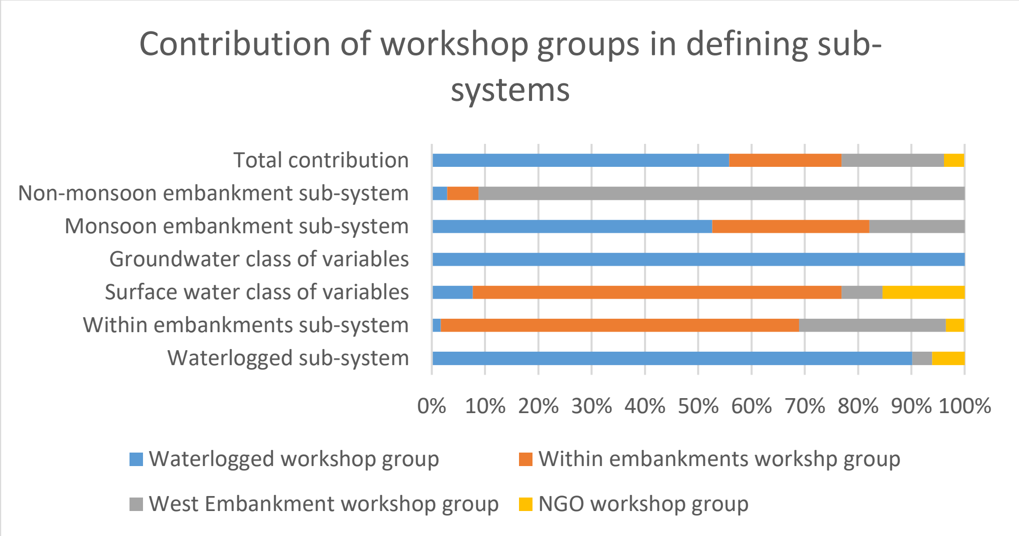


Figure 6-7 Workshop group contribution in defining Kosi Basin sub-systems (data source: Nvivo 12 pro)

Moreover, the findings of workshop group contribution in defining Kosi Basin sub-systems helped to identify the sub-system groups. Sub-system groups (Table 6-2) were defined as the participating community groups connected to a particular sub-system. In this research, the concept of sub-system groups was introduced to easily compare and analyse the perspective of the three spatial communities concerning the Kosi Basin sub-systems they belong to. There were two types of connections:

1) For a human-flood interacting sub-system, the participating group either lives in the area belonging to that sub-system or used to reside in that area.

2) For surface water or groundwater class of variables, the participating group either interacts with either surface water or groundwater class of variables.

E.g. the sub-system group for monsoon embankment sub-system consist of waterlogged, within embankments and embankment communities. All three spatial communities belong to the monsoon embankment sub-system because, during monsoon, the waterlogged and within embankments communities temporary reside on the embankment with the embankment community. Therefore, only the eighteen participating community groups (groups 1-18) and not the NGO group were included as sub-system groups in defining the sub-systems. However, the NGO findings were not ignored and were later included along with the community groups findings to build the causal loop diagrams.

As explained in Table 6-2, sub-system groups for the surface water and monsoon embankment were the maximum, i.e., 18, because all the participating communities are a part of both these sub-systems. For the waterlogged and groundwater class of variables, the sub-systems=10 included the participating community groups living or used to live in the waterlogged area.

Table 6-2 Defining sub-system groups

Sub-system	Workshop community groups	Sub-system groups	Relationship of a participating group with the sub-system	Total Sub-system groups
Human-flood interacting sub-systems				
Waterlogged	Waterlogged community	Groups 1-9	Reside in the waterlogged area	10
	Embankment community	Group 12	Used to reside in the waterlogged area	
Within embankments	Within embankments community	Groups 14-18	Reside in the area within the embankments	8
	Embankment community	Groups 10, 11 and 13	Used to reside in the waterlogged area	
Monsoon embankment	Within embankments community	Groups 14-18	Interact with the hydraulic sub-system	18
	Waterlogged community	Groups 1-9	Interact with the hydraulic sub-system	
	Embankment community	Groups 10-13	Interact with the hydraulic sub-system	
Non-monsoon embankment	Embankment community	Groups 10-13	Reside on the west embankment	4
Surface water and groundwater class of variables				
Surface water	Within embankments community	Groups 14-18	Interact with surface water floods	18

Sub-system	Workshop community groups	Sub-system groups	Relationship of a participating group with the sub-system	Total Sub-system groups
	Waterlogged community	Groups 1-9	Interact with surface water floods	
	Embankment community	Groups 10-13	Interact with surface water floods	
Groundwater	Waterlogged community	Groups 1-9	Interact with groundwater floods	13
	Embankment community	Groups 12	Used to interact with groundwater floods	

6.4.2. Identification of themes in sub-systems

The workshop community groups identified a total of 35 themes. The themes are the broad categories used to summarise the variables in the sub-system. Table 6-3 shows the identified themes in different sub-systems. The themes identified were 77.1% in the waterlogged sub-system of the total themes, whereas 57.1% belonged to the within embankments sub-system. On the other hand, communities identified only three themes for the surface water sub-system class of variables. Analysing the comparison between the groundwater and surface water sub-systems, community groups mentioned three themes, namely: Intensity and time period of flooding, Kosi Barrage and Kosi River dynamics for surface water flooding. For groundwater class of variables, they identified one theme: Kosi River dynamics.

Table 6-3 Themes identified by participating groups in the identified sub-systems

S.no.	Theme	Sub-system				Class of Variables	
		Waterlogged	Within embankments	Non-monsoon embankment	Monsoon embankment	Groundwater	Surface water
1	Agricultural activities	✓	✓	✓			
2	Attitude of communities	✓	✓				
3	Boats	✓	✓		✓		
4	Children	✓			✓		
5	Communities	✓		✓			
6	Commute	✓	✓		✓		
7	Death rate	✓			✓		
8	Early warning system		✓	✓			
9	Education facility	✓	✓	✓	✓		
10	Elderly and disabled		✓		✓		
11	Evacuation	✓	✓				
12	Faith and belief	✓					

S.no.	Theme	Sub-system				Class of Variables	
		Waterlogged	Within embankments	Non-monsoon embankment	Monsoon embankment	Groundwater	Surface water
13	Financial constraints	✓			✓		
14	Flood water				✓		
15	Government authorities	✓		✓			
16	Government facilities	✓	✓		✓		
17	Health and well being	✓			✓		
18	Intensity and time period of flooding						✓
19	Kosi Barrage						✓
20	Kosi River dynamics					✓	✓
21	Land and infrastructure	✓	✓	✓	✓		
22	Livelihood and employment opportunity	✓					

S.no.	Theme	Sub-system				Class of Variables	
		Waterlogged	Within embankments	Non-monsoon embankment	Monsoon embankment	Groundwater	Surface water
23	Livestock	✓	✓	✓	✓		
24	Migration rate	✓	✓				
25	Movement of people	✓	✓				
26	Physical phenomenon	✓	✓	✓			
27	Pollution	✓					
28	Power politics		✓	✓	✓		
29	Psychological impact	✓	✓	✓			
30	Quality of temporary shelter				✓		
31	Relief and compensation	✓	✓		✓		
32	Sanitation and drinking water	✓	✓	✓	✓		
33	Stored food and fodder	✓	✓		✓		
34	Waterlogging	✓					

S.no.	Theme	Sub-system				Class of Variables	
		Waterlogged	Within embankments	Non-monsoon embankment	Monsoon embankment	Groundwater	Surface water
35	Women	✓	✓	✓	✓		
	Total	27	20	12	18	1	3

The participation contribution of the respective sub-system group was analysed in identifying the themes in that sub-system. This step helped in understanding each sub-system group's participation contribution and the gendered perspective of the communities in defining the sub-system. The Crosstab Tools function was used to create coding reference percentages along the row in Nvivo (Figure 6-8). The coding reference displays the number of references coded at each code and intersecting case. In the codes option, <themes> for a sub-system were selected, and in the cases, option respective sub-system groups were selected. The evaluation process included participating contributions of a sub-system group for identifying a particular theme and all themes with respect to all sub-system groups.

Theme contribution of a sub-system group (Equation 6-3): The theme contribution of a sub-system group is defined as the percentage of coding references made by that sub-system group to identify a particular theme occurring in the sub-system where that sub-system group belongs.

$$Theme\ contribution\ of\ a\ sub-system\ group = \frac{Coding\ references\ for\ a\ theme\ by\ that\ sub-system\ group}{Coding\ references\ for\ that\ theme\ by\ all\ sub-system\ groups} \times 100 \qquad (6\text{-}3)$$

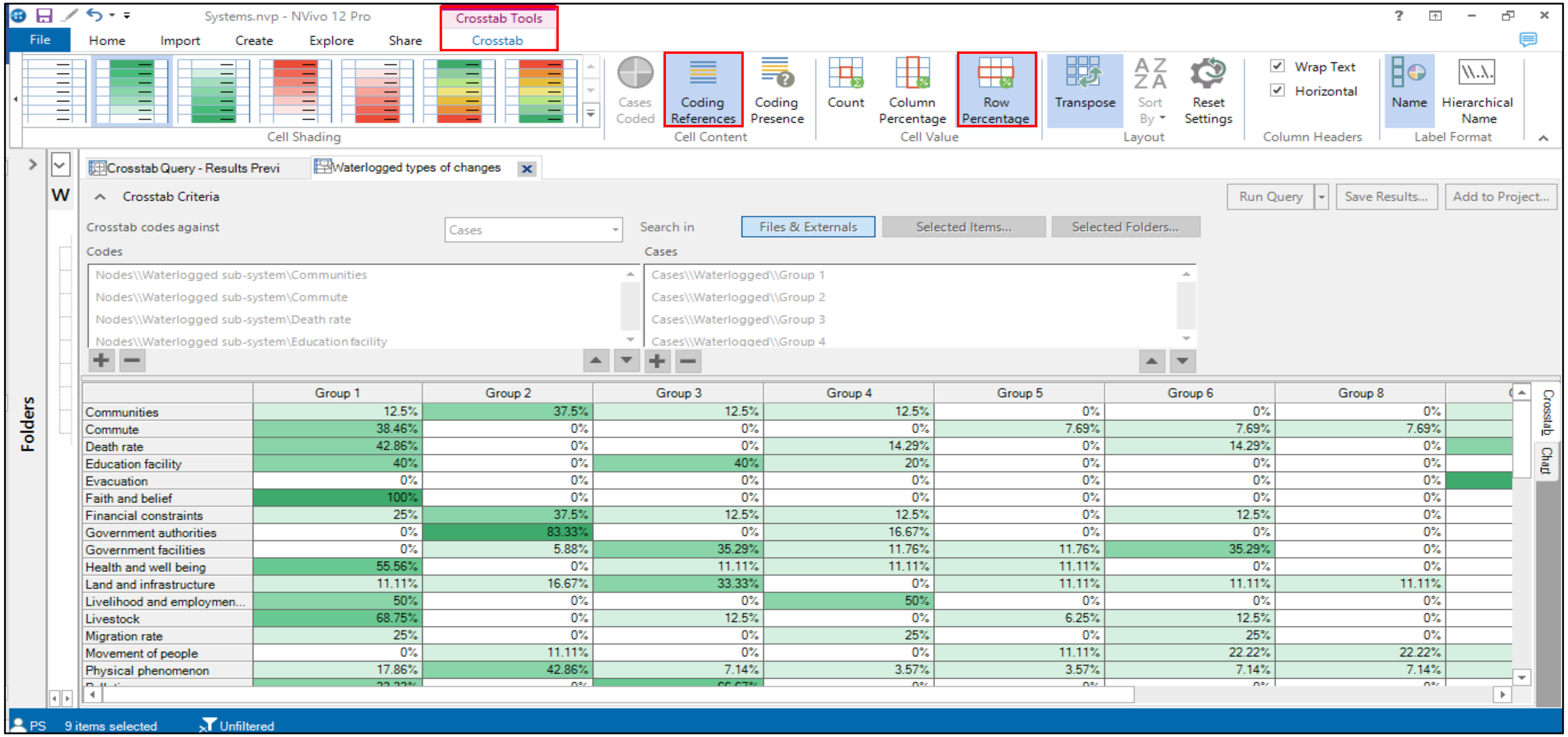


Figure 6-8 Contribution of sub-system groups in identifying a theme in Nvivo 12 Pro

6.4.2.1. Theme contribution of sub-system groups

In the waterlogged sub-system groups, the group of men had a 100% contribution in identifying themes like 'psychological impact', 'pollution', 'livelihood and employment opportunities', 'government authorities', 'faith and belief', and 'education facility'. In contrast, women groups focused on the themes like 'stored food and fodder', 'evacuation', 'boats'. This gendered perspective shows that the men are more concerned about the source of income and physical characteristics of the area, but the women focus on the household and day-to-day activities. Some themes like 'migration rate' and 'commute' get nearly equal attention of men and women (Figure 6-9). There were a total of 262 coding references made by the waterlogged sub-system groups. The 'physical phenomenon' (=30) was the most referenced theme, followed by 'waterlogging' (=26), 'land and infrastructure' (=20), and 'agricultural activities' (=20). In the waterlogged communities, the loss of agricultural activities, destruction of land and infrastructure plays a vital role in their livelihood, which is impacted by waterlogged caused by the physical phenomenon, hence, justifying more coding references in these themes.

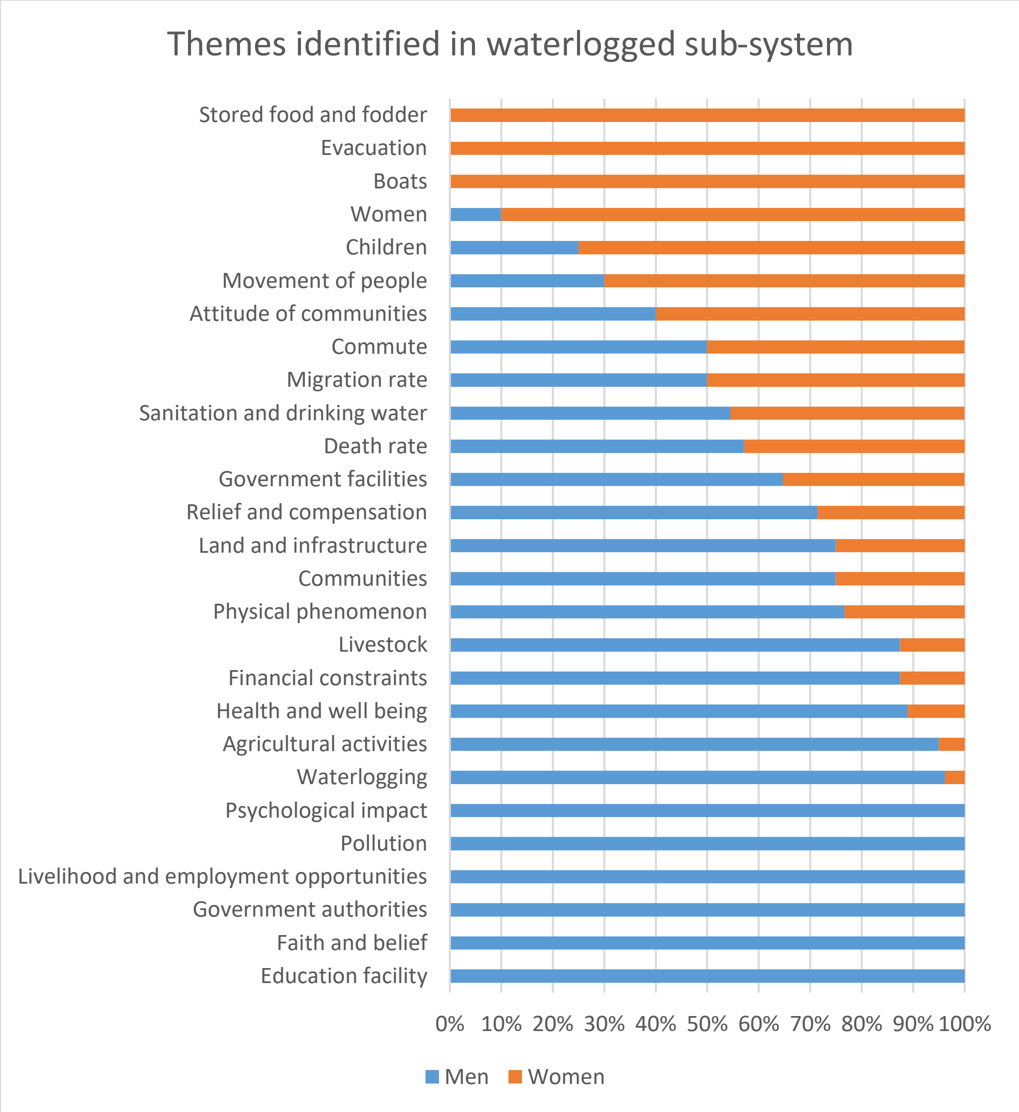


Figure 6-9 Gendered perspective in waterlogged sub-system groups

In the within embankments sub-system groups, men contributed 59.5% compared to women (40.5%) for identifying themes. The total coding references were 84. The themes like ‘migration rate’, ‘education facility’, and ‘early warning system’ were the main focus of women groups, whereas men focused on ‘power politics’, ‘boats’ and ‘attitude of communities’. Themes like the ‘movement of people’, ‘livestock’, ‘elderly and disabled’, and ‘commute’ got equal attention (Figure 6-10). Among all themes, the ‘land and infrastructure’ (=22) was pointed out the most; 59.5% by men and 40.5% by women and was one theme pointed out by all sub-system groups.

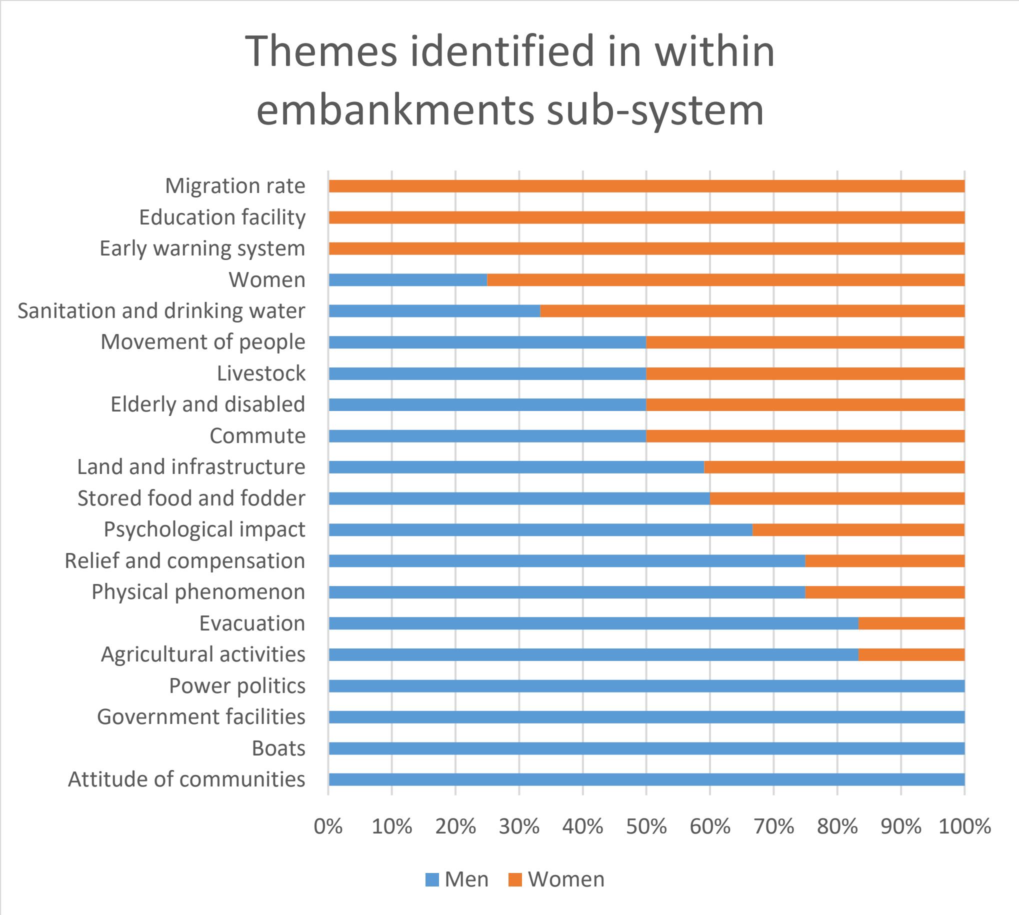


Figure 6-10 Gendered perspective in within embankments sub-system groups

For the non-monsoon embankment sub-system, there were four participating sub-system groups: 3 groups of men (group 10, 11, 12) and 1 group of women (group 13). The men were focused on the themes such as 'women', 'education facility' and 'early warning system', whereas the women were more interested in the 'physical phenomenon', 'livestock' and 'agricultural activities'. 'Land and infrastructure' got equal attention from men and women (Figure 6-11). In total, there were 39 coding references for all themes, 'Government authorities' and 'land and infrastructure' were the two themes that got attention from all their sub-system groups. It shows that these two themes concern the communities permanently living on the Kosi west embankment the most.

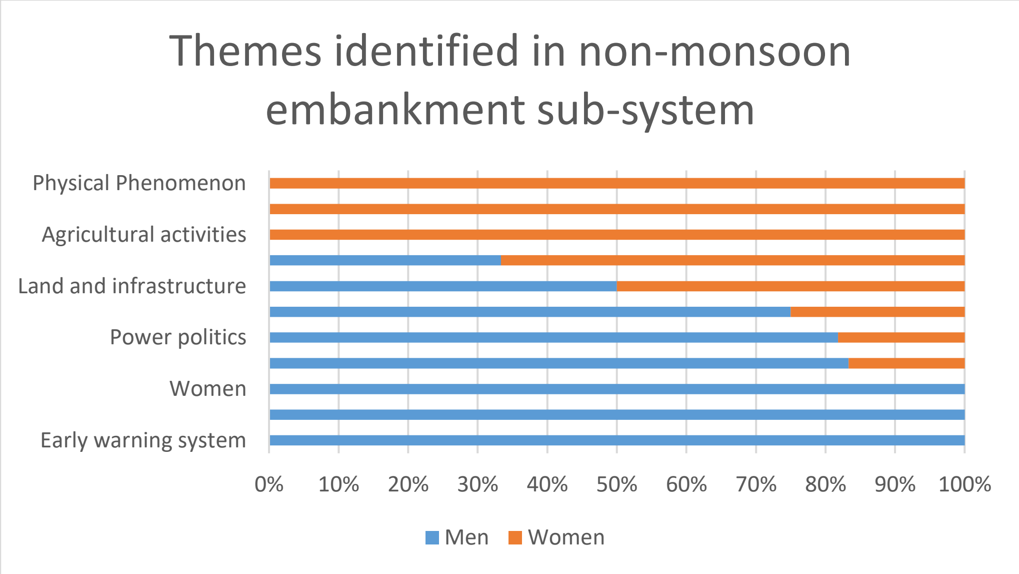


Figure 6-11 Gendered perspective in non-monsoon embankment sub-system groups

For the monsoon sub-system groups, women were focused on these four themes: handicapped and disabled people, floodwater, financial constraints, and children. Land and infrastructure, education facilities, and boats were the themes in which men were interested. Stored food and fodder, sanitation and drinking water, and livestock got a nearly equal response from men and women (Figure 6-12). The most referenced themes were 'government facilities' and 'sanitation and drinking water', both referenced 22 times each out of a total of 105 coding references. Both types of change got contributions from all monsoon embankment sub-system groups.

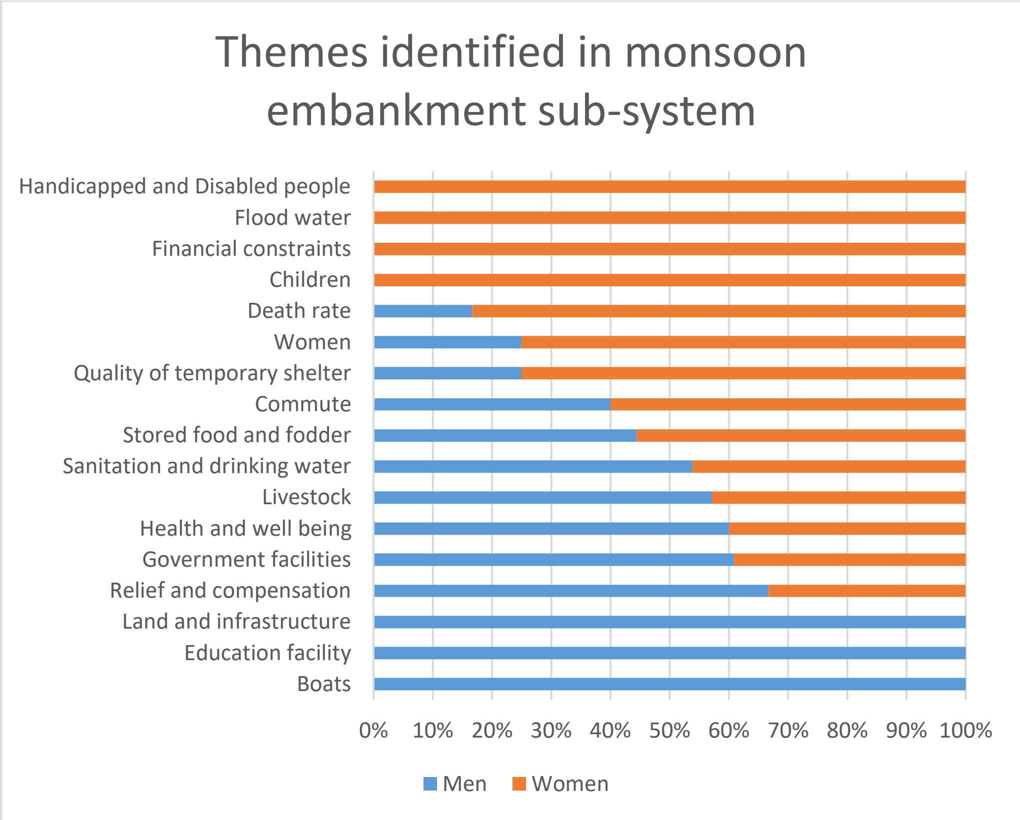


Figure 6-12 Gendered perspective in monsoon embankment sub-system groups

For identifying the themes in the surface water and groundwater, the total contribution of men was 62.5% compared to women. The women group pointed out the ‘Kosi Barrage’, whereas the men focused on the ‘Kosi River dynamics’. The other two themes, i.e., ‘turning of Kosi River water’ and ‘intensity and time period of flooding’, got 3:2 (men:women) responses (Figure 6-13). The total theme contribution for surface water and ground water flooding was 16, in which one type of change, i.e., ‘intensity and time period of flooding’, got the highest coded references=8. The results suggest that the participants were more focused on the impacts of the Kosi River on their lives than the Kosi River's hydraulics.

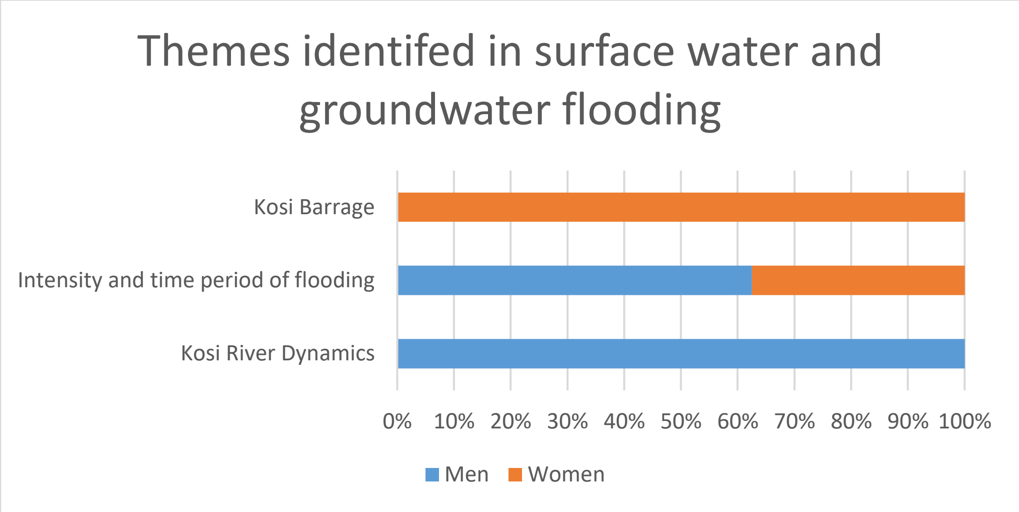


Figure 6-13 Gendered perspective in hydraulic sub-systems groups

6.4.3. Identification of variables in sub-systems

6.4.3.1. Variables in the waterlogged sub-system

The sub-system groups identified a total of 120 variables, and the details of 53 most frequent variables are shown in Table 6-4. The sub-system groups that belonged to the waterlogged sub-system were groups 1-9 from the waterlogged area and group 12 from the embankment area (which used to live in the waterlogged area), in total 10. The variables were ranked based on the number of groups that emphasised that variable. The ranking indicated the importance a sub-system group provided to a variable. Variables such as 'yield or successful harvest of food crops', 'the temporary settlement on the embankment' and 'area getting waterlogged' were the ones which were ranked 1. Therefore, for the waterlogged sub-system, the system-groups were more concerned about the impeding agricultural activities in the area due to waterlogging. Also, the temporary settlement of these communities on the west embankment during surface water flooding has a high impact on their quality of life. Hence, these variables were the top-ranked in the waterlogged sub-system.

Table 6-4 Most frequent variables identified by waterlogged sub-system groups in waterlogged sub-system

S.no.	Theme	Variable	Direction of change	Sub-system groups	Rank
1	Agricultural activities	Yield or successful harvest of food crops	↓	6	1
2	Movement of people	Temporary settlement on the embankment	↑	6	1
3	Waterlogging	Area getting waterlogged	↑	6	1
4	Physical phenomenon	Kosi and Kamla Balan River floodwater in the waterlogged area	↑	5	2
5	Communities	Impact on lifestyle	↑	4	3
6	Commute	People going by foot in flood water for day-to-day commute	↑	4	3
7	Government facilities	Infrastructural development of the area	↓	4	3
8	Government facilities	Government facilities in the area	↓	4	3
9	Health and well being	Number of people affected by the potential spread of water-borne diseases and infections	↑	4	3
10	Migration rate	Migration of young men	↑	4	3
11	Physical phenomenon	The volume of Kosi River backflow water entering in waterlogged area	↑	4	3
12	Sanitation and drinking water	Number of toilets	↓	4	3
13	Waterlogging	Amount of waterlogging	↑	4	3

S.no.	Theme	Variable	Direction of change	Sub-system groups	Rank
14	Agricultural activities	Destruction of standing crops during floods	↑	3	4
15	Commute	Connectivity issues	↑	3	4
16	Education facility	Time period for the school is open	↓	3	4
17	Financial constraints	Financial capacity to sustain life	↓	3	4
18	Financial constraints	Financial losses in agriculture	↑	3	4
19	Land and infrastructure	Number of houses flooded	↑	3	4
20	Livestock	Number of people unable to get fodder for livestock	↑	3	4
21	Movement of people	Permanent settlement on the embankment	↑	3	4
22	Physical phenomenon	Drainage density	↓	3	4
23	Physical phenomenon	Impacts of 3 rivers, Kosi, Kamla Balan and Gehua	↑	3	4
24	Sanitation and drinking water	Open Defecation	↑	3	4
25	Boats	Number of people not owing personal boats	↑	2	5
26	Children	Facilities and resources for childcare and development	↓	2	5
27	Communities	People become homeless	↑	2	5
28	Communities	Worsening condition of Dalit communities	↑	2	5

S.no.	Theme	Variable	Direction of change	Sub-system groups	Rank
29	Commute	Commute by foot for collecting fodder	↑	2	5
30	Commute	Commute time	↑	2	5
31	Commute	Inability to use boats when the water level is low	↑	2	5
32	Death rate	Deaths from infections and diseases	↑	2	5
33	Education facility	Facilities in School	↓	2	5
34	Government authorities	Disparity in implementation of government-issued policies	↑	2	5
35	Government facilities	Government healthcare facilities in the area	↓	2	5
36	Land and infrastructure	Condition of village roads	↓	2	5
37	Land and infrastructure	Connectivity issues	↑	2	5
38	Land and infrastructure	Destruction of infrastructure due to floods	↑	2	5
39	Land and infrastructure	Number of houses surrounded by waterlogging year around (Island)	↑	2	5
40	Land and infrastructure	Number of villages wholly submerged in floodwater	↑	2	5
41	Livelihood and employment opportunities	Rate of losing potential working days in agriculture	↑	2	5
42	Livestock	Number of government veterinary hospitals in the area	↓	2	5

S.no.	Theme	Variable	Direction of change	Sub-system groups	Rank
43	Physical phenomenon	Area covered by invasive species (water hyacinth) and water grass	↑	2	5
44	Physical phenomenon	Chance of flood outbreak	↑	2	5
45	Physical phenomenon	Volume of Kamla Balan River water entering the villages through the sluice gate	Trigger	2	5
46	Pollution	Amount of littering in waterlogged area	↑	2	5
47	Psychological impact	Feeling of helplessness; being poor	↑	2	5
48	Relief and compensation	Number of farmers getting compensation for the destruction of the crop	↓	2	5
49	Relief and compensation	Discrepancy in the distribution of compensation	↑	2	5
50	Sanitation and drinking water	Lack of sources of drinking water	↑	2	5
51	Sanitation and drinking water	Quality of drinking water	↓	2	5
52	Waterlogging	Time period of waterlogging	↑	2	5
53	Women	Chances of getting infections and diseases	↑	2	5

Where,

Direction of change= Direction of change of the item, (↑=increase, ↓=decrease, trigger= item introduced new variables in the system)

Sub-system group= Total number of system groups which identified that variable in the sub-system

Rank= Ranking of variable; where Rank 1 = Most sub-system groups identified the variable

6.4.3.2. Variables in within embankments sub-system

The total sub-system groups for within embankments sub-system were 8. These sub-systems were groups 14-18 (composed of participants residing within the Kosi embankments) and groups 10, 11, 13 (participants residing on the Kosi west embankment who used to live within the embankments). These sub-groups identified 35 variables with a total of 86 coding references (Table 6-5). The most highly ranked variables were 'number of houses washed away or cut due to river erosion' and 'permanent settlement on the embankment'. These communities live in the danger of their houses getting washed away during the monsoon season, left with the only option to move to the embankment permanently to live.

The second-ranked variable was 'flooding of stored food and fodder', which indicates that during surface water flooding, these communities lose all their crops of floods which severely impacts their livelihood. The variables given the third rank were 'destruction of standing crops during floods', 'number of villages trapped within the tributaries of Kosi River' and 'cutting of soil with the impact of Kosi River'. This ranking suggests that the within embankments community were most significantly concerned about the destruction of crops and the flooding of villages during surface water floods.

Table 6-5 Variables identified by within embankments sub-system groups in within embankments sub-system

S.no.	Theme	Variable	Direction of change	Sub-system groups	Rank
1	Land and infrastructure	Number of houses washed away or cut due to river erosion	↑	6	1
2	Movement of people	Permanent settlement on the embankment	↑	6	1
3	Stored food and fodder	Flooding of stored food and fodder	↑	5	2
4	Agricultural activities	Destruction of standing crops during floods	↑	4	3
5	Land and infrastructure	Number of villages trapped within the tributaries of Kosi River	↑	4	3
6	Physical phenomenon	Cutting of soil with the impact of Kosi River	↑	4	3
7	Evacuation	Problems in Evacuation	↑	3	4
8	Movement of people	Temporary settlement on the embankment	↑	3	4
9	Commute	Connectivity issues	↑	2	5
10	Education facility	Difficulty to reach school premises	↑	2	5
11	Elderly and disabled	Degree of dependency on others increases	↑	2	5
12	Evacuation	Number of boats required	↑	2	5
13	Land and infrastructure	Number of houses flooded	↑	2	5
14	Land and infrastructure	Number of villages wholly submerged in floodwater	↑	2	5

S.no.	Theme	Variable	Direction of change	Sub-system groups	Rank
15	Livestock	Problems in getting livestock to the embankment	↑	2	5
16	Relief and compensation	Discrepancy in the distribution of compensation	↑	2	5
17	Relief and compensation	Number of families not able to get government allocated compensation land or money	↑	2	5
18	Sanitation and drinking water	Number of toilets	↓	2	5
19	Agricultural activities	Lack of irrigation facilities (Non-Monsoon)	↑	1	6
20	Agricultural activities	Yield or successful harvest of food crops	↓	1	6
21	Attitude of communities	Number of people relying on government for support	↑	1	6
22	Boats	Number of people not owing personal boats	↑	1	6
23	Government facilities	Government facilities in the area	↓	1	6
24	Land and infrastructure	Area under a high volume of water during monsoon every year	↑	1	6
25	Land and infrastructure	Area becoming a pit due to river erosion	↑	1	6
26	Land and infrastructure	River flows in the area after the house has been washed away	↑	1	6
27	Migration rate	Migration of young men	↑	1	6
28	Power politics	People taking advantage of strong financial status	↑	1	6
29	Psychological impact	Fear of losing loved ones at home while at work	↑	1	6

S.no.	Theme	Variable	Direction of change	Sub-system groups	Rank
30	Psychological impact	Feeling of helplessness; being poor	↑	1	6
31	Psychological impact	Living in fear of house being washed away or cut in floods	↑	1	6
32	Sanitation and drinking water	Number of people using bamboo toilets	↑	1	6
33	Women	Facilities and resources for pregnant women to practice standards of well being	↓	1	6
34	Women	Household responsibilities on Women	↑	1	6
35	Women	Number of women employed	↑	1	6

Where,

Direction of change= Direction of change of the item, (↑=increase, ↓=decrease, trigger= item introduced new variables in the system)

Sub-system group= Total number of system groups which identified that variable in the sub-system

Rank= Ranking of variable, where Rank 1 = Most sub-system groups identified the variable

6.4.3.3. Variables in the non-monsoon embankment sub-system

The non-monsoon embankment sub-system was composed of 4 sub-system groups (groups 10-13, the participants were all living on the Kosi west embankment). A total of 21 variables were identified with 43 coding references (Table 6-6). ‘Negligence and indifference of authorities’ was the highest ranked, emphasising the struggle of this community having no land rights.

The second most ranked variables were ‘number of people approaching the authorities for land issues’, ‘number of people to be moved when embankment works take place’ and ‘number of Zamindar threatening the embankment people’. These variables suggest that the embankment community's quality of life and sense of security is low because of having no land rights. The third most ranked variables were ‘forced acquisition of land by people with social and political standing’ and ‘feeling of helplessness’. All the highly ranked variables suggest that the problems for the embankment community were related to land rights and lower socio-economic status.

Table 6-6 Variables identified by non-monsoon embankment sub-system groups in non-monsoon embankment sub-system

S.no.	Theme	Variable	Direction of change	Sub-system groups	Rank
1	Government authorities	Negligence and indifference of authorities	↑	4	1
2	Government authorities	Number of people approaching the authorities for land issues	↑	3	2
3	Land and infrastructure	Number of people to be moved when embankment works take place	↑	3	2
4	Power politics	Number of Zamindar threatening the embankment people	↑	3	2
5	Power politics	Forced acquisition of land by people with social and political standing	↑	2	3
6	Psychological impact	Feeling of helplessness	↑	2	3
7	Agricultural activities	Land for agriculture	↓	1	4
8	Communities	Inability to go back to the previous house; landless	↑	1	4
9	Communities	People with an unsure living situation	↑	1	4
10	Communities	People with weaker social, financial status and lack of education	↑	1	4
11	Education Facility	Number of children going to school	↓	1	4
12	Land and infrastructure	Construction of NH17	Trigger	1	4
13	Land and infrastructure	Land value near the embankment	↓	1	4

S.no.	Theme	Variable	Direction of change	Sub-system groups	Rank
14	Land and infrastructure	Area on the embankment to live	↓	1	4
15	Livestock	Difficulty in keeping livestock	↑	1	4
16	Physical Phenomenon	Number of people surrounded by Kosi on one side and Balan on the other	↑	1	4
17	Power politics	Zamindars feel that the land belongs to them as it is in front of their house	↑	1	4
18	Psychological impact	People feel living on the embankment is their last resort	↑	1	4
19	Sanitation and drinking water	Number of toilets	↓	1	4
20	Women	Standard of care to pregnant women	↓	1	4
21	Early warning system	Absence of early warning system	↑	1	4

Where,

Direction of change= Direction of change of the item, (↑=increase, ↓=decrease, trigger= item introduced new variables in the system)

Sub-system group= Total number of system groups which identified that variable in the sub-system

Rank= Ranking of variable; where Rank 1 = Most sub-system groups identified the variable

6.4.3.4. Variables in monsoon embankment sub-system

The total sub-system groups in the monsoon embankment sub-system were 18 identifying a total of 55 variables (Table 6-7). The total coding references were 146. The most highly rank variables were ‘number of people unable to get fodder’, ‘open defecation in flood water’. Eight sub-system groups mentioned these two variables, showcasing that sanitation and having fodder for their livestock were two significant problems these communities face.

The second-ranked variable was ‘number of clean water sources getting submerged in flood water’, pointing out the unavailability of clean water sources while these communities temporarily lived on the embankment during the monsoon period. The variable ‘ability to have adequate nutritious food for self-sustenance’ was third-ranked in the list. The highly ranked items in the monsoon embankment sub-system depicted the life of communities on the embankment during the monsoon.

Table 6-7 Variables identified by monsoon embankment sub-system groups in monsoon sub-system

S.no.	Theme	Variable	Direction of change	Sub-system groups	Rank
1	Livestock	Number of people unable to get fodder	↑	8	1
2	Sanitation and drinking water	Open defecation in flood water	↑	8	1
3	Sanitation and drinking water	Number of clean water sources getting submerged in flood water	↑	7	2
4	Stored food and fodder	Ability to have adequate nutritious food for self-sustenance	↓	6	3
5	Government facilities	Inability to get healthcare on time	↓	5	4
6	Sanitation and drinking water	Problems in getting clean drinking water	↑	5	4
7	Commute	Problems in commute	↑	4	5
8	Government facilities	Infrastructural development of the area	↓	4	5
9	Government facilities	Government facilities in the area	↓	4	5
10	Health and well being	Number of people in danger of snake and insect bites	↑	4	5
11	Livestock	Space for livestock during floods	↓	4	5
12	Government facilities	Number of healthcare facilities	↓	3	6
13	Health and well being	Health-related issues	↑	3	6
14	Relief and compensation	Discrepancy rate in relief distribution	↑	3	6

S.no.	Theme	Variable	Direction of change	Sub-system groups	Rank
15	Sanitation and drinking water	Usage of contaminated water for fulfilling basic needs	↑	3	6
16	Stored food and fodder	Flooding of stored food and fodder	↑	3	6
17	Children	Difficulty in taking care of children during floods	↑	2	7
18	Commute	Going by foot in floodwater to bring clean drinking water if available	↑	2	7
19	Death rate	Death due to not getting medical attention on time	↑	2	7
20	Education facility	Time period for the school is open	↓	2	7
21	Government facilities	Time for reaching the existing healthcare facilities in the city	↑	2	7
22	Livestock	Death rate	↑	2	7
23	Quality of temporary shelter	People living under plastic shelter or slum hut	↑	2	7
24	Sanitation and drinking water	Number of people drinking floodwater	↑	2	7
25	Sanitation and drinking water	Number of people going by foot for defecating in the flooded area	↑	2	7
26	Sanitation and drinking water	Open defecation using boats	↑	2	7
27	Women	Chances of getting infections and diseases	↑	2	7
28	Women	Facilities and resources for pregnant women to practice standards of well being	↓	2	7

S.no.	Theme	Variable	Direction of change	Sub-system groups	Rank
29	Women	Standard of personal hygiene of women and adolescent girls	↓	2	7
30	Boats	Requirement of boats	↑	1	8
31	Children	Children drowning during flooding	↑	1	8
32	Children	Children following their mother to the flooded area	↑	1	8
33	Children	Malnutrition	↑	1	8
34	Death rate	Due to drowning	↑	1	8
35	Death rate	Due to malnutrition	↑	1	8
36	Education facility	Improper functioning of the school	↑	1	8
37	Financial constraints	Financial capacity to sustain life	↓	1	8
38	Flood water	Dead bodies floating	↑	1	8
39	Flood water	Flood water with rotten smell and containing a large amount of water hyacinth	↑	1	8
40	Handicapped and Disabled people	Dependency on others	↑	1	8
41	Health and well being	People facing healthcare-related issues	↑	1	8
42	Health and well being	Skin infections	↑	1	8
43	Land and infrastructure	Accessibility of land to bury the dead body	↓	1	8

S.no.	Theme	Variable	Direction of change	Sub-system groups	Rank
44	Livestock	Bring livestock to the embankment	↑	1	8
45	Livestock	Number of animals getting sick	↑	1	8
46	Power politics	Number of people taking advantage of their social and political standing	↑	1	8
47	Quality of temporary shelter	People living on the embankment for flood period	↑	1	8
48	Quality of temporary shelter	Livestock and personal belongings get stolen	↑	1	8
49	Quality of temporary shelter	Sense of safety in women	↓	1	8
50	Relief and compensation	Lack of management	↑	1	8
51	Sanitation and drinking water	Problem in defecation	↑	1	8
52	Sanitation and drinking water	Taking a bath in flood water	↑	1	8
53	Women	Facilities and resources for women to practice standards of personal hygiene	↓	1	8
54	Women	Standard of care to pregnant women	↓	1	8
55	Women	Women go far to defecate due to shyness in women	↑	1	8

Where,

Direction of change= Direction of change of the item, (↑=increase, ↓=decrease, trigger= item introduced new variables in the system)

Sub-system group= Total number of system groups which identified that variable in the sub-system

Rank= Ranking of variable; where Rank 1 = Most sub-system groups identified the variable

6.4.3.5. Groundwater and surface water class of variables

The sub-system groups involved were 18. They identified five variables with 11 coding references (Table 6-8). The 'volume of Kosi River water discharge' was the highest rank variable with three sub-system groups mentioning it, followed by the variable 'current of Kosi River water'. It demonstrates that the communities' knowledge about the hydraulic parameters was focused on the impacts of the Kosi River on their lives.

Table 6-8 Surface water and groundwater class of variables identified by hydraulic sub-system groups

S.no.	Theme	Variable	Direction of change	Sub-system groups	Rank
1	Intensity and time period of flooding	Volume of Kosi River water discharge	↑	3	1
2	Intensity and time period of flooding	Current of Kosi River water	↑	2	2
3	Intensity and time period of flooding	Time period of flooding	↑	1	3
4	Kosi Barrage	Volume of water released from the Kosi barrage	↑	1	3
5	Kosi River Dynamics	Meandering of Kosi River	↑	1	3

Where,

Direction of change= Direction of change of the item, (↑=increase, ↓=decrease, trigger= item introduced new variables in the system)

Sub-system group= Total number of system groups which identified that variable in the sub-system

Rank= Ranking of variable; where Rank 1 = Most sub-system groups identified the variable

6.4.4. Socio-environmental relationships

The details of the socio-environmental relationships identified in the defined human-flood interaction sub-systems are presented here. The identified human-flood interaction sub-systems include 1) waterlogged sub-system, 2) within embankments sub-system, 3) monsoon embankment sub-system, and 4) non-monsoon embankment sub-system. The analysis was conducted to draw out the relationships mentioned by the sub-system groups between the variables in the Kosi Basin’s sub-systems.

6.4.4.1. Relationships identified between variables in waterlogged sub-system

Total relationships identified in the waterlogged sub-system were 158, and 74 of the most mentioned by the sub-groups are displayed here in Table 6-9. The most mentioned relationship was the negative impact of the area getting waterlogged on the yield or successful harvest of food crops. This relationship was mentioned by four out of the ten waterlogged sub-system groups. This relationship was followed by four other relationships with 30% sub-group participation. Those relationships were: 1) a positive relationship between the Volume of Kosi River backflow water entering in the waterlogged area and the area getting waterlogging; 2) a positive relationship between Kosi and Kamla Balan River floodwater in the waterlogged area and temporary settlement on the embankment; 3) a negative relationship between yield or successful harvest of food crops and financial losses in agriculture; 4) a positive relationship between the volume of

Kosi River backflow water entering in waterlogged area and amount of waterlogging. These findings show the most concerning impacts of groundwater flooding in the area. As pointed out by the sub-system groups, waterlogging is a significant problem in the area, and its impact on agricultural activities is severe. These communities incur financial losses due to the loss of agriculture to waterlogging.

Table 6-9 Relationships between variables in waterlogged sub-system

S.no.	Variable (A)	Relationship	Variable (B)	Sub-system groups	Coding references
1	Area getting waterlogged	Negative	Yield or successful harvest of food crops	4	4
2	Volume of Kosi River backflow water entering in waterlogged area	Positive	Area getting Waterlogging	3	3
3	Kosi and Kamla Balan River floodwater in the waterlogged area	Positive	Temporary settlement on the embankment	3	4
4	Yield or successful harvest of food crops	Negative	Financial losses in agriculture	3	4
5	Volume of Kosi River backflow water entering in waterlogged area	Positive	Amount of waterlogging	3	3
6	Amount of waterlogging	Negative	Yield or successful harvest of food crops	2	3
7	Number of people not owing personal boats	Positive	Number of people reaching the higher ground on foot	2	2
8	Impacts of 3 rivers, Kosi, Kamla Balan and Gehua	Positive	Area getting waterlogged	2	2
9	Littering in waterlogged area	Positive	Number of people affected by the potential spread of water-borne diseases and infections	2	2

S.no.	Variable (A)	Relationship	Variable (B)	Sub-system groups	Coding references
10	Number of people going by foot in flood water for day-to-day commute	Positive	Chances of getting infections and diseases	2	2
11	Standard of personal hygiene of women and adolescent girls	Negative	Chances of getting infections and diseases	2	2
12	Yield or successful harvest of food crops	Negative	Migration of young men	2	2
13	Time for reaching the existing healthcare facilities in the city	Positive	Inability to get healthcare on time	2	2
14	Drainage density	Negative	Amount of waterlogging	2	2
15	Animals getting sick	-	No government veterinary facilities in the village	2	2
16	Number of animals getting infected with contagious diseases	Positive	Death rate of animal	1	3
17	Area getting waterlogged	Positive	Area covered by invasive species	1	1
18	Area covered by invasive species (water hyacinth) and water grass	Negative	Yield or successful harvest of food crops (water hyacinth) and water grass	1	1
19	Area covered by invasive species (water hyacinth) and water grass	Positive	Number of animals getting infected with contagious diseases	1	2
20	Area getting waterlogged	Positive	Commute time	1	1
21	Animals getting sick	Positive	Death rate	1	1

S.no.	Variable (A)	Relationship	Variable (B)	Sub-system groups	Coding references
22	Financial capacity to sustain life; poverty	Negative	People unable to afford a good private veterinarian	1	1
23	People unable to afford a good private veterinarian	Positive	Death rate of animal	1	1
24	Yield or successful harvest of food crops	Negative	Number of animals eating water hyacinth	1	1
25	Number of animals eating water hyacinth	Positive	Animals getting sick	1	2
26	No government veterinary facilities in the village	Positive	Death rate of animal	1	1
27	Area getting waterlogged	Positive	Delaying agricultural activities	1	1
28	Delaying agricultural activities	Negative	Yield or successful harvest of food crops	1	1
29	Impacts of 3 rivers, Kosi, Kamla Balan and Gehua	Positive	Feeling of helplessness; being poor	1	1
30	Expertise and knowledge of government authorities	Negative	Negligence and indifference of Authorities	1	1
31	Negligence and indifference of Authorities	Positive	People in the waterlogged area are not considered flood-affected	1	1

S.no.	Variable (A)	Relationship	Variable (B)	Sub-system groups	Coding references
32	Struggle to buy agricultural implements	Positive	Number of people selling their personal belongings	1	1
33	Disparity in implementation of government-issued policies	Negative	Financial capacity to sustain life; poverty	1	1
34	Negligence and indifference of Authorities	Positive	Feeling of helplessness; being poor	1	1
35	Negligence and indifference of Authorities	Negative	Financial and infrastructure assistance from the government	1	1
36	Amount of waterlogging	Negative	Land pollution due to drying to waterlogged area	1	1
37	Littering in waterlogged area	Positive	Number of animals drinking water of degraded quality	1	1
38	Unable to do the paperwork (Illiterate)	Positive	Disparity in implementation of government-issued policies	1	1
39	Lack of knowledge about the government policies and facilities	Positive	Disparity in implementation of government-issued policies	1	1
40	Area getting waterlogged	Negative	Time period for the school is open	1	1
41	Amount of waterlogging	Negative	Time period for the school is open	1	1
42	Number of houses flooded	-	Financial and infrastructure assistance from the government	1	1

S.no.	Variable (A)	Relationship	Variable (B)	Sub-system groups	Coding references
43	Volume of Kosi River water discharge	Positive	Volume of Kosi River backflow water entering in waterlogged area	1	1
44	Facilities and resources for pregnant women to practice standards of well being	Positive	Standard of care to pregnant women	1	1
45	Voices not heard due to corruption	Negative	Facilities and resources for child care and development	1	2
46	Area covered by invasive species (water hyacinth) and water grass	Positive	Number of people affected by the potential spread of water-borne diseases and infections	1	1
47	Area getting waterlogged	Positive	Number of people affected by the potential spread of water-borne diseases and infections	1	1
48	Unable to use boats when the water level is low	Positive	Going by foot in flood water for day to day commute	1	1
49	Living near the embankment	Positive	Chance of flood outbreak	1	1
50	Non-uniform policies, not taking into account flooding	Positive	Disparity in implementation of government-issued policies	1	1
51	Time period of flooding	Positive	Time period for the school is open	1	1
52	Yield or successful harvest of food crops	-	Compensation to the farmer for the destruction of the crop	1	1

S.no.	Variable (A)	Relationship	Variable (B)	Sub-system groups	Coding references
53	Number of people not owing personal boats	Positive	Commute by foot for collecting fodder	1	1
54	Unable to use boats when the water level is low	Positive	Commute by foot for collecting fodder	1	1
55	Facilities and resources for women to practice standards of personal hygiene	Positive	Standard of personal hygiene of women and adolescent girls	1	2
56	Financial capacity to sustain life; poverty	Positive	Standard of personal hygiene of women and adolescent girls	1	1
57	Going by foot in flood water for day to day commute	Negative	Standard of personal hygiene of women and adolescent girls	1	1
58	Rate of losing potential working days in agriculture	Positive	Migration of young men	1	1
59	Impeding agricultural opportunities	Positive	Migration of young men	1	1
60	Amount of waterlogging	Positive	Impact on lifestyle	1	1
61	Impact on lifestyle	Positive	Temporary settlement on embankment	1	1
62	Villages wholly submerged in flood water	Positive	Temporary settlement on the embankment	1	1
63	Financial capacity to sustain life	Positive	Number of toilets	1	1
64	Infrastructural development of the area	Positive	Facilities in School	1	1

S.no.	Variable (A)	Relationship	Variable (B)	Sub-system groups	Coding references
65	Lack of government facilities	Positive	Household responsibilities on Women	1	1
66	Discrepancies in management of resources	Positive	Lack of government facilities	1	1
67	Lack of government facilities	Positive	Time to reach the existing healthcare facilities in the city	1	1
68	Connectivity issues	Positive	Inability to get healthcare on time	1	1
69	Amount of river water discharge	Positive	Fear of embankment breaking	1	1
70	Facilities and resources for pregnant women to practice standards of well being	Negative	Death rate due to not getting medical attention on time	1	1
71	Unable to get healthcare on time	Positive	Death rate due to not getting medical attention on time	1	1
72	Open Defecation	Positive	Number of people affected by the potential spread of water-borne diseases and infections	1	1
73	Yield or successful harvest of food crops	Negative	People unable to get fodder for livestock	1	1
74	Number of people affected by the potential spread of water-borne diseases and infections	-	Lack of government facilities	1	1

Where,

Relationship = The direction of change in the value of variable (B) because of variable (A), (positive = an increase/decrease in (A) leads to an increase/decrease in (B), negative = an increase/decrease in (A) leads to a decrease/increase in (B))

Sub-system group = The total number of system groups that identified a relationship in the sub-system

Coding references = Coding references made by the sub-system groups in identifying a relationship

6.4.4.2. Relationships identified between variables in the within embankments sub-system

The total relationships identified in the within embankments sub-system were 26 (Table 6-10). With 5 out of 8 sub-system groups mentioning a positive relationship between houses washed away or cut due to soil erosion and permanent settlement on the embankment, this relationship was the most mentioned. This relationship was followed by a positive relationship between the cutting of soil with the impact of the Kosi River and houses washed away or cut due to soil erosion. This relationship was mentioned by three within embankments sub-groups. These two relationships show that the major problem for within embankments communities is the impact of surface water flooding during the monsoon season. The most severe impact of flooding is that the houses get washed away, making the marginalised communities permanently settle on the Kosi west embankment.

The three other relationships which were mentioned by 25% of the sub-system groups were 1) a positive relationship between the current of Kosi River water and problems in an evacuation; 2) a positive relationship between the current of Kosi River water and houses washed away or cut due to river erosion; 3) a positive relationship between the villages wholly submerged in floodwater and problems in an evacuation. These three relationships show that evacuation is also a major concern for these communities as they face the direct impact of the high current of Kosi water during surface water flooding.

Table 6-10 Relationships between variables in the within embankments sub-system

S.no.	Variable (A)	Relationship	Variable (B)	Sub-system groups	Coding references
1	Houses washed away or cut due to soil erosion	Positive	Permanent settlement on the embankment	5	7
2	Cutting of soil with the impact of Kosi River	Positive	Houses washed away or cut due to river erosion	3	4
3	Current of Kosi River water	Positive	Problems in Evacuation	2	2
4	Current of Kosi River water	Positive	Houses washed away or cut due to river erosion	2	2
5	Villages wholly submerged in flood water	Positive	Problems in Evacuation	2	2
6	Number of villages trapped within the tributaries of Kosi River	Positive	Cutting of soil with the impact of Kosi River	1	1
7	Meandering of Kosi River	Positive	Number of villages trapped within the tributaries of Kosi River	1	1
8	Problems in Evacuation	Positive	Requirement of boats	1	1
9	Number of villages trapped within the tributaries of Kosi River	Positive	Difficulty to reach school premises	1	1
10	Current of Kosi River water	Positive	Destruction of standing crops during floods	1	1
11	Current of Kosi River water	Positive	Problems in getting livestock to the embankment	1	1

S.no.	Variable (A)	Relationship	Variable (B)	Sub-system groups	Coding references
12	Volume of Kosi River water discharge	Positive	Living in fear of house being washed away or cut in floods	1	1
13	Houses washed away or cut due to river erosion	Positive	Number of families not able to get government allocated compensation land or money	1	1
14	Cutting of soil with the impact of Kosi River	Positive	Area becoming a pit due to river erosion	1	1
15	Houses washed away or cut due to river erosion	Positive	River flows in the area after the house has been washed away	1	1
16	Number of houses flooded	Positive	Temporary settlement on the embankment	1	1
17	Volume of water released from the Kosi barrage	-	Absence of early warning system	1	1
18	Problems in Evacuation	Positive	Dependency on others increases for elderly and disabled	1	1
19	Number of women employed	Positive	Fear of losing loved ones at home while at work	1	1
20	Villages wholly submerged in flood water	Positive	Temporary settlement on the embankment	1	1
21	Volume of Kosi River water discharge	Positive	Villages wholly submerged in flood water	1	1

S.no.	Variable (A)	Relationship	Variable (B)	Sub-system groups	Coding references
22	Villages wholly submerged in flood water	Positive	Problems in getting livestock to the embankment	1	1
23	Number of toilets	Negative	Use bamboo toilets	1	1
24	Migration of young men	Positive	Household responsibilities on Women	1	1
25	Number of villages trapped within the tributaries of Kosi River	Positive	Connectivity issues	1	1
26	Number of houses flooded	Positive	Flooding of stored food and fodder	1	1

Where,

Relationship = The direction of change in the value of variable (B) because of variable (A), (positive = an increase/decrease in (A) leads to an increase/decrease in (B), negative = an increase/decrease in (A) leads to a decrease/increase in (B))

Sub-system group = The total number of system groups that identified a relationship in the sub-system

Coding references = Coding references made by the sub-system groups in identifying a relationship

6.4.4.3. Relationships identified between variables in the non-monsoon embankment sub-system

The total relationships identified for the non-monsoon embankment sub-system were 16 (Table 6-11). The four most mentioned (50% sub-system groups) were: 1) a positive relationship between the number of people to be moved when embankment works take place and Zamindar threatens and uses force to scare the embankment people; 2) a gap between the number of people approaching the authorities for land issues and negligence and indifference of authorities; 3) a positive relationship between negligence and indifference of authorities and feeling of helplessness; 4) a positive relationship between the construction of Supaul-Kasraur road and number of Zamindar threatening the embankment people. These most mentioned relationships show that the most concerning problem for the embankment community is the displacement from their ancestral lands. Living on the embankment, this community can be moved by the government or the Zamindars.

Table 6-11 Relationships between variables in non-monsoon embankment sub-system

S.no.	Variable (A)	Relationship	Variable (B)	Sub-system groups	Coding references
1	Number of people to be moved when embankment works take place	Positive	Zamindar threatens and uses force to scare the embankment people	2	3
2	Number of people approaching the authorities for land issues	-	Negligence and indifference of Authorities	2	2
3	Negligence and indifference of Authorities	Positive	Feeling of helplessness	2	2
4	Construction of Supaul-Kasraur road	Positive	Number of Zamindar threatening the embankment people	2	2
5	Zamindars feel that the land belongs to them as it is in front of their house	Positive	Number of Zamindar threatening the embankment people	1	1
6	Forced acquisition of land by people with social and political standing	Positive	Inability to go back to the previous house; landless	1	1
7	Number of Zamindar threatening the embankment people	Positive	Feeling of helplessness	1	1
8	Number of people surrounded by Kosi on one side and Balan on the other	Negative	Area on the embankment to live	1	1
9	Area on the embankment to live	Positive	Land for agriculture	1	1
10	Area on the embankment to live	Negative	Difficulty in keeping livestock	1	1
11	Land for agriculture	Negative	Difficulty in keeping livestock	1	1

S.no.	Variable (A)	Relationship	Variable (B)	Sub-system groups	Coding references
12	People with weaker social, financial status and lack of education	Positive	Negligence and indifference of Authorities	1	1
13	Construction of NH17	Positive	Land value near the embankment	1	1
14	Land value near the embankment	Positive	Number of Zamindar threatening the embankment people	1	1
15	Volume of water released from the Kosi barrage	-	Absence of early warning system	1	1
16	Unsure living situation	Negative	Number of toilets	1	1

Where,

Relationship = The direction of change in the value of variable (B) because of variable (A), (positive = an increase/decrease in (A) leads to an increase/decrease in (B), negative = an increase/decrease in (A) leads to a decrease/increase in (B))

Sub-system group = The total number of system groups that identified a relationship in the sub-system

Coding references = Coding references made by the sub-system groups in identifying a relationship

6.4.4.4. Relationships identified between variables in the monsoon embankment sub-system

The total relationships identified in the monsoon embankment sub-system were 45 (Table 6-12). The most mentioned relationship was a positive relationship between the temporary settlement on the embankment and open defecation in floodwater. This relationship was mentioned by 4 out of 18 monsoon embankment sub-system groups. The second most mentioned relationship was a positive relationship between the inability to get healthcare on time and death due to not getting medical attention. And the seven most mentioned relationships were: 1) a negative relationship between the standard of personal hygiene of women and adolescent girls and chances of getting infections and diseases; 2) a positive relationship between the number of clean water sources getting submerged in floodwater and the number of people drinking floodwater; 3) a positive relationship between problems in getting clean drinking water and usage of contaminated water for fulfilling basic needs; 4) a positive relationship between the number of clean water sources getting submerged in floodwater and problems in getting clean drinking water; 5) a positive relationship between temporary settlement on the embankment and problems in getting clean drinking water; 6) a positive relationship between lack of government facilities and time for reaching the existing healthcare facilities in the city; 7) a positive relationship between the number of people in danger of snake and insect bites and inability to get healthcare on time.

These relationships show that sanitation, unsafe living conditions on the west embankment and healthcare are the primary concerns during the monsoon. These communities have no clean water sources, no toilets and are in danger of snake bites while they stay on the embankment. In case of a medical emergency, the healthcare facilities in the area are inadequate, leading to high mortality.

Table 6-12 Relationships between variables in the monsoon embankment sub-system

S.no.	Variable (A)	Relationship	Variable (B)	Sub-system groups	Coding references
1	Temporary settlement on embankment	Positive	Open defecation in flood water	4	4
2	Inability to get healthcare on time	Positive	Death due to not getting medical attention	3	4
3	Standard of personal hygiene of women and adolescent girls	Negative	Chances of getting infections and diseases	2	2
4	Number of clean water sources getting submerged in flood water	Positive	Number of people drinking floodwater	2	2
5	Problems in getting clean drinking water	Positive	Usage of contaminated water for fulfilling basic needs	2	2
6	Number of clean water sources getting submerged in flood water	Positive	Problems in getting clean drinking water	2	2
7	Temporary settlement on the embankment	Positive	Problems in getting clean drinking water	2	2
8	Lack of government facilities	Positive	Time for reaching the existing healthcare facilities in the city	2	2
9	Number of people in danger of snake and insect bites	Positive	Inability to get healthcare on time	2	2
10	Number of people going by foot for defecating in the flooded area	Positive	Chances of getting infections and diseases	1	1

S.no.	Variable (A)	Relationship	Variable (B)	Sub-system groups	Coding references
11	Flood water with rotten smell and containing a large amount of water hyacinth	Positive	Number of people going by foot for defecating in the flooded area	1	1
12	Livestock left behind in the flooded area	Positive	Death rate of livestock	1	1
13	People are unable to get fodder	Positive	Death rate of livestock	1	1
14	Ability to have adequate nutritious food for self-sustenance	Negative	Malnutrition in children	1	1
15	Number of clean water sources getting submerged in flood water	Positive	Taking a bath in flood water	1	1
16	Number of clean water sources getting submerged in flood water	Negative	Going by foot in floodwater to bring clean drinking water if available	1	1
17	Usage of contaminated water for fulfilling basic needs	Positive	Health-related issues	1	1
18	Flooding of stored food and fodder	Positive	People are unable to get fodder	1	1
19	Time period of flooding	Positive	Health-related issues	1	1
20	Current of Kosi River water	Positive	People are unable to get fodder	1	1
21	Quality of temporary shelter	Positive	Ability to have adequate food for self-sustenance	1	1

S.no.	Variable (A)	Relationship	Variable (B)	Sub-system groups	Coding references
22	Women go far to defecate due to shyness	Positive	Children follow their mother	1	1
23	Children follow their mother	Positive	Death due to drowning	1	1
24	Problems in getting clean drinking water	Positive	Drinking flood water	1	1
25	Facilities and resources for women to practice standards of personal hygiene	Positive	Standard of personal hygiene of women and adolescent girls	1	2
26	Usage of contaminated water for fulfilling basic needs	Positive	Inability to get healthcare on time	1	1
27	Death rate	-	No place to bury the dead body	1	1
28	Time for reaching the existing healthcare facilities in the city	Negative	Facilities and resources for pregnant women to practice standards of well being	1	1
29	Facilities and resources for pregnant women to practice standards of well being	Positive	Standard of care to pregnant women	1	1
30	Infrastructural development of the area	Negative	Improper functioning of the school	1	1
31	Time period of flooding	Positive	Time period for the school is open	1	1
32	People taking advantage of their social and political standing	Positive	Discrepancy rate in relief distribution	1	1

S.no.	Variable (A)	Relationship	Variable (B)	Sub-system groups	Coding references
33	Facilities and resources for pregnant women to practice standards of well being	Negative	Death due to not getting medical attention	1	1
34	Difficulty in taking care of children during floods	Positive	Death due to not getting medical attention	1	1
35	Poor; financial constraints	Positive	Death due to not getting medical attention	1	1
36	Taking a bath in flood water	Positive	Skin infections	1	1
37	Number of animals getting sick	Positive	Death rate of animals	1	1
38	Problem in defecation	Positive	Open defecation in flood water	1	1
39	Open defecation in flood water	Positive	Requirement of boats	1	1
40	Problems in commute	Positive	Requirement of boats	1	1
41	Live on the embankment for flood period	Positive	Problems in getting clean drinking water	1	1
42	Live on the embankment for flood period	Positive	Problem in defecation	1	1
43	Live on the embankment for flood period	Positive	Live under plastic shelter or slum hut	1	1
44	Live on the embankment for flood period	Positive	Bring livestock to the embankment	1	1

S.no.	Variable (A)	Relationship	Variable (B)	Sub-system groups	Coding references
45	Lack of management of government authorities	Positive	Discrepancy rate in relief distribution	1	1

Where,

Relationship = The direction of change in the value of variable (B) because of variable (A), (positive = an increase/decrease in (A) leads to an increase/decrease in (B), negative = an increase/decrease in (A) leads to a decrease/increase in (B))

Sub-system group = The total number of system groups that identified a relationship in the sub-system

Coding references = Coding references made by the sub-system groups in identifying a relationship

6.5. System behaviour

6.5.1. Causal loop diagrams and their characteristics

The Kosi Basin system involved multiple sub-systems consisting of interacting processes, feedback, and time delays, and the causal loop diagram is a suitable tool to explore the dynamic behaviour of a system (Sterman, 2000). The fundamental concept of using causal loop diagrams to define the Kosi Basin system dynamics was understanding how the Kosi system structure behaves as a 'whole' formed by continuous processes rather than 'parts' made of discrete events (Schaffernicht, 2007). Understanding the interactions and feedback mechanisms allows understanding of how the behaviour manifests itself in the system (Haraldsson, 2004). The findings can be utilised to inform the decision-making process for policymaking in local flood risk management.

In causal loop diagrams, terms like polarity, causality, causal links are used to describe the system dynamics. Bowen (1992) emphasised that polarity was required to convert the knowledge about the structure into knowledge about the behaviour of the feedback loop/variable. Variable polarity determines the direction of an independent variable's influence on the dependant variable. In a causal loop diagram, while defining the polarity of a specific variable, an assumption is made that the first variable (the cause) is an independent variable and the second variable (the effect) is a dependent variable. The polarity can be positive (+) or negative (-) as defined below:

- **Positive (+) polarity of a variable-** The value of a dependent variable will become more or less than what it has been following the change in the signs + or – of the independent variable, respectively (Richardson, 1997). In simple words, when independent and dependent variables change in the same direction, the polarity is positive.

- **Negative (-) polarity of a variable-** The value of a dependent variable will become less or more than what it has been following the change in the signs + or – of the independent variable, respectively (Richardson, 1997). In simple words, when independent and dependent variables change in the opposite direction, the polarity is positive.

Therefore, the polarity of a variable signifies the change in a variable's behaviour caused by a change in another variable's behaviour (Schaffernicht, 2007). The link formed between these two variables is called a causal link, where one variable acts as a cause and the other as an effect. Consequently, the polarity of the feedback loop is measured by taking into consideration the polarity of all the variables involved in that particular loop. As per the measured polarity, the loop can either be reinforcing (+) or balancing (-), defined below:

- **Reinforcing loops (R):** Reinforcing loops have positive polarity. These represent a growing effect on the feedback loop where all the variables collectively amplify the action produced. Because of their strengthening nature, reinforcing loops can either produce desirable effects in the positive direction acting as virtuous loops or undesirable negative effects acting as vicious loops (Rwashana et al., 2014).

- **Balancing loops (B):** These loops are neutralising in nature with negative polarity. Their neutralising behaviour arises from their ability to counter the change with a push in the opposite direction. These balancing loops consist of goal-seeking behaviour and can be applied in an attempt to solve a problematic situation (Rwashana et al., 2014).

Therefore, either of variable or loop, polarity helps identify a particular variable or loop's effect on the loop or system.

6.5.2. Steps for drawing causal loop diagrams

A protocol was designed to draw the Kosi Basin sub-system causal loop diagrams. The protocol involved a series of steps for maximising the efficiency for drawing out the dynamic behaviour of the sub-systems. The steps are mentioned below:

Step 1: Creating causal links for a sub-system in Vensim

The abstracted socio-environmental relationships for a sub-system were used to draw the causal links in Vensim for that particular sub-system. These causal links were refined to build the sub-system causal loop diagram. E.g. some groups mentioned a relationship in detail: A → B → C while others defined it as A → C. So, the links were refined as A → B → C to capture the detailed causal link. Moreover, while drawing the causal links, some of the variables were renamed to convert them into quantifiable variables. Plotting these refined causal links resulted in building the causal loop diagram for that sub-system. It is to note that no external information was used to drawn causal links. The causal links were only drawn based on the information abstracted by the participants.

Step 2: Distinguishing between positive and negative polarity

Colour coding was used to distinguish a causal link's negative or positive polarity. The orange colour was used to represent the negative polarity and blue for positive polarity with signs "-" and "+", respectively (Figure 6-14).

Step 3: Establishing triggers and cross-boundary interactions of a sub-system with other sub-systems

The cross-boundary interactions and triggers were colour coded (Figure 6-14) to distinguish the relationships a particular sub-system has with other sub-systems.

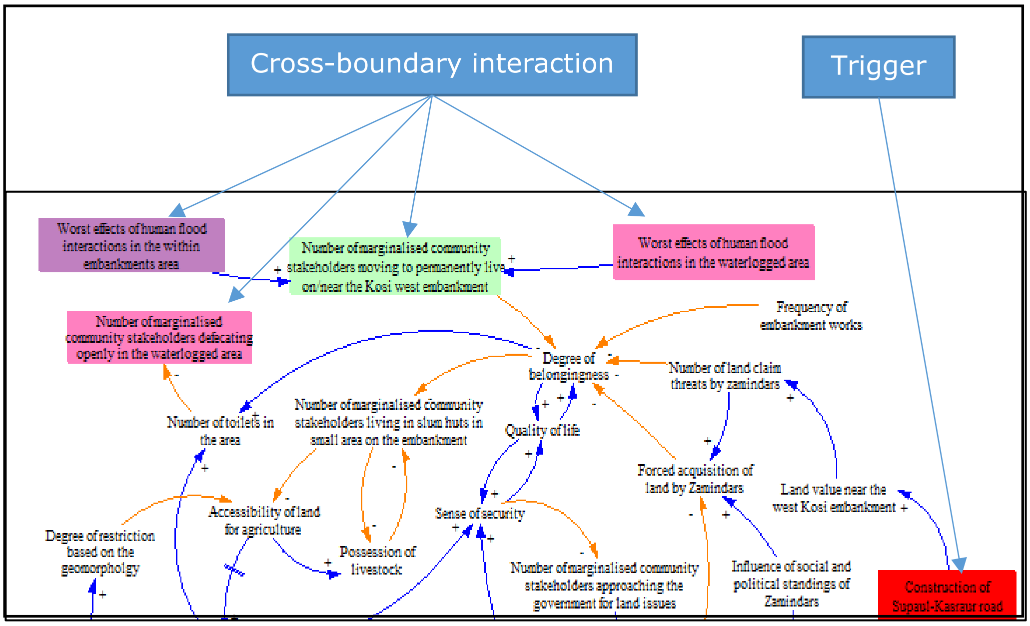


Figure 6-14 Colour coding of cross-boundary interactions and trigger

The coding framework (Table 6-13) was developed to colour code the background of the variables belonging to different sub-systems. Furthermore, the triggers were with a red background to differentiate them from other variables. Triggers were the exogenous variables that initiated a chain of events in the sub-system.

Table 6-13 Colour coded background of a variable with respect to sub-systems and triggers

Background colour	Sub-system/Trigger
	Waterlogged sub-system variables
	Within embankments sub-system variables
	Embankment non-monsoon sub-system variables
	Embankment monsoon sub-system variables
	Surface water and groundwater class of variables
	Trigger variables

6.5.3. Sub-system causal loop diagrams for Kosi Basin system

Each human-flood interaction sub-system has monsoon and non-monsoon variations, showing the interactions of the three spatial communities with floods. Therefore, a total of six causal loop diagrams for the three human-flood interaction sub-systems were drawn and all the causal loop variables are defined in Appendix A. The causal loop diagrams presented in the figures below are:

1) Non-monsoon waterlogged sub-system (Figure 6-15): This causal loop diagram showcases the interactions between waterlogged community and

waterlogging during the non-monsoon season. The main focus of this diagram is on how the waterlogging negatively impacts the livelihood opportunities, making this community financial unstable.

2) Monsoon waterlogged sub-system (Figure 6-16): This causal loop diagram depicts how the surface water floods cause economic loss to waterlogged community after they temporarily settle on Kosi west embankment to safeguard themselves from surface water flooding. The economic loss includes washing away of house, losing standing crops and livestock to floods.
3) Non-monsoon within embankments sub-system (Figure 6-17): This causal loop diagram demonstrates the impact of power politics on the marginalised community stakeholders. They lose their ancestral lands and face discrepancies in flood compensation due to bribery and corruption.
4) Monsoon within embankments sub-system (Figure 6-18): The monsoon within embankments sub-system causal loop diagram is similar to the monsoon waterlogged sub-system. This diagram also depicts the economic losses for the within embankment community due to surface water flooding.
5) Non-monsoon embankment sub-system (Figure 6-19): The non-monsoon embankment sub-system also explores the impact of power dynamics on the marginalised community stakeholders, similarly to non-monsoon within embankments sub-system.

6) Monsoon embankment sub-system (Figure 6-20): This causal loop diagram depicts the situation when the waterlogged and within embankment communities temporarily settle on the Kosi west embankment. This transient sub-system showcases the problems all three spatial communities face while they stay on Kosi west embankment.

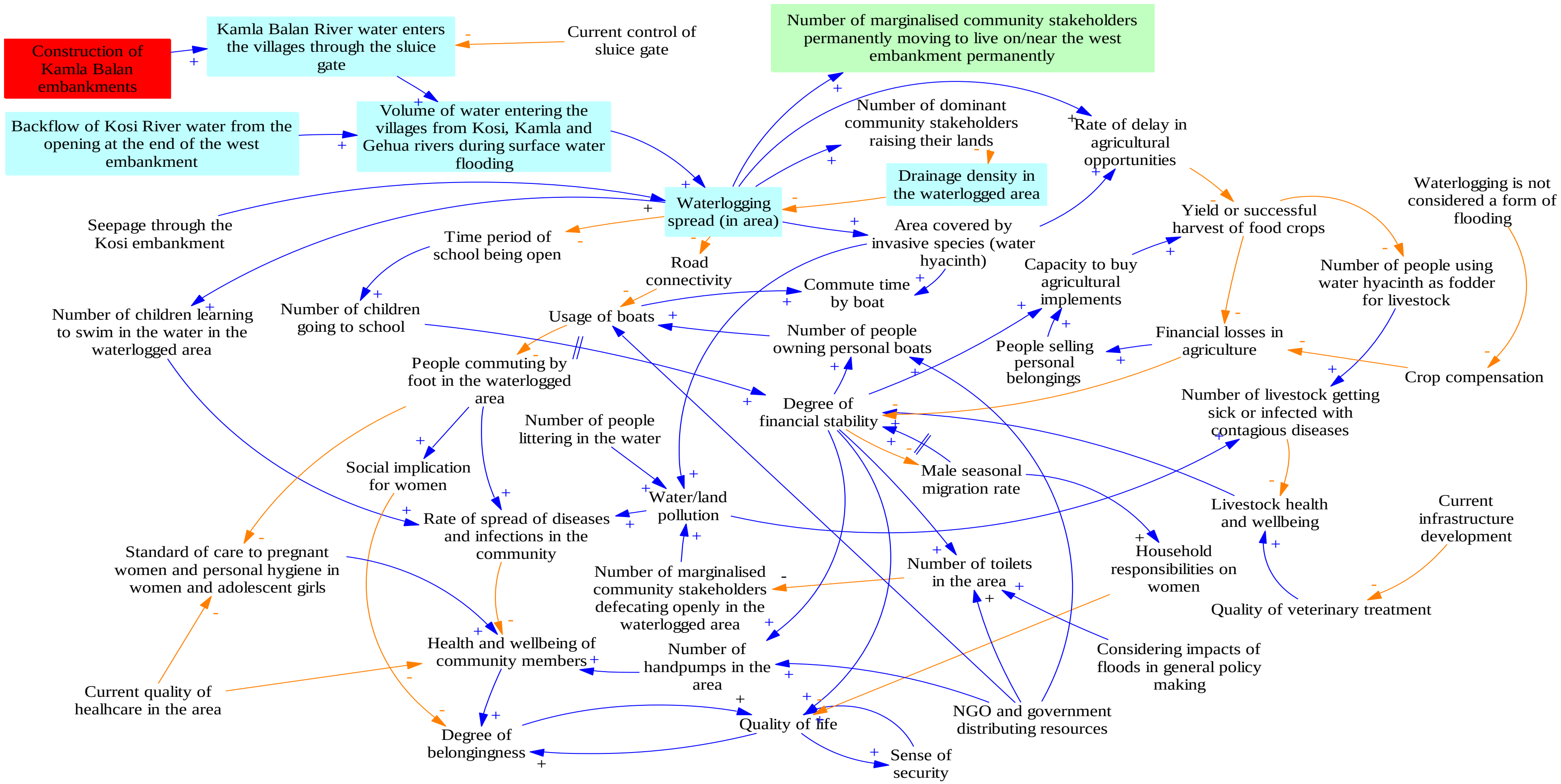


Figure 6-15 Non-monsoon waterlogged sub-system causal loop diagram

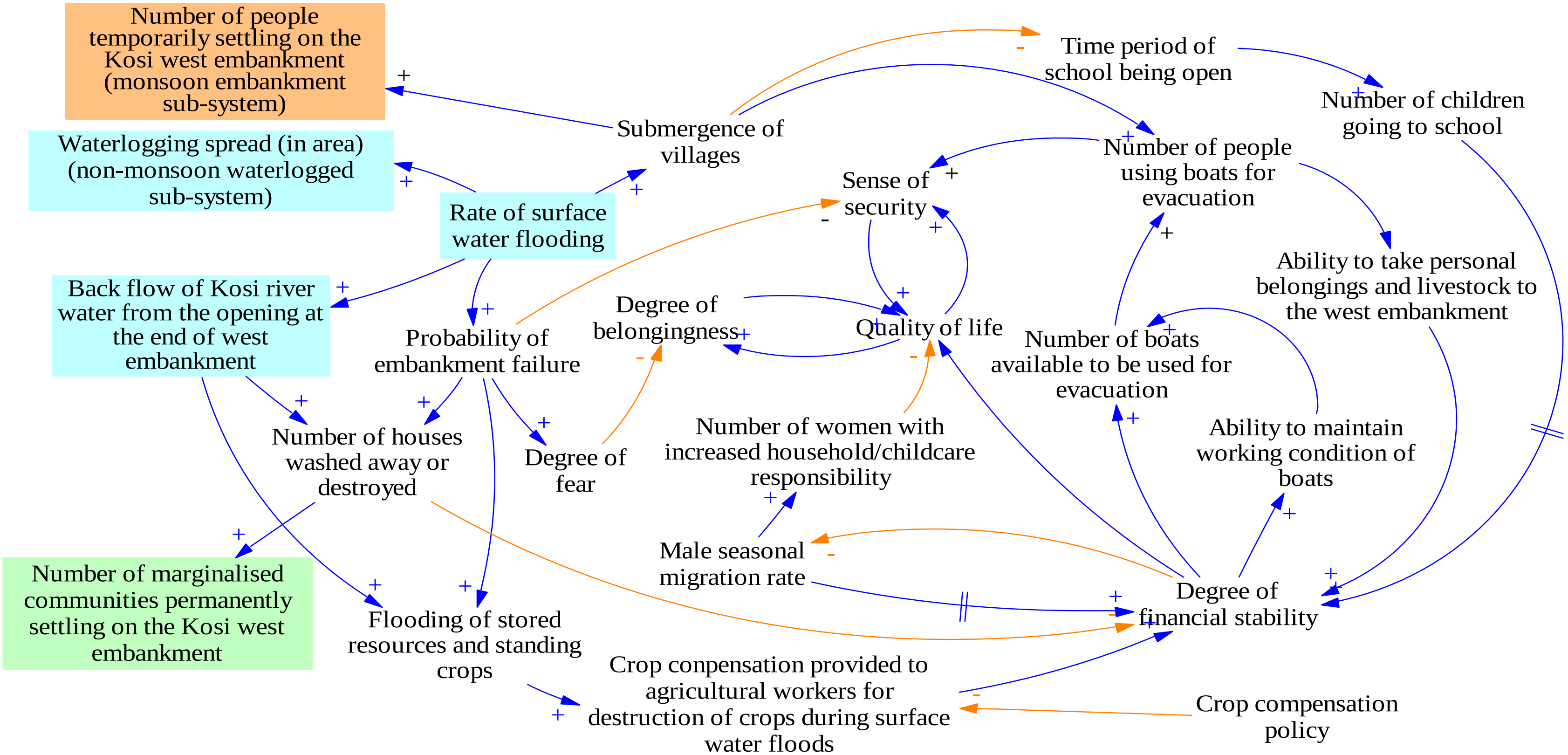


Figure 6-16 Monsoon waterlogged sub-system causal loop diagram

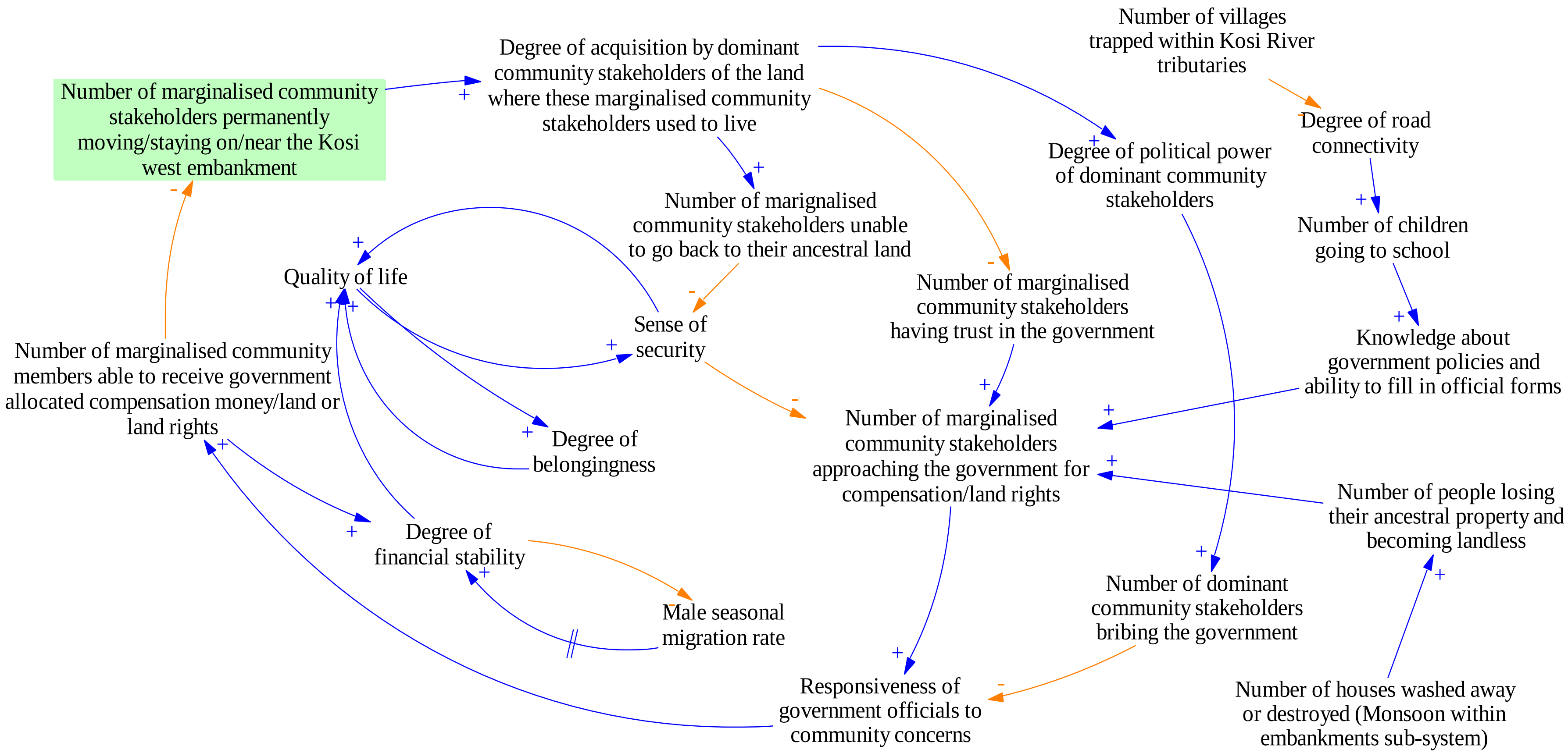


Figure 6-17 Non-monsoon within embankments sub-system causal loop diagram

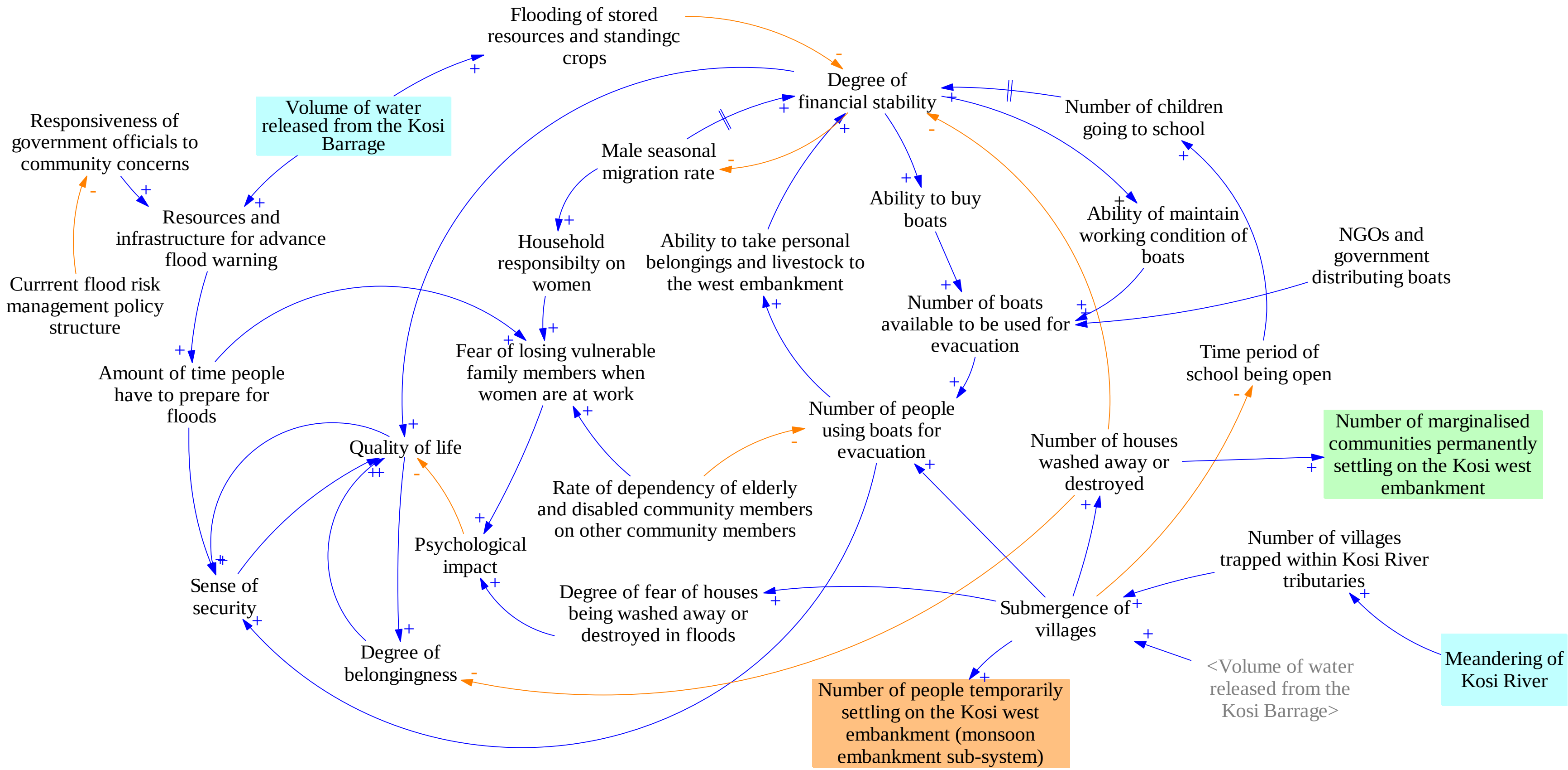


Figure 6-18 Monsoon within embankments sub-system causal loop diagram

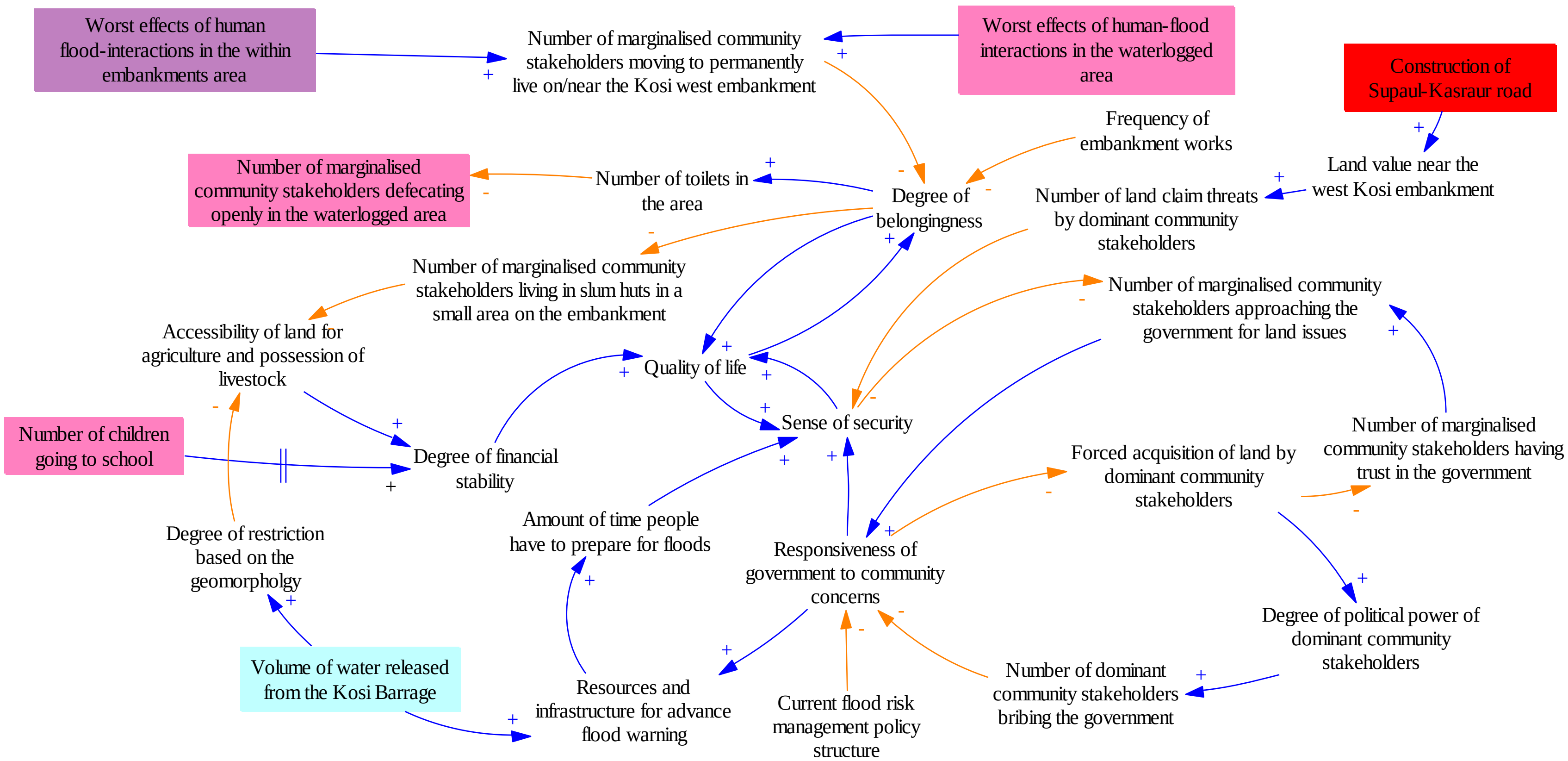


Figure 6-19 Non-monsoon embankment sub-system causal loop diagram

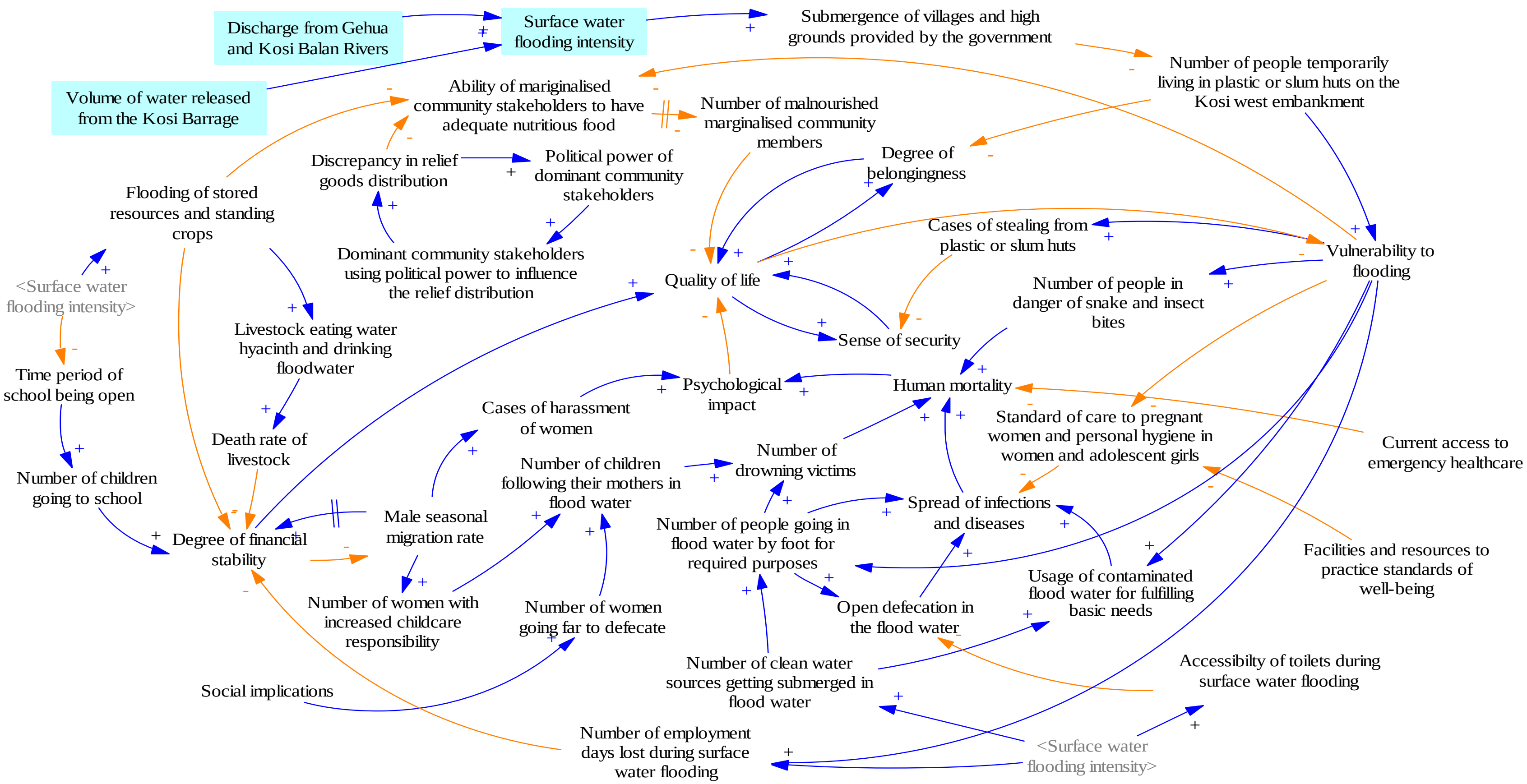


Figure 6-20 Monsoon embankment sub-system causal loop diagram

6.6. Chapter summary

This chapter explained how rich picture workshops were conducted in the behavioural representation stage to acquire an in-depth understanding of the Kosi system behaviour from participants' perceptions. The rich picture data was then formalised, in which the workshop data was abstracted to identify identifying themes and the variables in the human-flood interacting sub-systems. Also, the interactions and feedback occurring in the sub-systems were elicited. The abstracted data, i.e., the elicited variable relationships, were plotted to derive the causal loop diagrams.

A total of six causal loops were drawn for the three spatial sub-systems, defining the behaviour of these sub-systems for the monsoon and non-monsoon periods. The causal loop diagrams were instrumental in putting together the behavioural dynamics of Kosi Basin socio-environmental system by drawing out the connections and feedbacks occurring in and amongst the different formalised human-flood interacting sub-systems. There were many cross-boundary interactions observed in these causal loop diagrams. E.g., the number of houses being flooded (non-monsoon waterlogged sub-system) and the number of marginalised community stakeholders moving to live on/near the west embankment permanently (Figure 6-15). These cross-boundary interactions suggest that these sub-systems are connected to each other and function together as a big socio-environmental system. The in-depth analysis of these causal loop diagrams is carried out in the next chapter, i.e., Chapter 7. This in-depth interrogation is instrumental in gathering an understanding of the overall behaviour of the system and identifying the key variables, interactions and feedback defining this current behaviour.

Chapter 7. System interrogation

7.1. Chapter overview

In this chapter, the causal loops drawn in the previous chapter, i.e., Chapter 6, are interrogated. While ideally, causal loop diagrams would be validated through close engagement with and input by local communities (e.g., elderly men, women), unfortunately this was not possible due to travel restrictions as a result of Covid-19. However, the researcher contacted the gatekeeper and discussed ways to connect with the participants. The only viable option was to connect with the participants via internet but was not successful due to the following reasons:

1. The spread of Covid-19 in the area.
2. The Covid-19 restrictions imposed by the government which meant people were not allowed to meet in groups.
3. The internet connectivity in the field site is poor.
4. Smart phones and laptops are a rare commodity in the area.
5. The majority of the participants in the area, especially women are illiterate. Therefore, the researcher's presence was required to go through the causal loop diagrams in person.

As such, the researcher went back to the original recordings of the interviews and workshops to check for validity/alignment in the absence of on-ground validation with local communities. The interrogation of system diagrams in this chapter includes simplifying the complicated causal loop diagrams obtained in Chapter 6 by abstracting feedback loops from causal loop diagrams. This simplification aids in investigating the feedback loops to identify key system characteristics such as the crucial system variables (endogenous or exogenous), interactions, feedbacks and dominant vulnerability dimensions responsible for the system behaving in a certain way.

7.1.1. Steps adopted for system interrogation

Figure 7-1 presents the steps adopted to interrogate the sub-systems identified in the Kosi Basin socio-environmental system. The set of steps was performed six times to account for the temporal variation in the three identified human-flood interaction sub-systems. Therefore, the sub-systems interrogated were: 1) Non-monsoon embankment sub-system (Section 7.2), 2) Monsoon embankment sub-system (Section 7.3), 3) Non-monsoon within embankments sub-system (Section 7.4), 4) Monsoon within embankments sub-system (Section 7.5), 5) Non-monsoon waterlogged sub-system (Section 7.6) and 6) Monsoon waterlogged sub-system (Section 7.7).

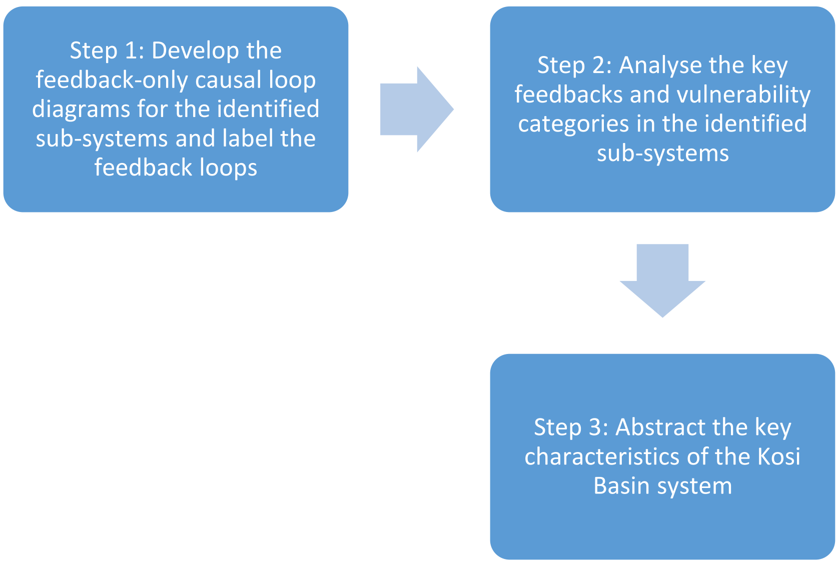


Figure 7-1 Steps followed for understanding the system's behaviour

Step 1: Develop feedback-only causal loop diagrams for the identified sub-systems and label feedback loops

Research question three (Page 11) is directed toward understanding the system's dynamic behaviour, which can be ascertained by studying feedback loops among system variables elicited from engagement with community members (see Chapter 6). Understanding cause and effect in the feedback loops allows analysis and interpretation of dynamic complexity in a system, i.e., how the changes happen in a system, both at temporal and spatial scales (Haraldsson, 2004). Therefore, causal loop diagrams were redrawn into simplified feedback-only causal loop diagrams, i.e. only variables that were logically connected to another based on interviews or rich pictures were included (Figure 7-3, Figure 7-12, Figure 7-22, Figure 7-29, Figure 7-33 and Figure 7-42). This step helped present the key components depicting interrelationships and interdependencies in the sub-systems (Nguyen and Bosch, 2013) and eliminate the linear relationships and variables that do not provide feedbacks and hence have a limited impact on the system dynamics (Fazey et al., 2011).

The next step was to label feedback loops. Narrating stories is "a primary way of distilling and coding information in memorable form" (Stroh, 2015: 30), and feedback loops are a powerful tool for creating a concise story related to issues and problems within a system (Mai et al., 2020). Labelling the loop, in simple terms, means attaching particular properties to feedback loops which aids in narrating these stories. Therefore, labels are advantageous for making sense of the system's complexities in a simplified way (Barbrook-Johnson and Penn, 2022). In this research, the properties included in labelling the loop were: 1) loop name, 2) loop type, i.e., reinforcing or balancing, and 3) dominant dimensions. A protocol was adopted for labelling the feedback loops to provide a standard theme to all loops in different sub-systems. The label was put in the middle of the feedback loops; dominant dimensions (top), type of feedback loop (middle), and name of the loop (below) (Figure 7-2).

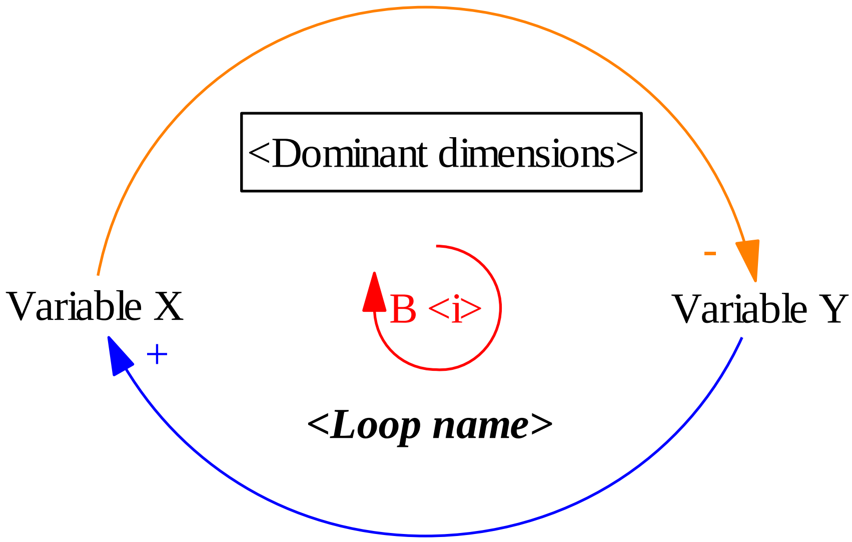


Figure 7-2 Coding used for presenting sub-loops

The dominant dimensions were placed in a box to differentiate them from the loop name easily. The dimension analysis carried out for ascertaining the dominant dimension in particular feedbacks included three steps (Appendix D):

1. Assigning a vulnerability dimension to each independent variable in the feedback loop. Vulnerability can be driven by social, political, economic, physical or technological factors (already defined in 5.2.3).

2. Counting the number of variable categories for each loop.

3. Defining the loop based on the variable category with the highest count.

Categorising variables in this way simplifies reality, but the advantage is that it indicates the overall nature of vulnerability and therefore is useful for deriving a broader picture of system dynamics.

The types of the feedback loops are balancing and reinforcing, represented as B<i> and R<i> respectively. The red colour is used for balancing loops, and blue is chosen for reinforcing loops. The clockwise or counter-clockwise directionality represents the direction of feedback in the loop. In this representation, <i> is the number of balancing or reinforcing loops.

The loop name is presented in bold and italics font. The loops were named to justify the story presented in that feedback loop. The advantage of providing a loop name is that it offers identity to different loops and simplifies the interrogation process.

Note: As discussed in Chapter 6, the causal links are of orange colour with an orange (-) sign for negative polarity and blue colour with a blue (+) sign for positive polarity.

Step 2: Analysis of the feedbacks and vulnerability categories in the identified sub-systems

Each sub-system was analysed separately for an in-depth analysis of the sub-systems (Sections 7.2.1 - 7.7.1). Analysing the feedbacks present in the sub-systems involved studying 1) each loop individually and 2) connections to other feedbacks and important variables. Separately studying the loops assists in deciphering the individual feedback loops and the variable interaction and interconnectedness in the loop. Studying the feedback loop in connection to other loops helped to look at the bigger picture for analysing the behaviour of the sub-system in question, i.e., understanding the system as a 'whole' and not in 'parts'. Understanding the interconnectedness between different feedback loops enables us to identify the key system characteristics (Stroh, 2015) that would otherwise have been missed (Barbrook-Johnson and Penn, 2022). Therefore, it was found instrumental to both 1) study the feedback loops individually, and 2) zoom out of individual feedbacks, and observe how they interact with other variables and feedbacks. Sometimes, a tree diagram was used to explain the impact of a particular variable on other variables. The tree diagrams are used chiefly for variables exogenous to the feedback loops. These variables are crucial to understanding the system's behaviour and are therefore, discussed below in some instances.

After feedback loops were defined, categories of vulnerability were identified and analysed. Vulnerability categories were already assigned (Appendix D) to the variables while labelling the loops to ascertain dominant dimensions. Assigning the social, political, economic, physical and technology dimensions to the variables showed that these variables are intertwined, and the Kosi Basin system is complex with different vulnerability categories at play. These vulnerability categories are often studied in isolation, and their relationship is usually neglected. However, it is pertinent to understand the presence of these vulnerability categories to ascertain the directions in which the actions to provide sustainable flood risk management solutions are required. Therefore, an analysis of vulnerability categories present in the sub-systems was carried out for each sub-system (Sections 7.2.2 - 7.7.2).

Step 3: Abstraction of key characteristics of the Kosi Basin system

This step presents key system characteristics derived from the analysis of the sub-systems (Section 7.8). These key findings are instrumental in identifying the drivers of vulnerability in the Kosi Basin, which are discussed in detail later in Section 9.2.1.

7.2. Non-monsoon embankment sub-system interrogation

The non-monsoon embankment sub-system comprises the landless people who have permanently moved to the embankment from within the embankments or waterlogged areas after facing the worse effects of flooding (either surface water flooding or groundwater flooding). This community comprised people who started settling there after the Kosi embankments were built, and their houses were destroyed during flooding. Their houses were either washed away or surrounded by water, and these landless people were unable to claim the rehabilitation land and decided to settle permanently on the embankment. The feedback-only causal loop diagram for the non-monsoon embankment sub-system has eight feedback loops (Figure 7-3), five reinforcing and three balancing loops. The detailed analysis of the feedback loops is presented in Section 7.2.1, followed by an analysis of vulnerability categories identified in the non-monsoon embankment sub-system (Section 7.2.2).

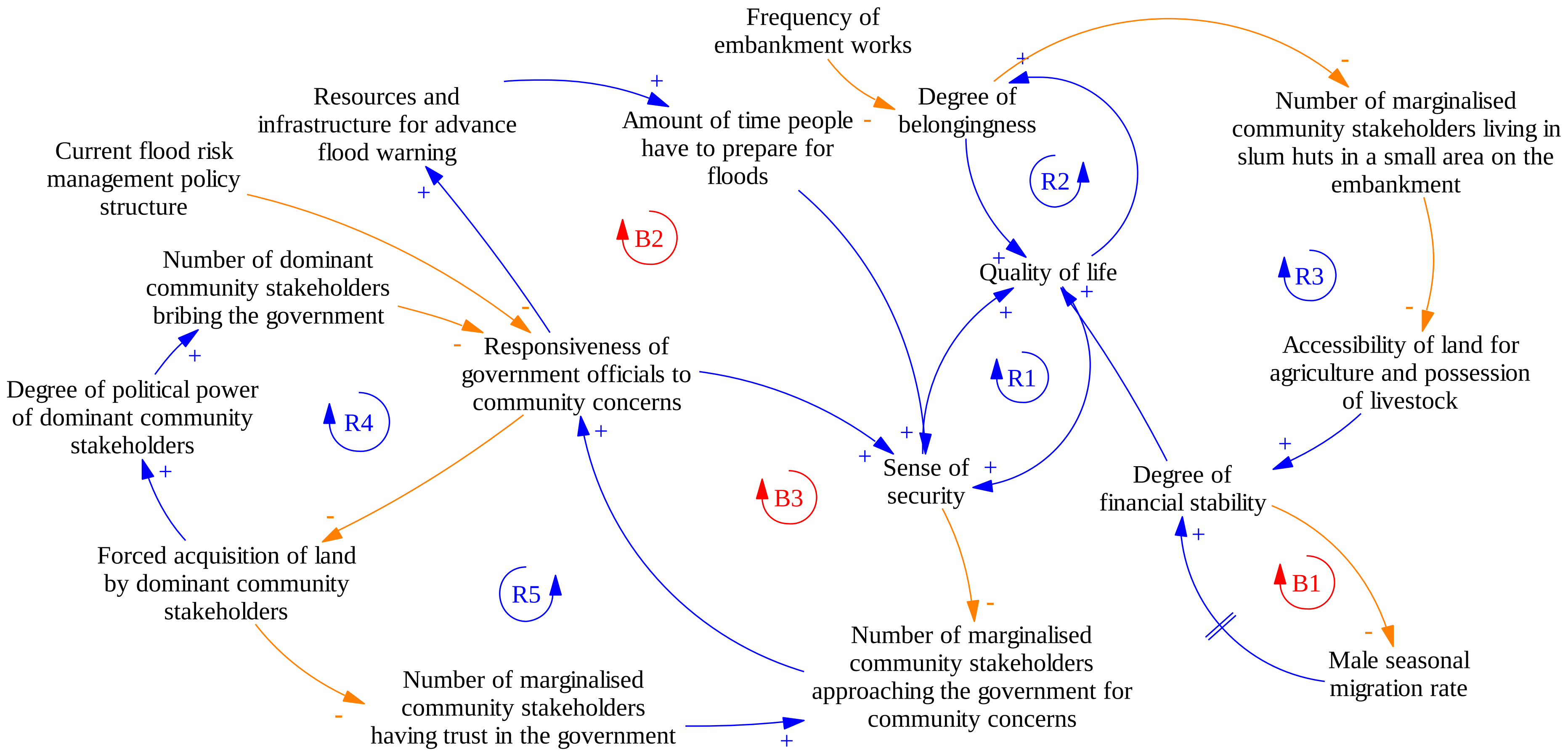


Figure 7-3 Feedback-only causal loop diagram for non-monsoon embankment sub-system

7.2.1. Analysis of feedback loops in the non-monsoon embankment sub-system

7.2.1.1. Security (R1) and belongingness (R2) feedback loops

The security (R1) and belongingness (R2) loops are present in all sub-systems depicting the impact on the community's quality of life. The security feedback loop comprises the sense of security and quality of life, and the belongingness feedback loop consists of the degree of belongingness and quality of life. While they seem small, they are central to the system's dynamics and impacted by other associated variables. These feedback loops are present in all the other system diagrams and are, therefore, fundamental to the dynamics of the Kosi Basin across all temporal phases. The behaviour of the security and belongingness loops is described below but is not replicated in subsequent sections of this chapter to avoid repetition.

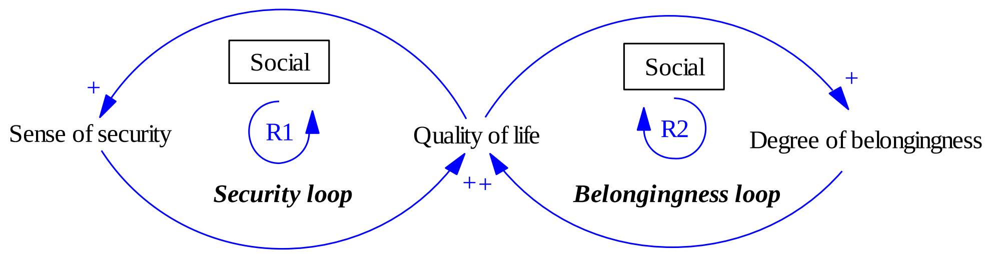


Figure 7-4 Security and belongingness feedback loops

In the non-monsoon embankment sub-system, the sense of security and the degree of belongingness depend on the embankment communities' quality of life. For example, if the embankment communities feel secure living on the embankment, their quality of life will improve, subsequently increasing their degree of belongingness. The variable quality of life is the central, most crucial variable in this causal loop because it shows how the life of the people in the embankment community is affected by the Kosi Basin socio-environmental system.

7.2.1.2. Male seasonal migration loop (B1)

The male seasonal migration loop (B1) (Figure 7-5) is a balancing loop in all the sub-systems. It also is presented only once here to avoid repeated descriptions. A number of men migrate to other cities/states all over India due to their low degree of financial stability. The flooding problems of the Kosi basin have rendered the people living in the floodplain areas of Kosi economically weak. Having no or few work opportunities, these communities formed a culture of men migrating to other places searching for work. This migration of men helps the communities to improve their socio-economic status. However, there is a time lag due to which these communities are only able to fulfil basic necessities. Therefore, the earnings from the male seasonal migration rate are not equivalent to the income that the job opportunities destroyed by flooding in the Kosi Basin could have provided.

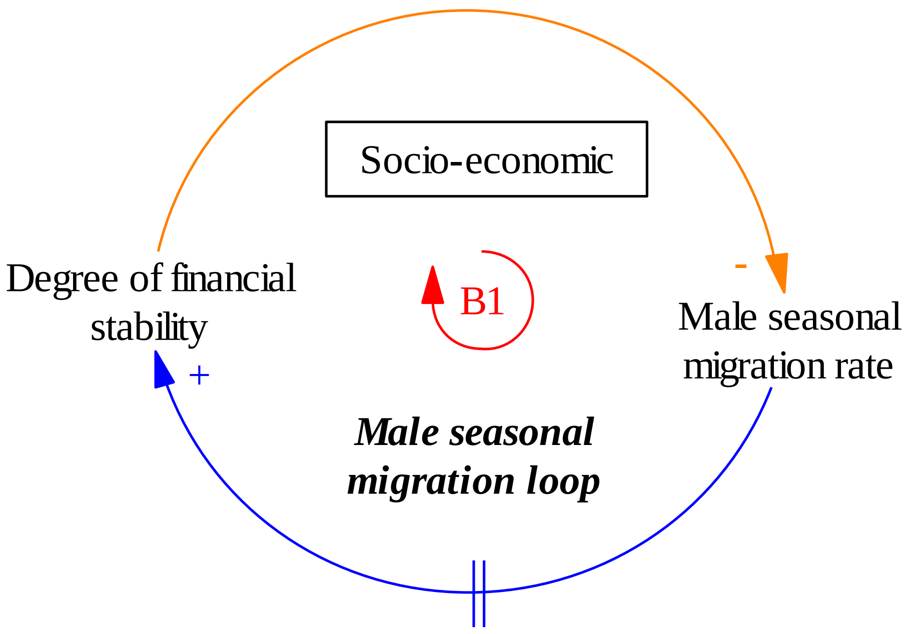


Figure 7-5 Male seasonal migration loop

7.2.1.3. Livelihood impact loop (R3)

The livelihood impact loop (Figure 7-6) is highly impacted by the exogenous variable frequency of embankment works – depicting outside decisions being made for the people by the engineers. The degree of belongingness of the embankment community has become low as a result of frequent embankment works and the physical disruption this entailed. These people live in slum huts in small areas on the embankment and do not have access to land for agriculture or keeping livestock. The geomorphology mainly restricts the area as the Kosi west embankment is surrounded by Kosi River water on the east and on the west by Gehua River water. This limited livelihood opportunity and loss of ancestral land led to a decrease in their degree of financial stability, ultimate lowering their quality of life.

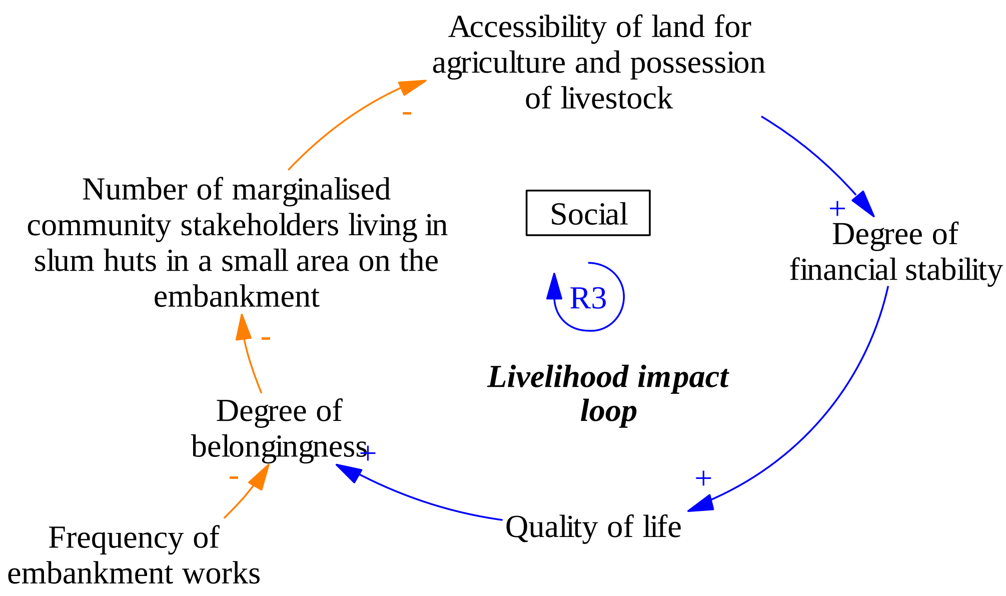


Figure 7-6 Livelihood impact loop

This loop suggests that the livelihood of the communities can be drastically improved if the agricultural lands are easily accessible to them. However, the accessibility of land for agriculture is highly restricted by the area's geomorphology as the Kosi west embankment is surrounded by water on both sides. Due to the meandering nature of the Kosi River and flooding during the monsoon season, the flooding of crops is highly probable, rendering the marginalised community members financially unstable and resulting in a lower quality of life.

7.2.1.4. Impact of power politics on the marginalised embankment community stakeholders

The political power (R4), land dispute (B1) and community trust (R5) loops are all connected, as shown in Figure 7-7. The connections between these loops demonstrate how the power politics in the area negatively impacts the sense of security of the marginalised community stakeholders. The dominant community stakeholders predominantly consist of Zamindars, and there is a dimension of elitism and exploitation. The caste dimension was already discussed in Section 5.2.3; an overview of the caste system was provided in Box 4-1.

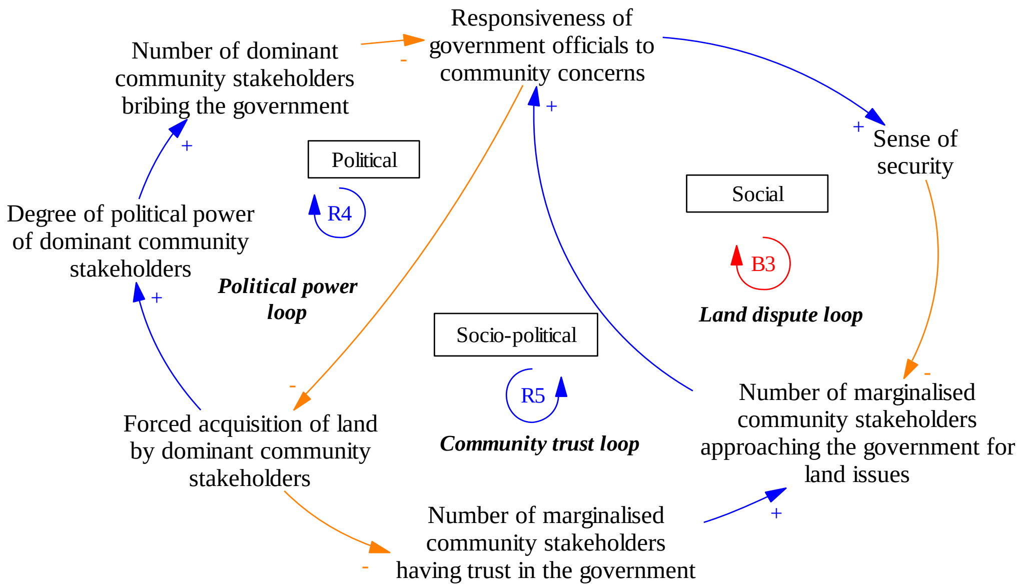


Figure 7-7 Impact of power politics on the marginalised embankment community stakeholders

The loops are discussed separately below to 1) determine the influence of key variables in each loop and 2) analyse the interconnectedness between the three feedback loops. The land dispute loop (Figure 7-8) is a core loop which identifies that responsiveness of government officials to the number of marginalised community stakeholders approaching the government for land issues is the key driver for increasing the sense of security of the embankment community. However, the current responsiveness of government officials is low, and the embankment community lacks a sense of security. This low responsiveness is due to the influence of the political power loop (Figure 7-9), which has diffused the otherwise balancing effect of the land dispute loop.

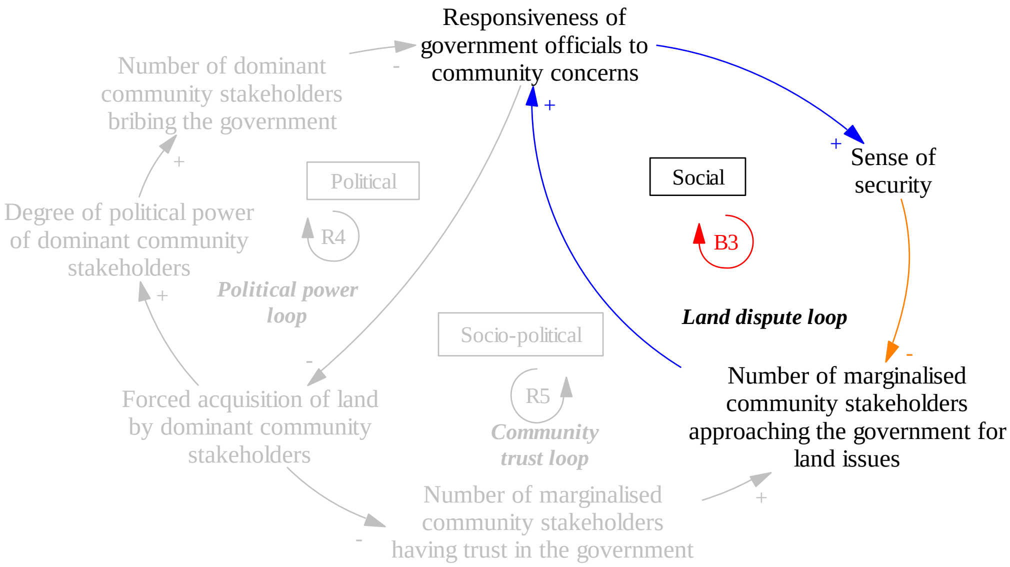


Figure 7-8 Land dispute loop

The political power loop (Figure 7-9) is a crucial loop that negatively impacts government officials' responsiveness to community concerns. With a high degree of political power, these dominant community stakeholders are able to bribe the government to sway the current responsiveness of government officials to community concerns to their benefit. Therefore, the number of forced acquisitions increases, providing positive feedback to the political power of dominant community stakeholders. The loop suggests a stronghold of power politics based on caste dynamics in the Kosi Basin area, which suppresses the sense of security of the marginalised community stakeholders. Therefore, R4 is a negatively reinforcing loop.

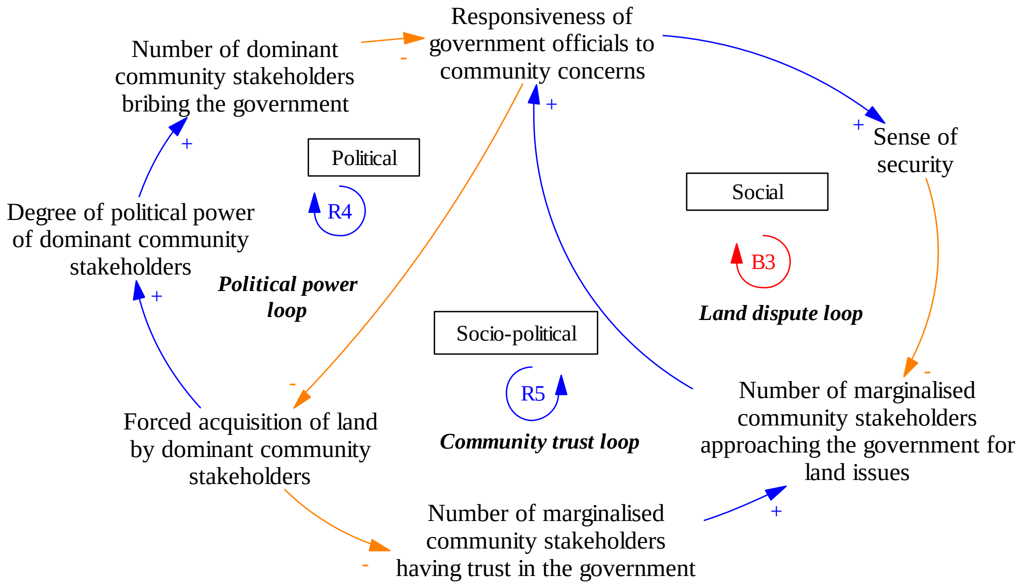


Figure 7-9 Political power loop

Moreover, with an increase in forced acquisitions, the trust of marginalised community stakeholders in the government decreases (Figure 7-10). With a low level of trust in the government, the number of marginalised community stakeholders approaching the government also decreases. With fewer people reaching the government with land issues, the government's responsiveness is also low. Therefore, the forced land acquisition by dominant community stakeholders results in no/low degree of trust in the government by marginalised community stakeholders, making R5 a negatively reinforcing loop.

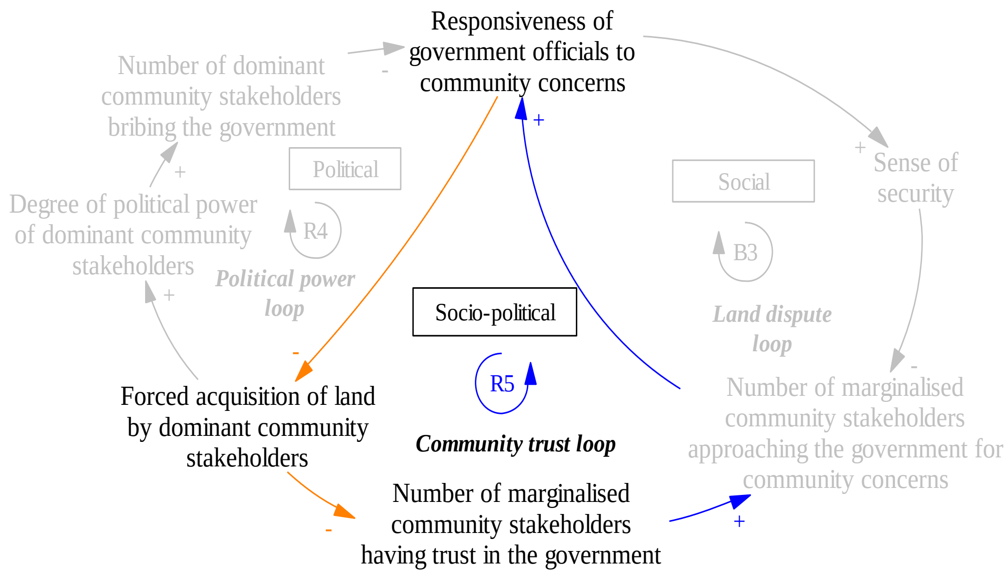


Figure 7-10 Community trust loop

Both the community trust (R5) and political power (R4) loops are negatively reinforcing loops influencing the land dispute (B1) balancing loop negatively, which lowers the sense of security of the embankment community.

7.2.1.5. Advance flood warning (B2) loop

The advance flood warning loop B2 (Figure 7-11) also emphasises the benefits of desired responsiveness of government officials to community concerns. Surface water flooding is a common phenomenon in this area, mainly occurring yearly during the monsoon season. Even with such a flooding situation, there is no advance flood warning measure to warn these communities when the water is released from the Kosi Barrage. Community members approach the government with these concerns regarding the absence of an advance flood warning system. However, the responsiveness of government officials is impacted by the current flood risk management policy structure. This policy structure does not provide any advance flood warning system, so people do not have time to prepare themselves for surface water floods. This current situation has lowered their sense of security. However, local communities no longer approach the government with their concerns as trust in government responsiveness has been undermined (Figure 7-10). As such, the otherwise balancing effect of this loop is limited in the current state of the system.

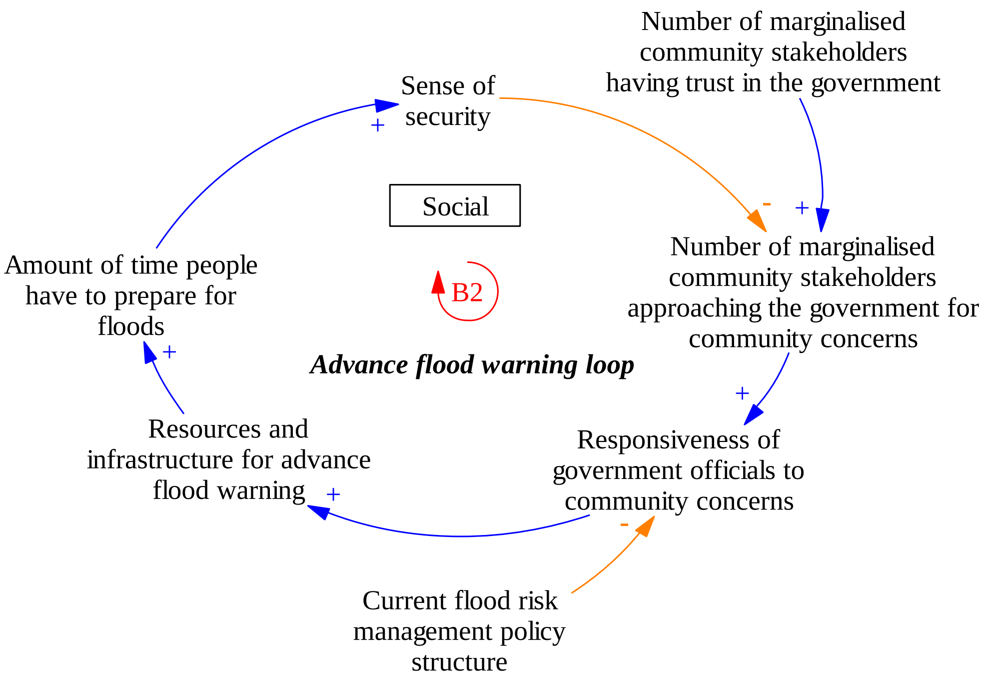


Figure 7-11 Advance flood warning loop

7.2.2. Analysis of vulnerability categories identified in the non-monsoon embankment sub-system

The details of the dominant variable dimensions existing in the reinforcing and balancing loops are presented in Appendix D Table D - 1. The dimensional analysis of reinforcing loops shows that the social category is the most prevalent (= 10), followed by the political category (= 6). This dimensional analysis clearly demonstrates that the social and political categories dominate the reinforcing loops. Moreover, in the balancing loops, the social (= 6) and political (= 2) categories characterise the loops. These two dimensions are followed by the occurrence of technology and economic categories (= 1). Therefore, the dimensional analysis of the non-monsoon feedback loops suggests that this sub-system is governed by the social and political categories.

7.3. Monsoon embankment sub-system interrogation

The monsoon embankment sub-system is a sub-system formed during surface water floods. The two spatial communities temporarily move from within the embankments and the waterlogged area to the Kosi west embankment and stay with the embankment community for the duration of surface floods (usually three months). The sub-system dynamics showcase the vulnerability of these three spatial communities living in temporary housing for three months. The feedback-only causal loop diagram for the monsoon embankment sub-system has fifteen feedback loops, of which fourteen are reinforcing, and one is a balancing loop (Figure 7-12). The detailed analysis of the feedback loops is presented in Section 7.3.1, followed by an analysis of vulnerability categories identified in the monsoon embankment sub-system (Section 7.3.2).

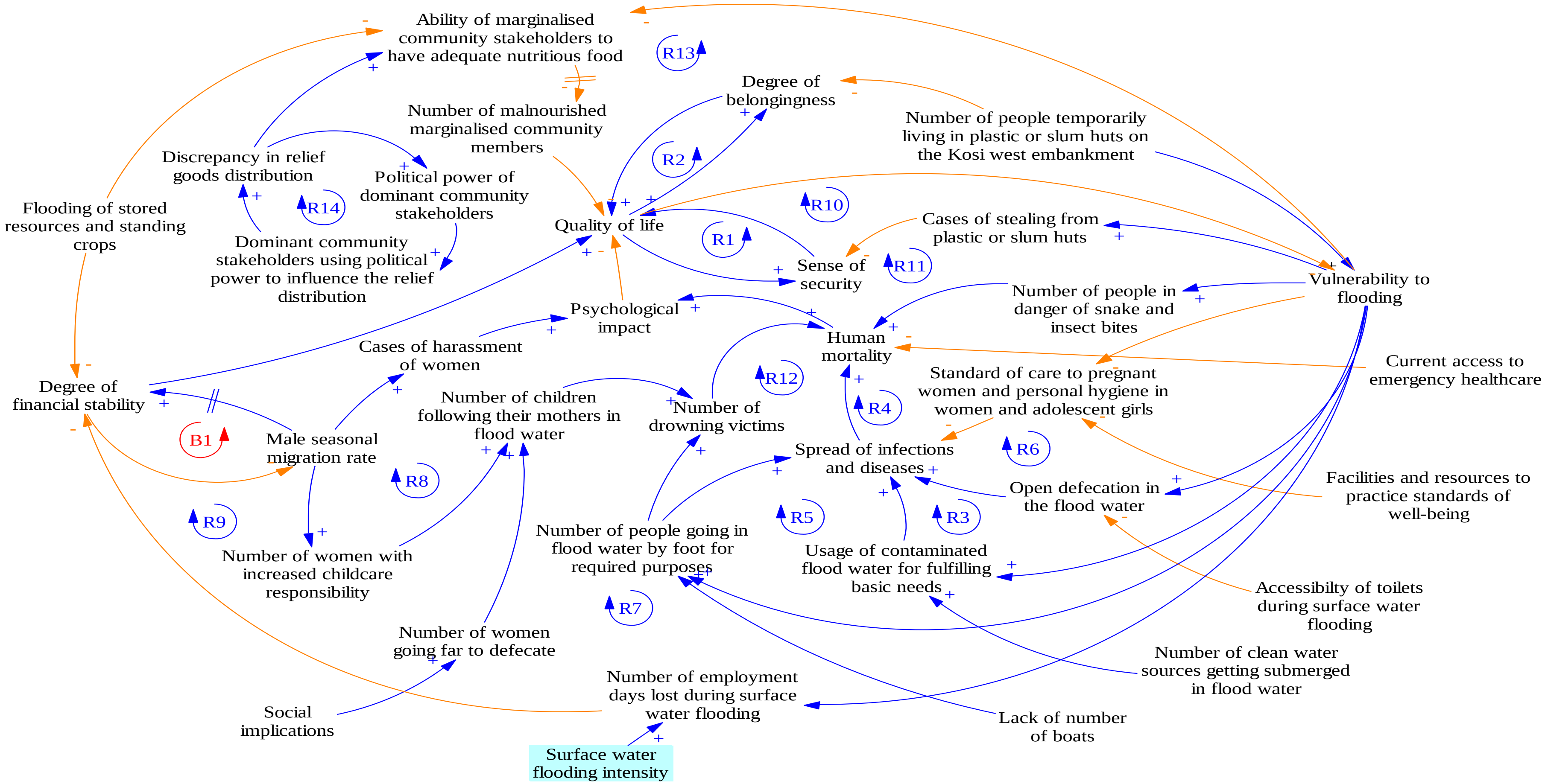


Figure 7-12 Feedback-only causal loop diagram for monsoon embankment sub-system

7.3.1. Analysis of feedback loops in the monsoon embankment sub-system

7.3.1.1. WASH loops- R3, R4, R5 and R6

During the surface water floods, the communities temporarily stay on the west embankment, increasing their vulnerability to flooding. These four feedback loops focus on water, sanitation and hygiene, i.e., WASH (Figure 7-13). R3 is about these community members using contaminated floodwater to fulfil basic needs such as cooking, drinking water, and bathing as the clean water sources get submerged in water. R4 suggests that the standard of care for pregnant women and personal hygiene in women and adolescent girls is low. This situation is also impacted by the lack of facilities and resources available to these women to practice well-being standards. R5 shows that more people go in flood water by foot for required purposes such as collecting resources from home or clean water if the submergence level in that area is low. R6 loop illustrates that the open defecation in the flood water increases because of the lack of toilet facilities. All these actions increase the spread of infections and diseases, which increases human mortality, causing psychological impact. This psychological impact decreases the quality of life, reducing the quality of life. Therefore, R3, R4, R5 and R6 are negative reinforcing loops.

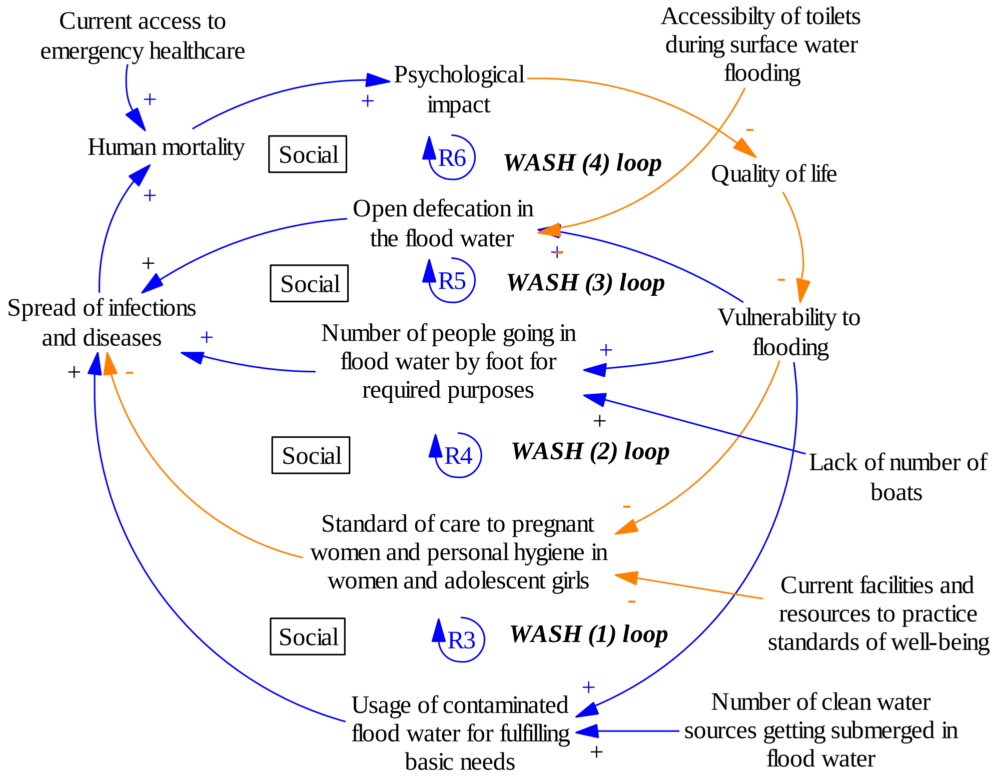


Figure 7-13 WASH loops

7.3.1.2. Male seasonal migration and its impact on women

The feedback loops: loss of livelihood (R7), the impact of male seasonal migration on women (R8), increased childcare responsibility on women (R9), and male seasonal migration (B1) are all connected. These feedbacks show the impact of male seasonal migration on women (Figure 7-14). The interconnectedness shows how the number of employment days lost during surface water flooding leads to male seasonal migration (R7). This male seasonal migration has more disadvantages than advantages as it leads to increased vulnerability in women. Moreover, the only advantage of male seasonal migration is improvement in financial stability, as seen in the male seasonal migration loop (B1), which is affected by the time lag between the male seasonal migration and financial stability. Therefore, the male seasonal migration is unable to provide equivalent financial stability as those are lost due to flooding in the Kosi Basin.

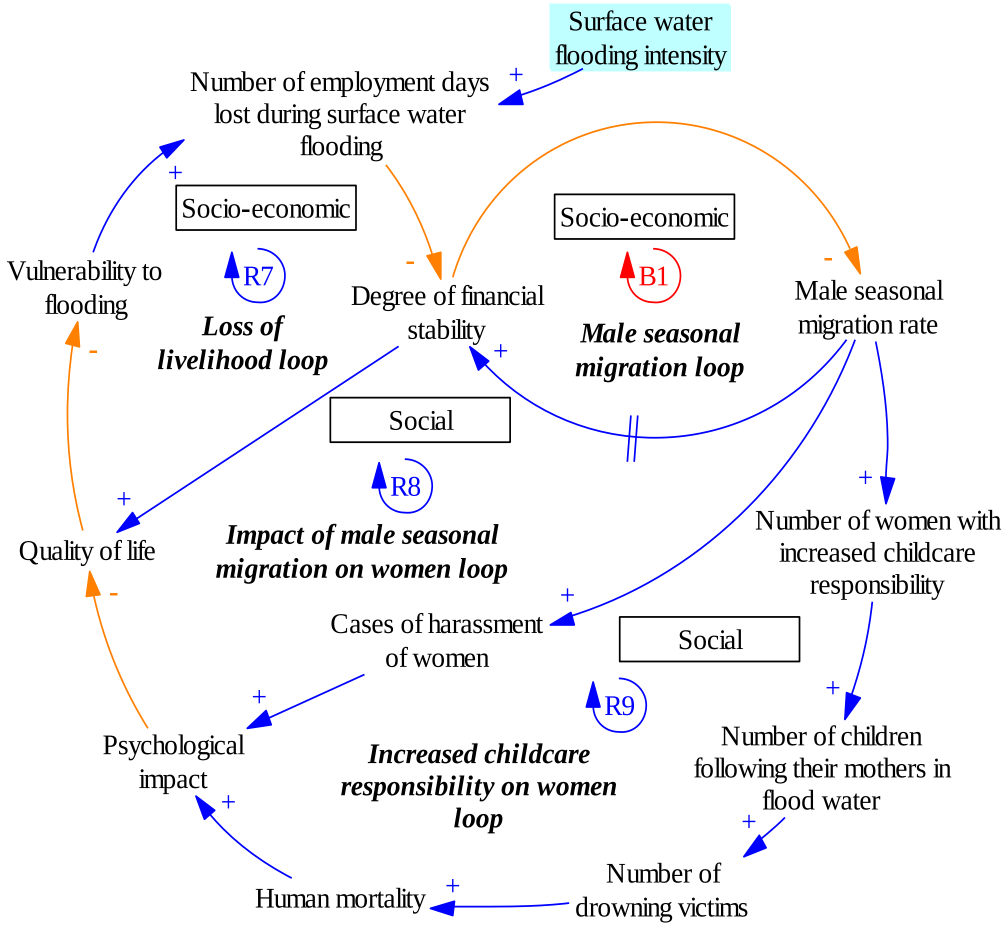


Figure 7-14 Male seasonal migration and its impact on women

The reinforcing loop, the impact of male seasonal migration on women (R8) (Figure 7-15), depicts how the employment days lost influence the male seasonal migration rate, which increases the cases of women harassment during their temporary stay on the Kosi embankment. The increase in harassment increases the psychological impact leading to a lower quality of life for the women. With low quality of life, the women's vulnerability to flooding increases while they live in temporary settlements for the duration of surface water flooding.

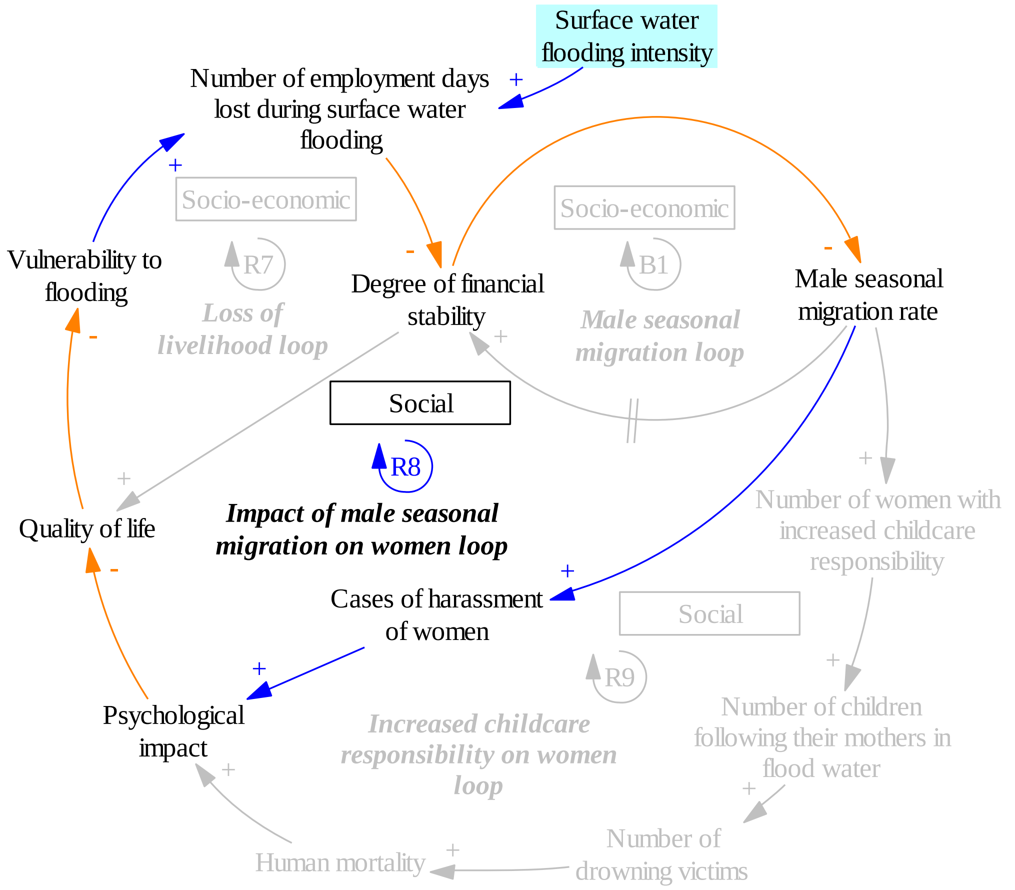


Figure 7-15 Impact of male seasonal migration on women (R8) loop

The reinforcing loop, increased childcare responsibility on women (R9) (Figure 7-16), is another depiction of how women suffer due to the migration of men. The male seasonal migration increases women's responsibilities to look after their children. With the high seasonal migration rate, most women are left behind in the area as the solely responsible parent for looking after their children. Being alone puts a burden on these women even to perform day-to-day activities. Sometimes, when the women go for defecation, their children follow them in floodwater and unfortunately drown, increasing the psychological impact and lowering the quality of life. This situation contributes to a high mortality rate, impacting the community members psychologically and decreasing their quality of life. Low quality of life increases the vulnerability of these community members to flooding.

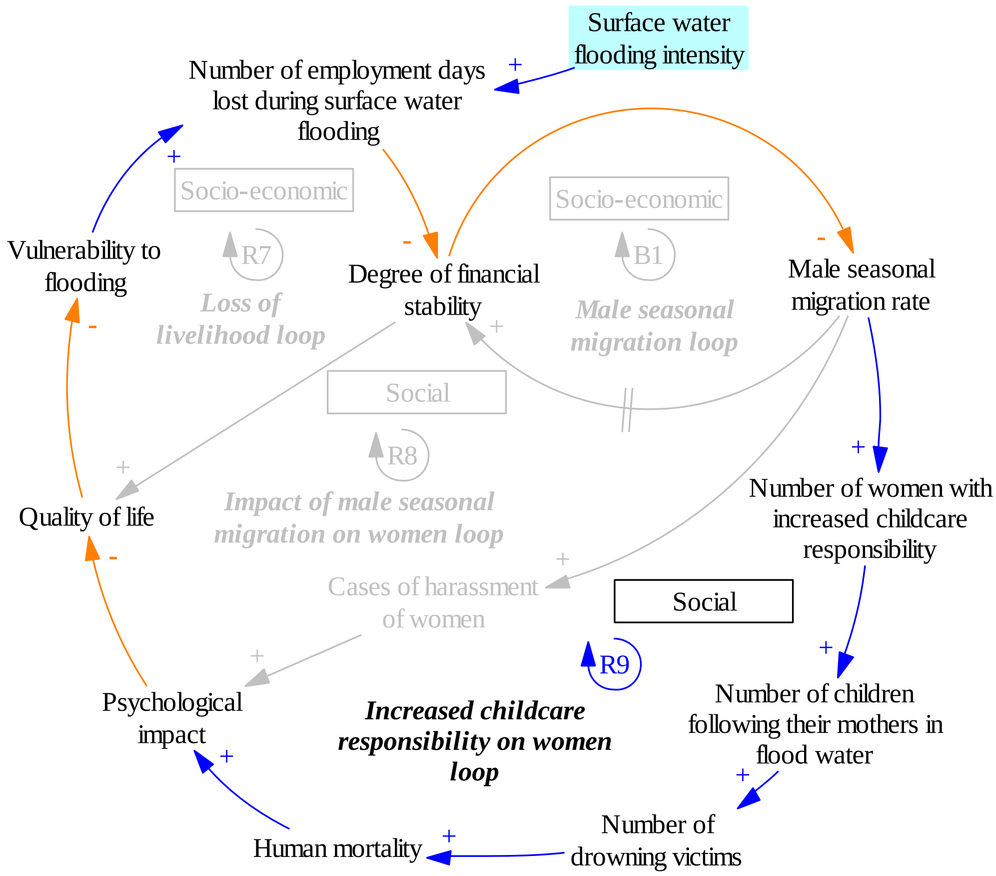


Figure 7-16 Increased childcare responsibility on women (R9) loop

However, even if the vulnerability is decreased, it would not result in fewer employment days lost during surface water flooding because the number of employment days lost strongly depends on the intensity of surface floods. Therefore, even if the vulnerability to flooding is decreased, the number of employment days lost cannot decrease. Only by creating employment opportunities in the area which would not get impacted by the surface water flooding can it result in 1) an improvement in the degree of financial stability and 2) a reduction in the vulnerability of women.

7.3.1.3. Increase in insecurity, snake bite victims and drowning cases

The community members live in plastic or slum huts during their temporary stay on the embankment. This situation increases their vulnerability to flooding. The three loops: Insecurity (R10), Danger to life (R11) and Drowning (R12) (Figure 7-17), showcase how the quality of life is degraded while these community members temporarily stay on the embankment to safeguard themselves from surface water floods.

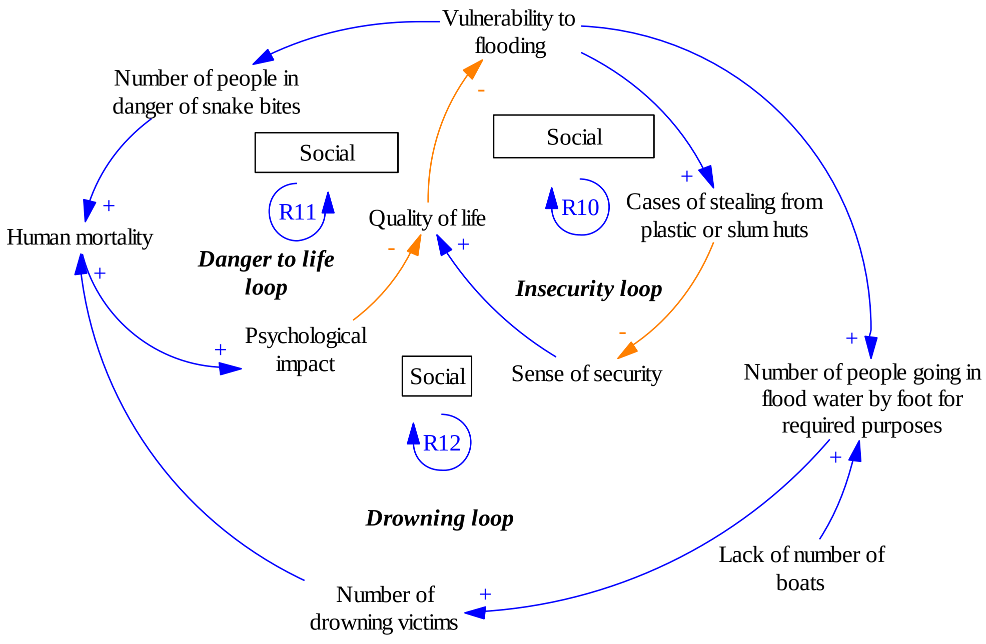


Figure 7-17 Increase in insecurity, snake bite victims and drowning cases

The reinforcing insecurity loop (R10) (Figure 7-18) shows that the increase in vulnerability by staying in the temporary settlement, i.e., the plastic or slum huts increases the number of cases of stealing from these huts. With an increase in the stealing cases, the sense of security decreases, resulting in a low quality of life and further increasing vulnerability. Therefore, R10 is a negatively reinforcing loop.

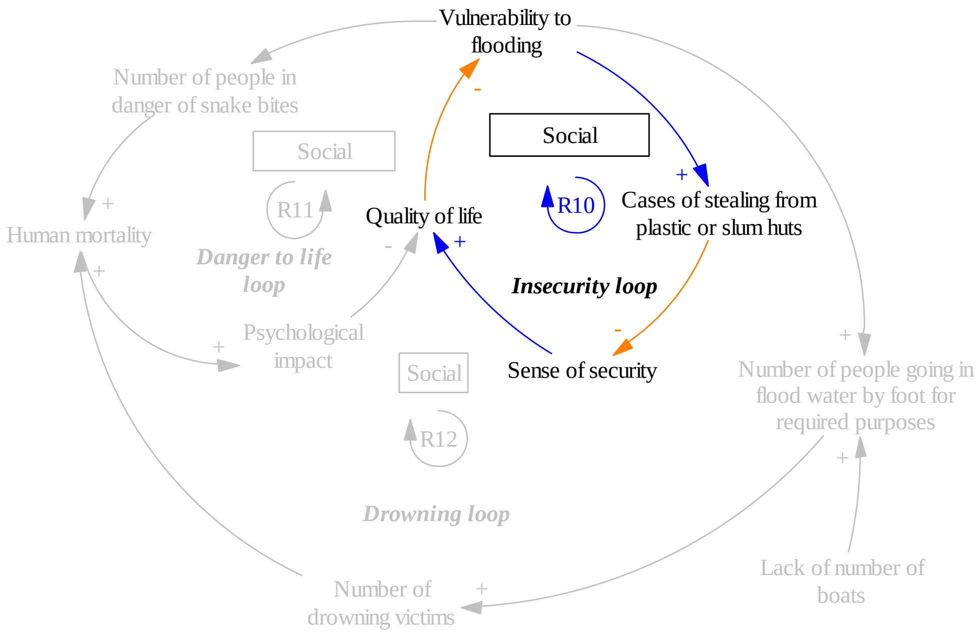


Figure 7-18 Insecurity loop

An increase in vulnerability due to the temporary settlement on the west embankment increases the community members' chance of getting bitten by snakes, as shown in danger to life loop (R11) (Figure 7-19). The snakes come up to the west embankment because their habitats are filled in by water during surface water flooding. This danger poses a risk to life, increasing the human mortality rate. A high mortality rate leads to psychological impact, decreasing the quality of life and hence increasing the community members' vulnerability to floods. Therefore, R11 is also a negatively reinforcing loop.

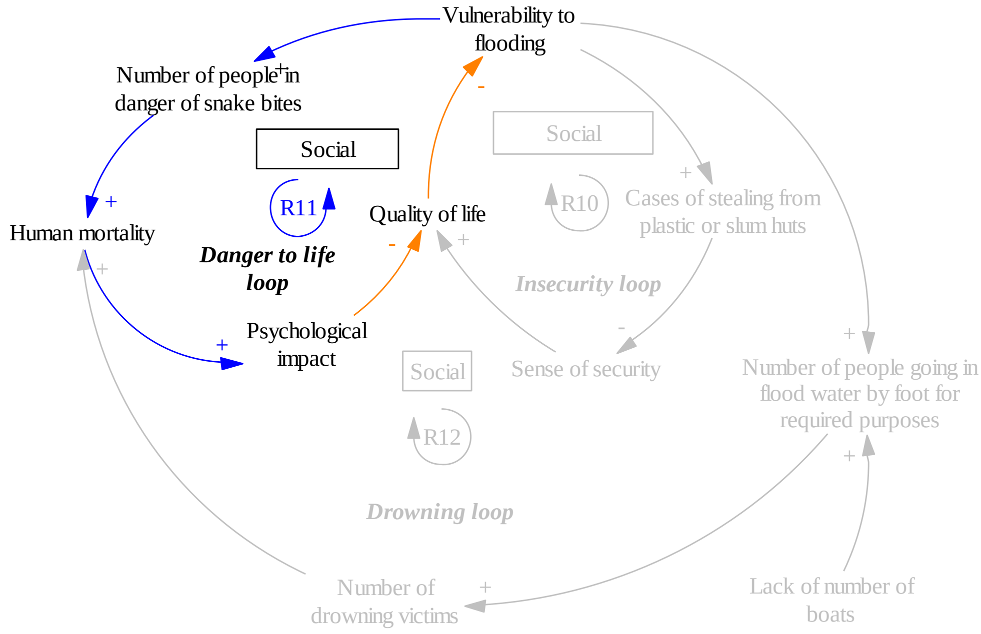


Figure 7-19 Danger to life loop

While living on the embankment increases vulnerability to surface floods. The community members go in the flood water on foot to fulfil required purposes such as collecting clean water if available. Another factor impacting this is the lack of boats. Going in flood water not only causes the spread of infections and diseases, as shown in Wash (3) loop (R5) (Figure 7-13) but also increases the number of drowning cases, as shown in the R12 loop (Figure 7-20). The drowning cases result in an increase in human mortality, negatively impacting the psychological health of the community members. The negative impact on psychological health lowers their quality of life and further increases their vulnerability.

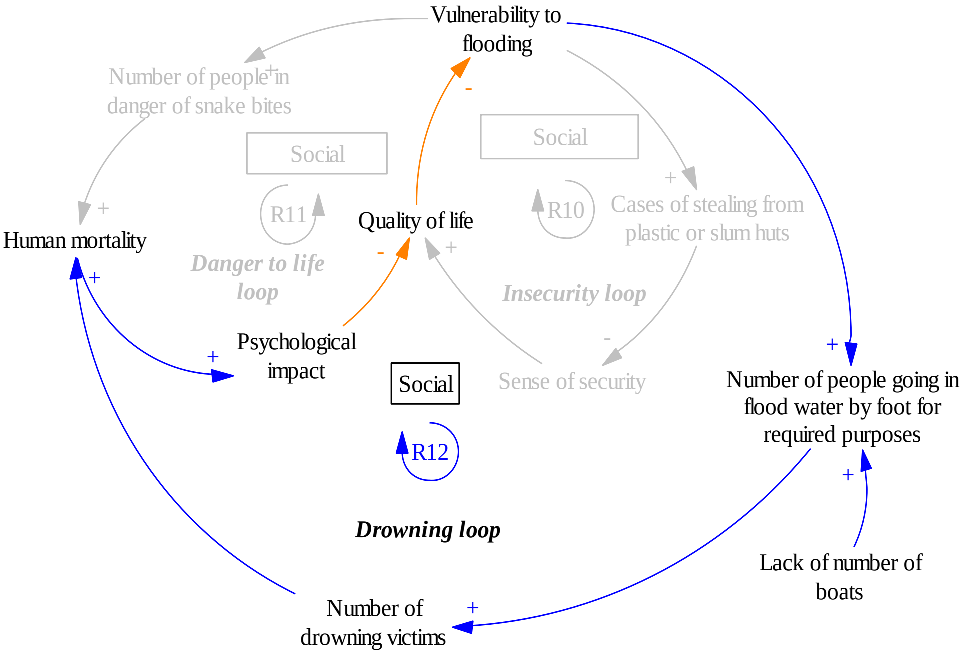


Figure 7-20 Drowning loop

7.3.1.4. Malnourishment in marginalised community stakeholders due to a discrepancy in relief distribution

The malnourishment loop (R13) (Figure 7-21) shows how the increase in vulnerability reduces the ability of malnourished community stakeholders to have adequate nutritious food. The inability leads to malnourishment over time and reduces the quality of life, increasing the vulnerability to flooding. The inability to have adequate nutritious food is highly impacted by the discrepancy in relief distribution (R14) (Figure 7-21). The discrepancy is due to the influence of the political power of the dominant community stakeholders. The discrepancy increases the political power of the dominant community stakeholders, hence increasing the chances of dominant community members using the increased political power next time to influence the relief distribution.

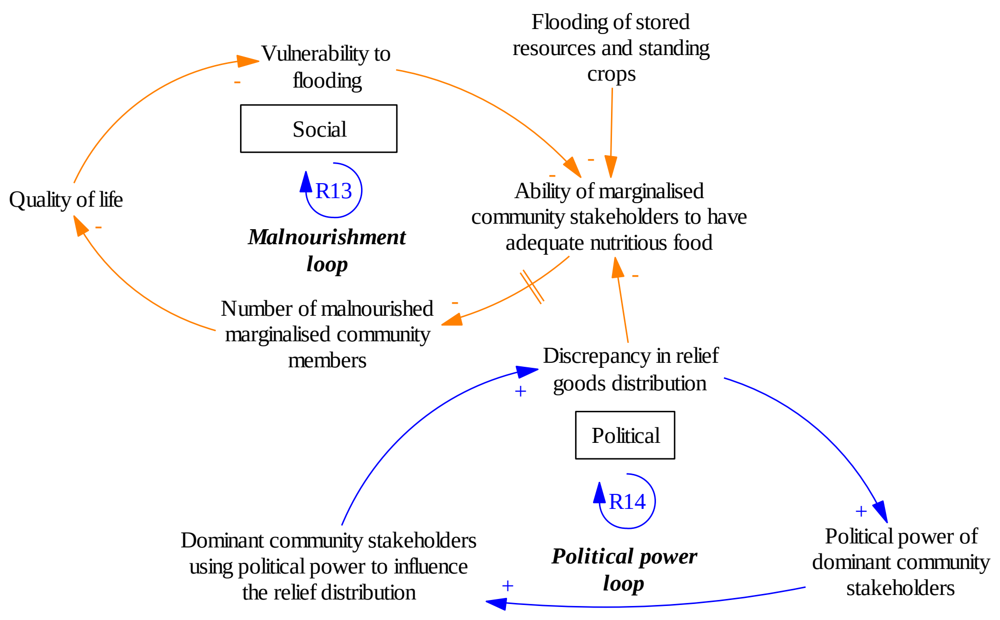


Figure 7-21 Discrepancy in relief distribution

7.3.2. Analysis of vulnerability characteristics identified in the monsoon embankment sub-system

In the monsoon embankment sub-system, the dimensional analysis (Appendix D Table D - 2) shows that the social category (= 58) is dominant in reinforcing loops, followed by economic (= 8), political (= 3), and physical (= 2) categories. In comparison, there is only one balancing loop, i.e., male seasonal migration with social (= 1) and economic (= 1) categories. The reinforcing loops show how the social, economic, political and physical categories negatively reinforce the sub-system. Predominantly, the increase in vulnerability due to temporary settlement and power politics highly impact the lives of the marginalised community stakeholders during the monsoon, and their management is vital for providing stability to the sub-system. The dimensional analysis of the monsoon feedback-only causal loop diagram suggests that this sub-system is government by the social category.

7.4. Non-monsoon within embankments sub-system interrogation

The non-monsoon within embankments sub-system depicts the aftermath of surface water flooding on the lives of community members residing within the embankments. Power politics play a significant role in the sub-system because of the irrigation value of the land. During non-monsoon as the Kosi River brings fertile soil with it during monsoon. Therefore, the dominant community stakeholders try to acquire as much land as possible within the embankments. The feedback-only causal loop diagram for the non-monsoon within embankments sub-system has seven feedback loops, four reinforcing and three balancing loops (Figure 7-22). The sub-system feedbacks are analysed in detail in Section 7.4.1, followed by an analysis of vulnerability categories identified in the sub-system (Section 7.4.2). It is worth mentioning that many of the same dynamics are present in the non-monsoon embankment sub-system (Section 7.2). The land value, i.e., ability to provide economic gains, stimulates both the system dynamics.

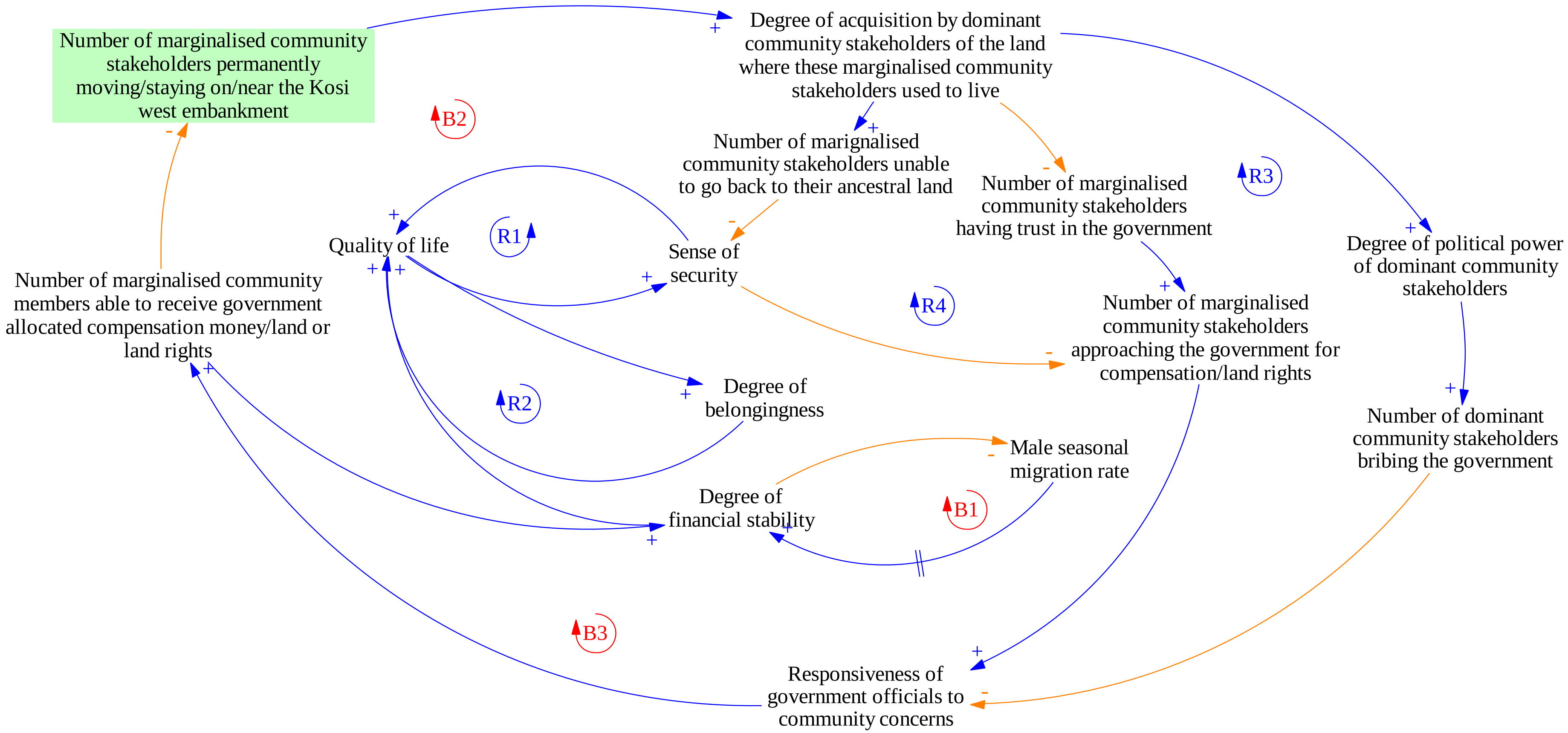


Figure 7-22 Feedback-only causal loop diagram for non-monsoon within embankments sub-system

7.4.1. Analysis of feedback loops in the non-monsoon within embankments sub-system

7.4.1.1. Impact of power politics on the marginalised community stakeholders residing within embankments

The community security (B2), compensation/land rights (B3), bribery (R3), and community trust (R4) loops show the impact of surface water flooding on the lives of the marginalised community stakeholders. After the surface water flooding is over, some people from the marginalised community living within the embankments lose their ancestral land because of the land erosion caused by river flooding. These four loops are presented together because these feedback loops are linked and impact each other. Hence, the loops are studied both collectively and separately. The collective interrogation would help to understand the combined impact of power politics, and separately studying each loop would be crucial in determining the key variables in each loop influencing/getting influenced by the power politics.

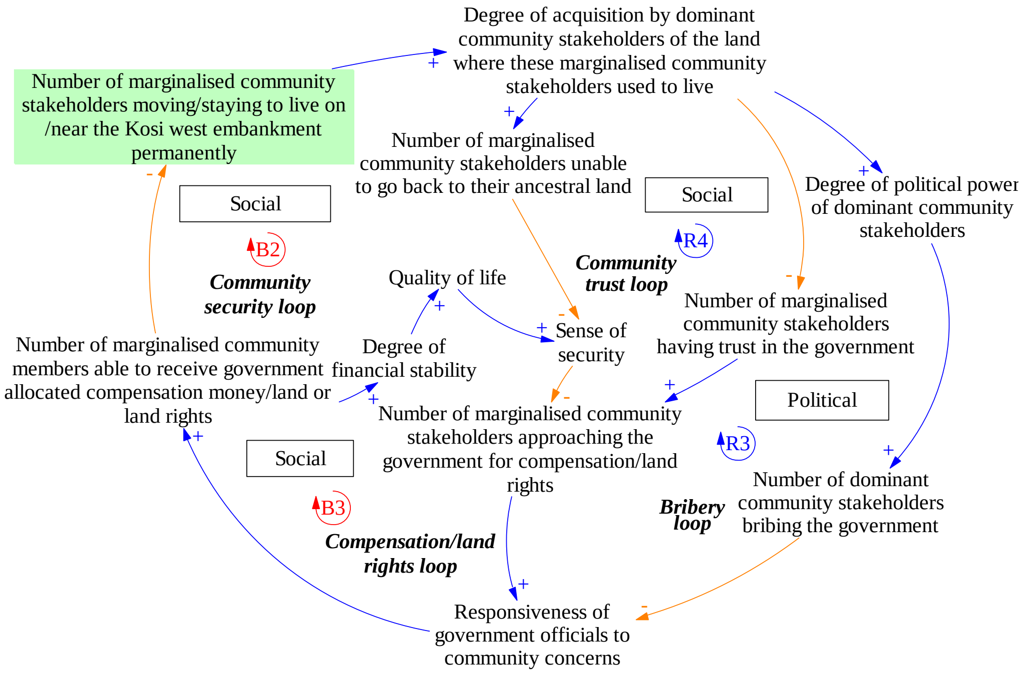


Figure 7-23 Impact of power politics on the marginalised community stakeholders residing within embankments

Compensation loop B3 (Figure 7-24), as seen secluded from the reinforcing loops 1) bribery (R3) and 2) community trust (R4), suggests that as more marginalised community stakeholders approach the government for compensation, the responsiveness of the government officials to community concerns increases. However, the responsiveness of government officials is highly impacted by bribery cases due to the influence of the bribery loop (R3) (page 353). Therefore, the responsiveness becomes low.

With low responsiveness, the marginalised community stakeholders are not able to get compensation money/land. This situation led these marginalised community members to settle on the Kosi embankment permanently. Moreover, without compensation, the degree of financial stability decreases, decreasing their quality of life and sense of security. Therefore, more people should be approaching the government for compensation with a decreased sense of security. However, the community trust loop (R4) (page 354) negatively influences the number of marginalised community stakeholders approaching the government, thus decreasing the number of approaches.

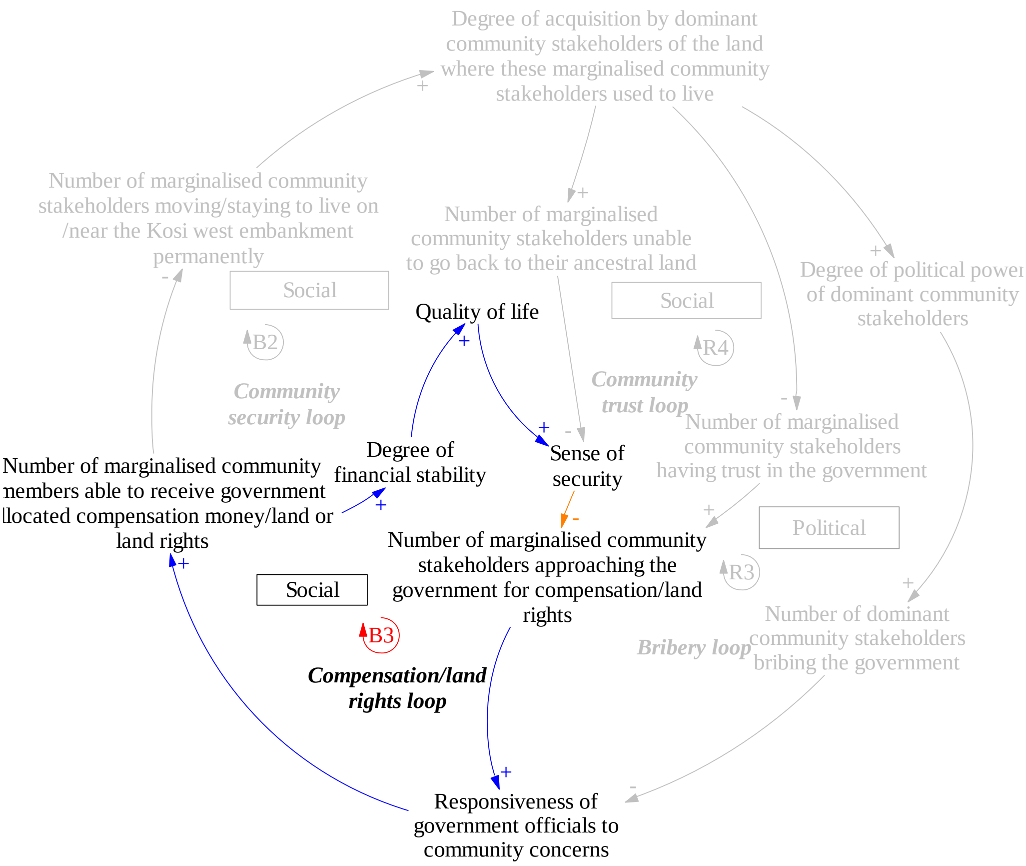


Figure 7-24 Compensation/land rights loop

After the communities are unable to get the allotted compensation money/land, these communities permanently move to the west embankment to live. When these marginalised communities move away from their ancestral lands, dominant community stakeholders acquire their land. The dominant community stakeholders are interested in the land within the embankments because of its suitability for agriculture, as surface water flooding brings fertile soil with it.

The community security loop (Figure 7-25) is an extension of the compensation/land rights loop (B3) (page 351). In the community security (B2) balancing loop, it can be seen that with less marginalised community members able to get compensation money/land, the marginalised community stakeholders move to the Kosi west embankment permanently. After these marginalised community stakeholders move away, the dominant community stakeholders acquire their land. Losing their ancestral land decreases the sense of security of these marginalised community members. A low sense of security should result in more people going to the government with their concerns, but the impact of reinforcing loops, namely community trust R4 (page 354) and bribery loop R3 (page 353) (Figure 7-26), results in fewer marginalised stakeholders approaching the government. The potentially balancing effect of the Compensation/Land rights loop is therefore diffused.

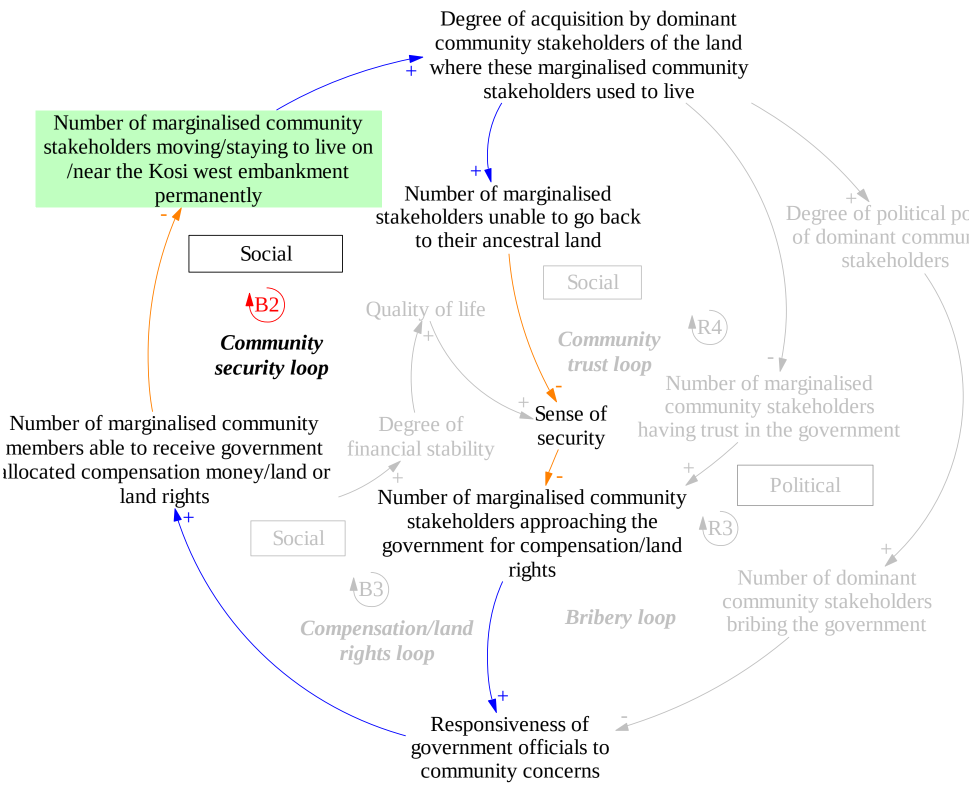


Figure 7-25 Community security loop

As seen in the bribery loop (R3) (Figure 7-26), the land acquisition by dominant community stakeholders consequently increases their political power. Increased political power subsequently increases dominant community stakeholders bribing the government. An increase in bribery cases negatively impacts the responsiveness of government officials to community concerns.

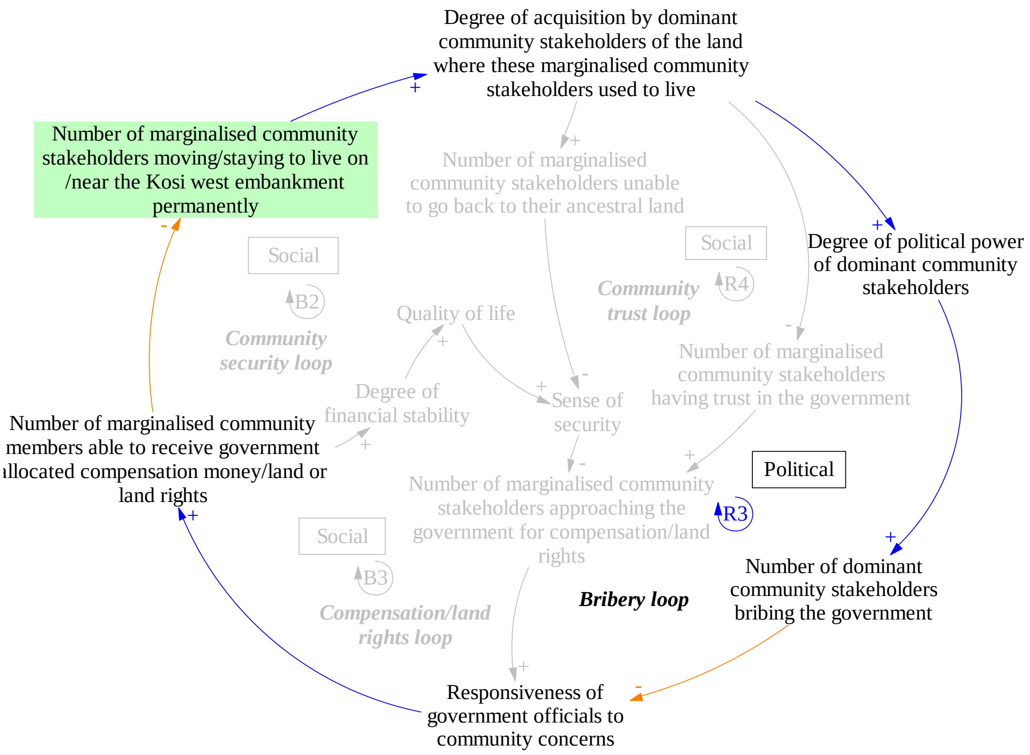


Figure 7-26 Bribery loop

Community trust (R4) (Figure 7-27) is a reinforcing loop that shows how the community's trust has been degraded over the year by the acquisition of ancestral land by dominant community stakeholders, predominantly by the Zamindars, and more marginalised community stakeholders are becoming landless. Land acquisition has decreased the number of marginalised community stakeholders having trust in government. With a low level of trust in the government, fewer people approach the government for compensation/land rights issues. With fewer people approaching, the responsiveness of the government decreases. The decreased responsiveness leads to fewer marginalised stakeholders getting allocated compensation money/land or land right. With no land rights, the marginalised community stakeholders stay on the embankment. Hence, this whole situation leads to more land acquisition by the dominant community stakeholders.

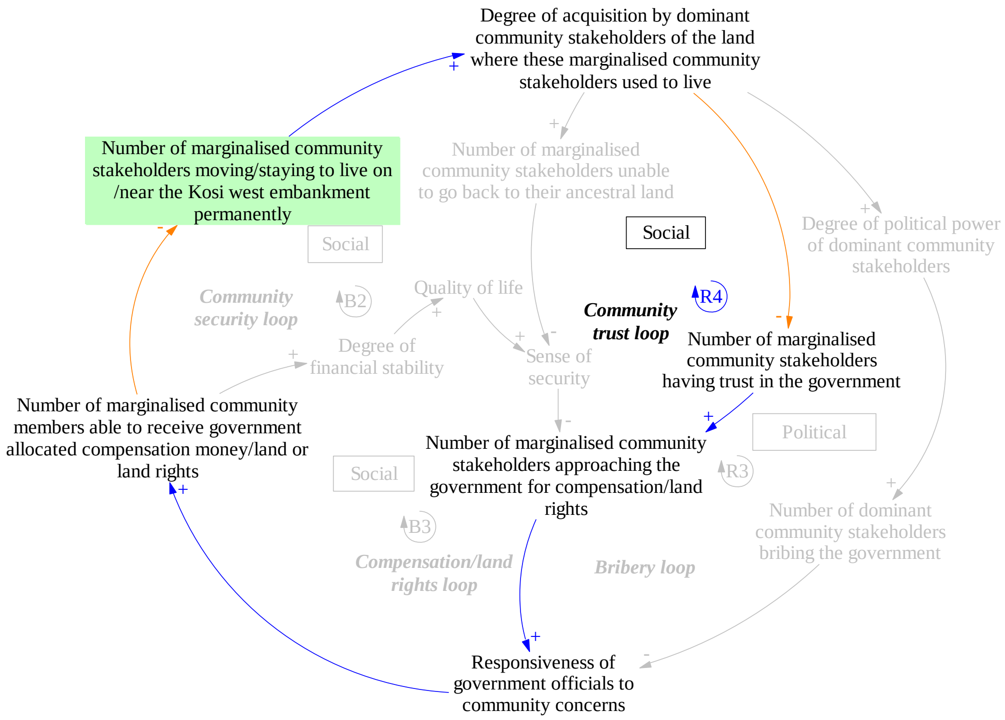


Figure 7-27 Community trust loop

7.4.2. Analysis of vulnerability characteristics identified in the non-monsoon within embankments sub-system

In the non-monsoon within embankments sub-system, the dimensional analysis (Appendix D Table D - 3) shows that the social (= 8) and political (= 6) categories are dominant in the reinforcing feedback loops, followed by the economic category (= 2). Similarly, balancing loops are dominated by social (= 8), economic (= 4), and political (= 3) categories. The dimensional analysis of the non-monsoon within embankments suggests that this sub-system is government by the political, social and economic dimensions. Chiefly how the allocation of the compensation money/land and land acquisition by dominant community stakeholders impact the lives of the marginalised communities during the non-monsoon season.

7.5. Monsoon within embankments sub-system interrogation

The monsoon within the embankment sub-system focuses on the evacuation process, i.e., when the community members temporarily move to the west embankment for the duration of floods. Boats (Figure 7-28) are highly significant to these community members as they aid in evacuation.

Figure 7-28 Boats used for evacuation and transportation

Also, the community members suffer financial losses due to the loss of stored resources and standing crops, and sometimes, their houses get washed away or destroyed. The sub-system also depicts how these losses over the years have led the young men in the Kosi Basin to migrate to other cities for better livelihood opportunities. The feedback-only causal loop diagram for the monsoon within embankments sub-system has five feedback loops, four reinforcing and one balancing loop (Figure 7-29). The details of the feedback loop analysis are presented in Section 7.5.1, followed by an analysis of vulnerability categories identified in the sub-system (Section 7.5.2).

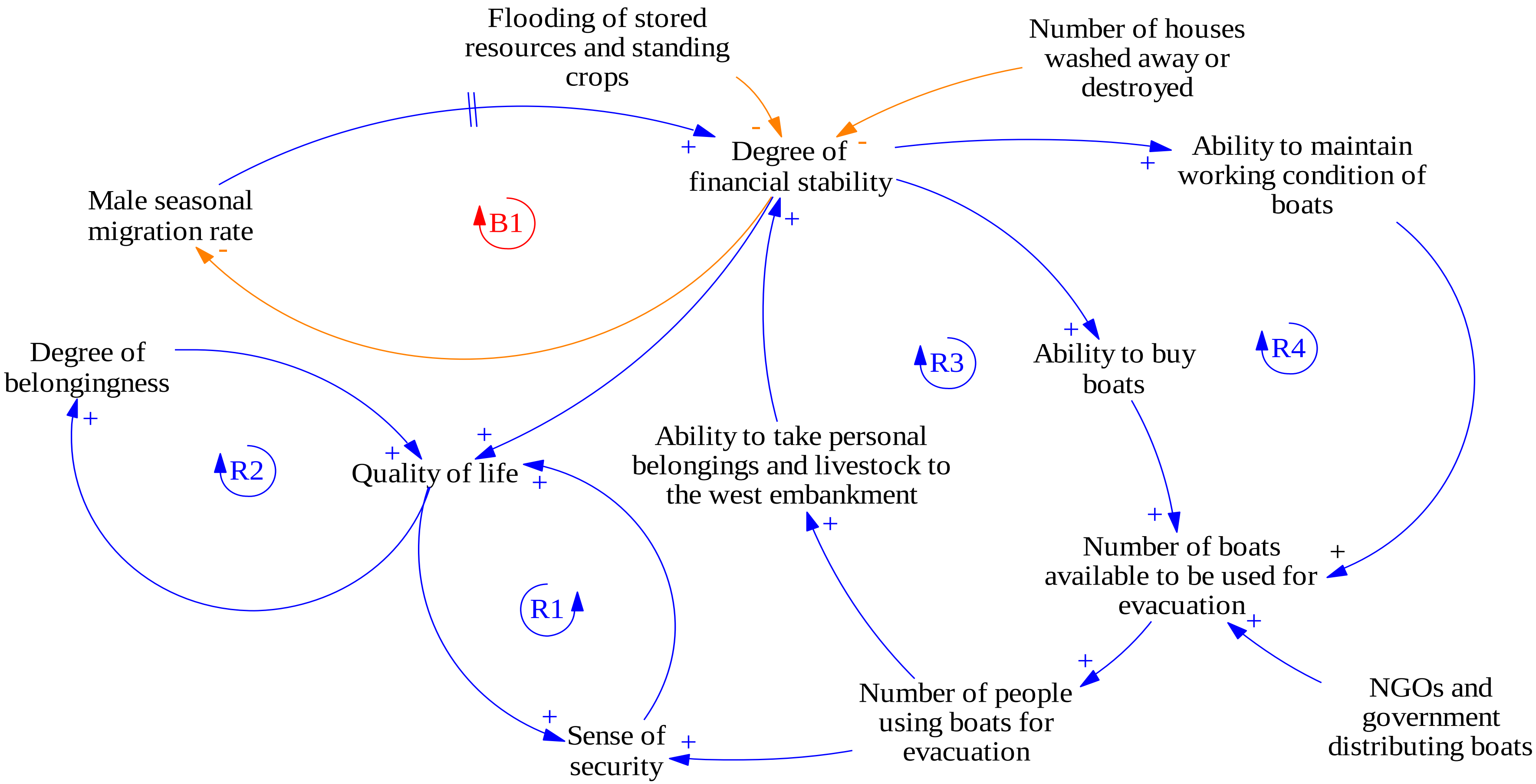


Figure 7-29 Feedback-only causal loop diagram for monsoon within embankments sub-system

7.5.1. Analysis of feedback loops in the monsoon within embankments sub-system

7.5.1.1. Importance of boats during evacuation

During surface water flooding, boats become a necessary means for these community members to evacuate. These community members use boats to reach Kosi west embankment and stay there temporarily for the duration of surface water floods. The loops boat usage (R3), boat maintenance (R4) and male seasonal migration (B1) are the crucial loops to understanding the number of boats available for use during evacuation in the area (Figure 7-30).

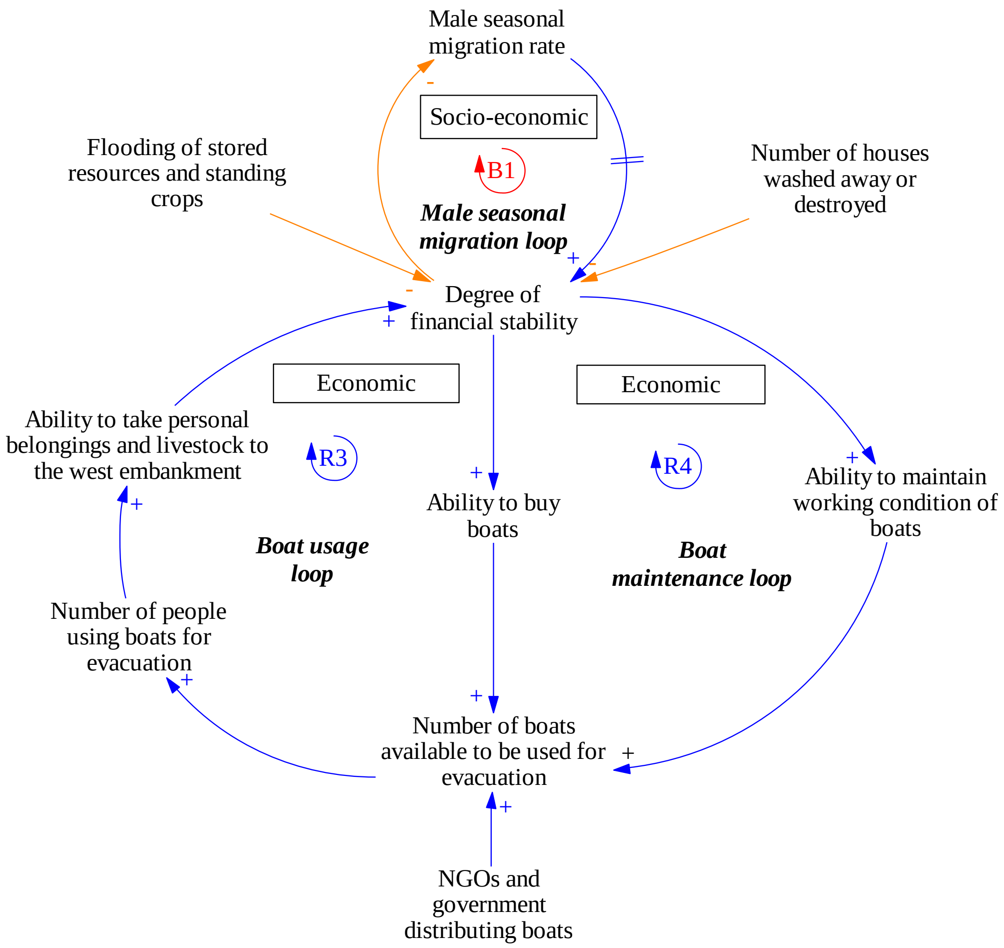


Figure 7-30 Importance of boats during evacuation

The reinforcing loop R3 (Figure 7-31) shows the importance of boats for evacuation during surface water floods. The boats are required to take people, their personal belongings and livestock to the embankment. Taking personal belongings enables these communities to maintain their financial stability to an extent. However, this feedback loop is negatively reinforcing in nature. This negative reinforcement is due to the loss of stored resources and standing crops and also losing their homes to surface water floods. The houses wash away or are destroyed due to the high velocity of Kosi River water. Moreover, the time lag between male seasonal migration and financial stability, as seen in loop B1, impedes income inflow.

Therefore, with low financial stability, the community members do not have enough boats, even though the NGOs and government distribute boats in the area. The reason for this is the marginalised community members' inability to maintain the working condition of boats after buying them or getting them from the government or NGOs, as seen in the boat maintenance loop (R4) (page 361). With fewer boats than required, people swim in the flood water to reach the west embankment, limiting their ability to take personal belongings and livestock with them.

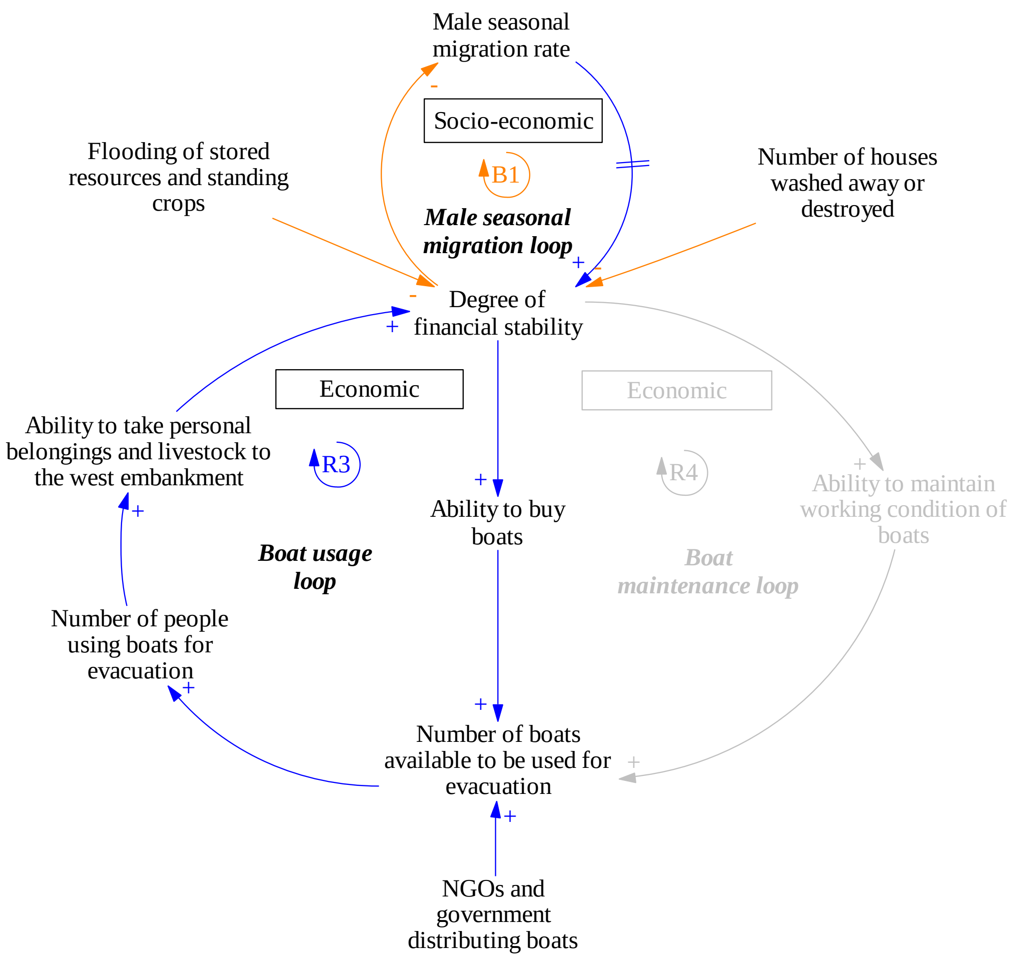


Figure 7-31 Boat usage loop

The boat maintenance loop defines the need to maintain the working condition of boats owned by the community members (Figure 7-32). With losses due to surface water floods, there are limited funds available. The limited finances restrict the communities' ability to maintain the working condition of the boats, limiting the number of boats available for evacuation during floods. Although the NGOs and government provide boats to the community members, with time, the inability of the community members to maintain the working condition of these boats limits the number of boats available in working conditions for evacuation. However, if the ability of the community members to maintain their boats can be enhanced, then more boats for evacuation can be made available.

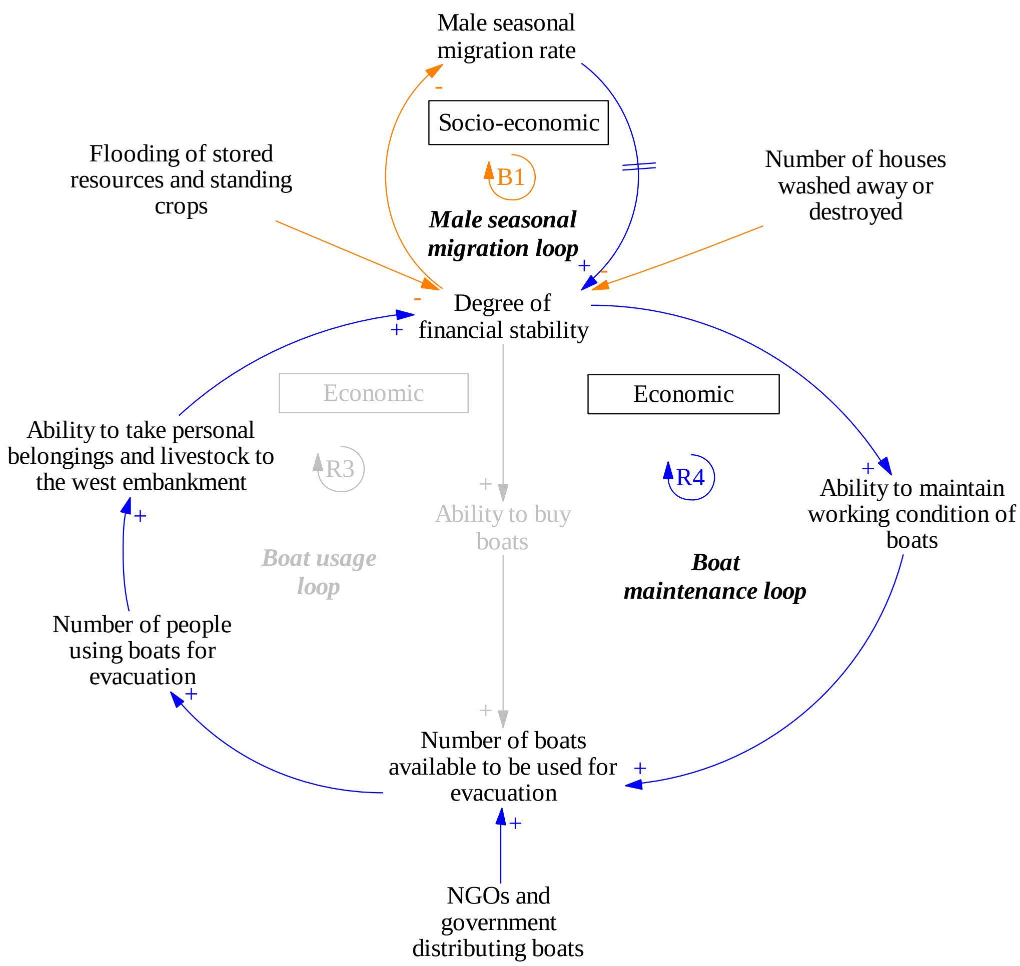


Figure 7-32 Boat maintenance loop

7.5.2. Analysis of vulnerability characteristics identified in the monsoon within embankments sub-system

In the monsoon within embankments sub-system, social and economic categories dominate the reinforcing and balancing loops (Appendix D Table D - 4). In the reinforcing, the economic and social categories appear eight and six times, respectively. In the balancing loops, social and economic categories appear once. This analysis suggests that social and economic categories dominate the feedback loops in the monsoon within embankments sub-system.

7.6. Non-monsoon waterlogged sub-system interrogation

The non-monsoon waterlogged sub-system depicts the interactions between the waterlogged community and waterlogging. During the non-monsoon period, the community suffers from waterlogging, lasting 6-12 months. The leading cause of waterlogging is seepage through the Kosi embankments. This situation disrupts the community's livelihood by limiting agricultural opportunities. The feedback-only causal loop diagram for the non-monsoon waterlogged sub-system has seven feedback loops: six reinforcing and two balancing loops (Figure 7-33). The detailed analysis of the feedback loops is presented in Section 7.6.1, followed by the analysis of vulnerability categories identified in the sub-system (Section 7.6.2).

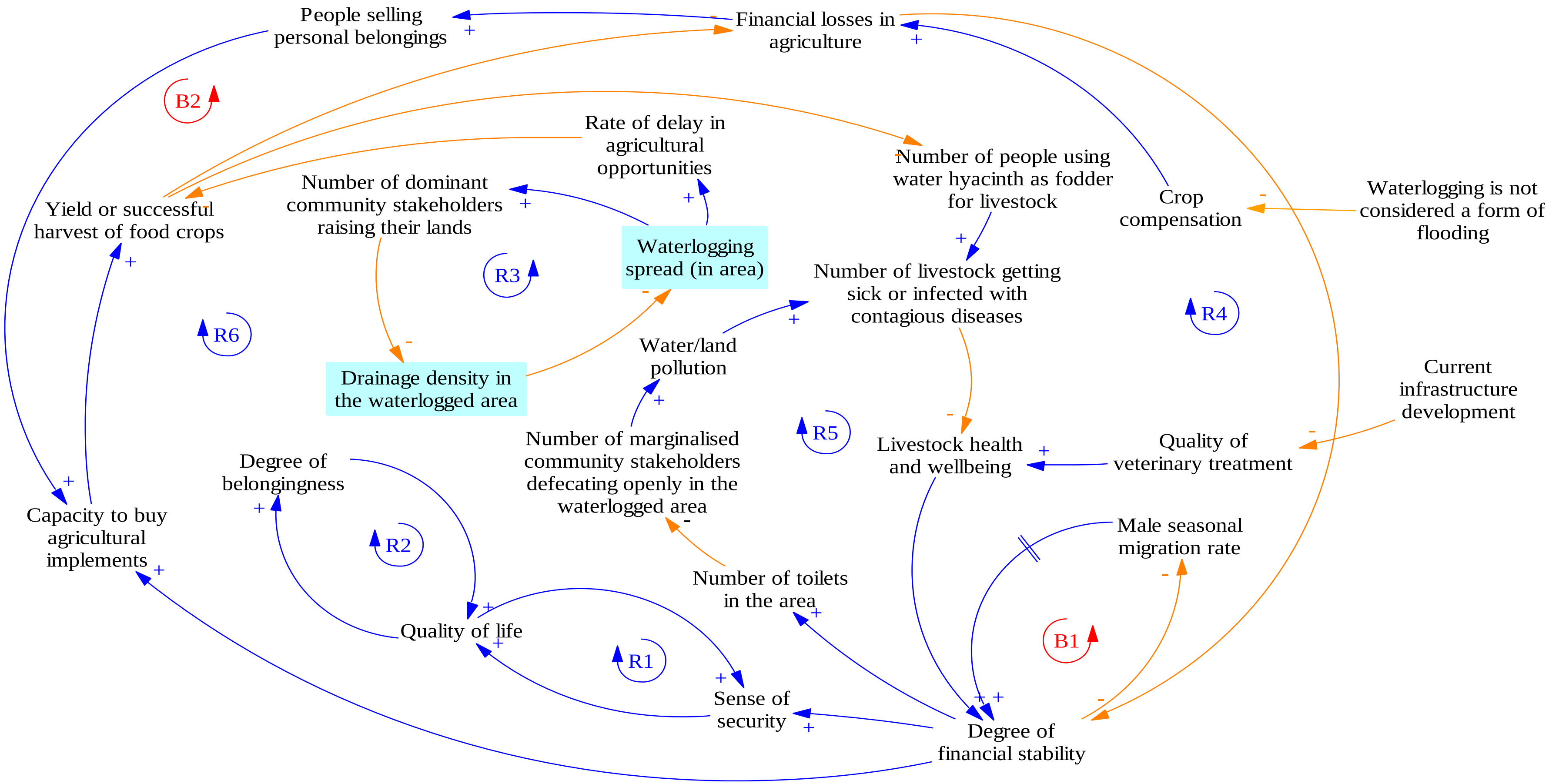


Figure 7-33 Feedback-only causal loop diagram for non-monsoon waterlogged sub-system

7.6.1. Analysis of feedback loops in the non-monsoon waterlogged sub-system

7.6.1.1. Impact on drainage loop

Due to waterlogging, the dominant community stakeholders raise their lands by physically increasing the height of the land. The height is increased by putting more soil to make the base of the house higher than the waterlogging elevation. However, the raising of land makes the land surface unequal in the area. The raised land disrupts the natural flow of water, and the lowered drainage density extends the waterlogging duration (Figure 7-34). Therefore, the lowered areas remain waterlogged for longer and are more vulnerable to flooding.

The construction of canals and railways are significant factors for waterlogging. However, the unplanned raising of land also disturbs the area's natural drainage. Studies carried out in recent times have focused on the impact of agricultural yield, toxic metals, and increase in soil salinity (Aslam et al., 2015, Singh, 2018, Gebrehiwot, 2018). The waterlogging period increases with this impeded drainage, impacting the agricultural activities in the area (Figure 7-34). Also, the stagnant waterlogged area becomes the breeding ground for mosquitoes and other insects, impacting the well-being of the community members and livestock.

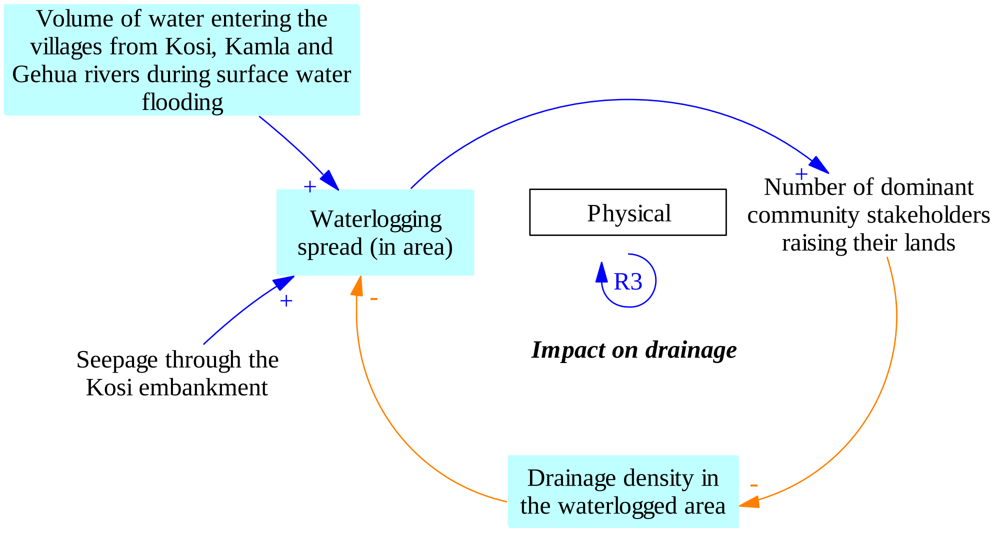


Figure 7-34 Impact on drainage loop

Moreover, the sluice in the east Kamla Balan embankment (located on the west side of the waterlogged area) is uncontrolled, i.e., there is no gate present to control the flow of the Kamla Balan River. When the river exceeds capacity, the river water floods the already waterlogged area, worsening the area's waterlogging (Figure 7-35). There is no provision for proper drainage of this water which has increased the period of waterlogging. It is required to have proper planning to control the sluice gate and provide proper drainage of the Kamla Balan River water.

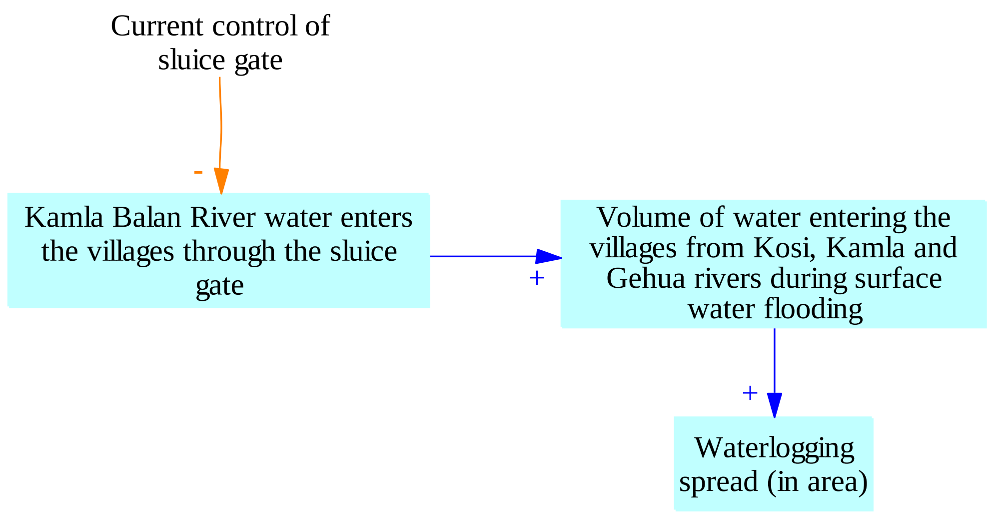


Figure 7-35 Requirement of sluice gate control

Infrastructure development planning should entail geohydrological considerations and drainage outlets to control perennial waterlogging (Pandey et al., 2012). This inclusion would help to increase the agricultural activities in the area, preserving the soil fertility and reducing soil salinisation.

7.6.1.2. Impact of waterlogging on livelihood

The two loops, R4 and B2, are presented together to show the impact of financial losses in agriculture (Figure 7-36). The waterlogging in the area results in delays in agricultural activities, which negatively impacts food crop yield/successful harvest. The impact on agriculture loop (R4) shows how the livelihood of the community members is impacted, and the selling personal belongings loop (B2) shows how these community members have to sell their personal belongings to buy agricultural implements (such as seeds, tools, and manure). Both these loops are explained in detail below.

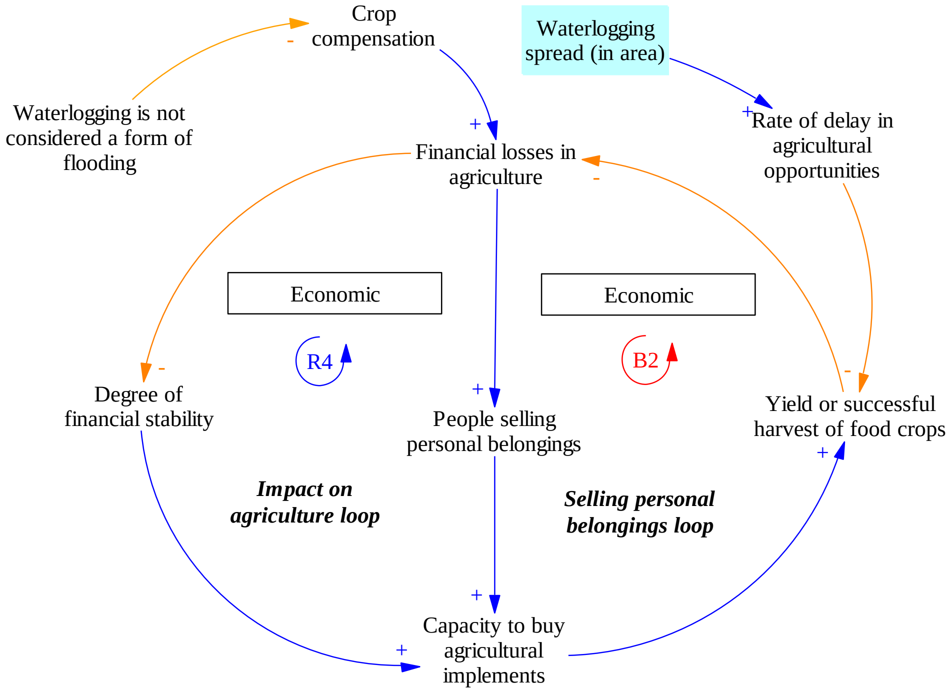


Figure 7-36 Impact of waterlogging on livelihood

The impact on the agriculture loop (R4) shows the impact of waterlogging on agricultural activities in the area (Figure 7-37). The delay in agricultural opportunities due to waterlogging in the area results in a low yield or unsuccessful harvest of food crops, resulting in financial losses. Low financial stability restricts their ability to buy agricultural implements. The yield or successful harvest of food crops decreases with a low capacity to buy agricultural tools.

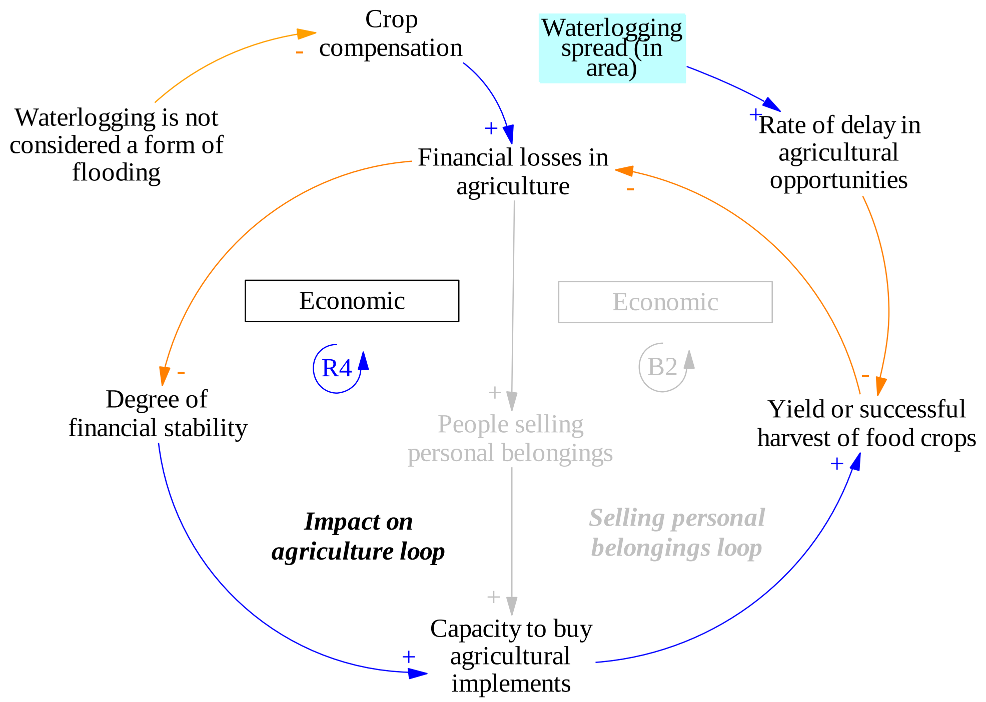


Figure 7-37 Impact on agriculture loop

Due to financial losses in agriculture, the community members sell their personal belongings to improve their capacity to buy agricultural implements, as shown in loop B2 (Figure 7-38). This balancing loop B2 is making the poor community members poorer because selling personal belongings does not ensure fewer financial losses next year. The financial losses depend on the duration for which the waterlogging remains in the area (lasting from 6-12 months). Overall, selling possessions is a maladaptive and unsustainable coping strategy, which only further undermines community resilience to future flood events.

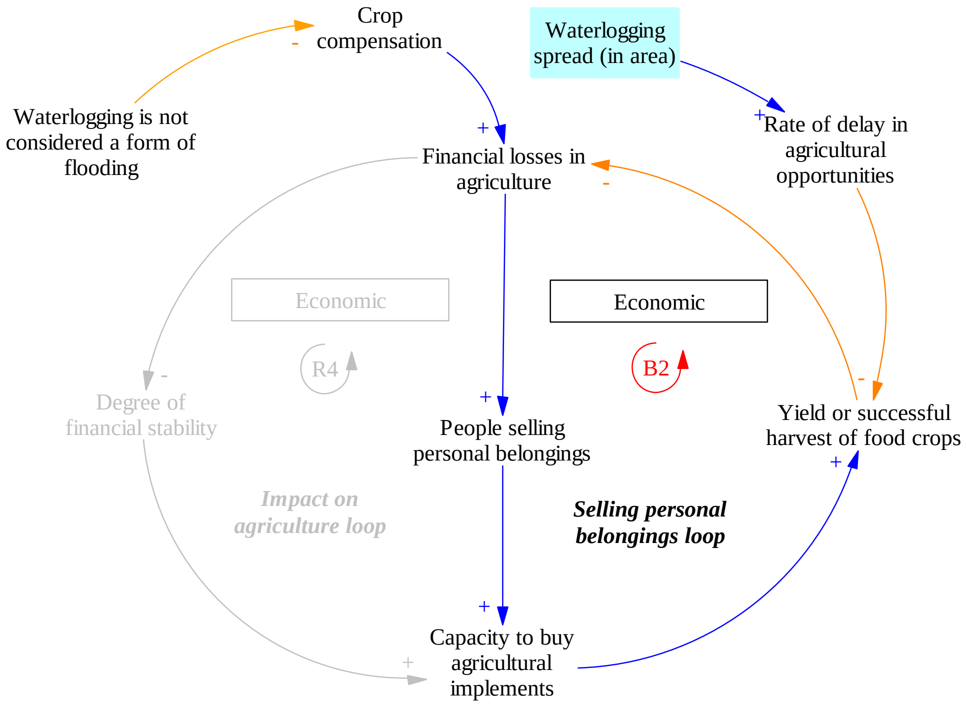


Figure 7-38 Selling personal belonging loop

With crop compensation, the financial losses can be reduced; however, currently, there is no flood compensation, as waterlogging is not considered a form of flooding by the government. If flood risk policies included waterlogging as a form of flooding, crop compensation can be provided to these community members, minimising their financial losses in agriculture and improving the communities' financial stability.

7.6.1.3. Impact of waterlogging on the sanitation and hygiene of the community

The sanitation and hygiene (R5) loop shows the impact of waterlogging on the sanitation and hygiene of the community members (Figure 7-39). Financial losses in agriculture and livestock getting sick negatively impact the degree of financial stability of the community members. Therefore, these community members are unable to build a toilet in their homes.

Therefore, most people openly defecate in the waterlogged area, which causes water/land pollution. With water pollution, livestock falls sick after drinking that water, impacting the health and well-being of the livestock. The polluted water also becomes a breeding ground for mosquitos and other insects, causing diseases in livestock. The illness/death of the livestock impacts the degree of financial stability of the communities.

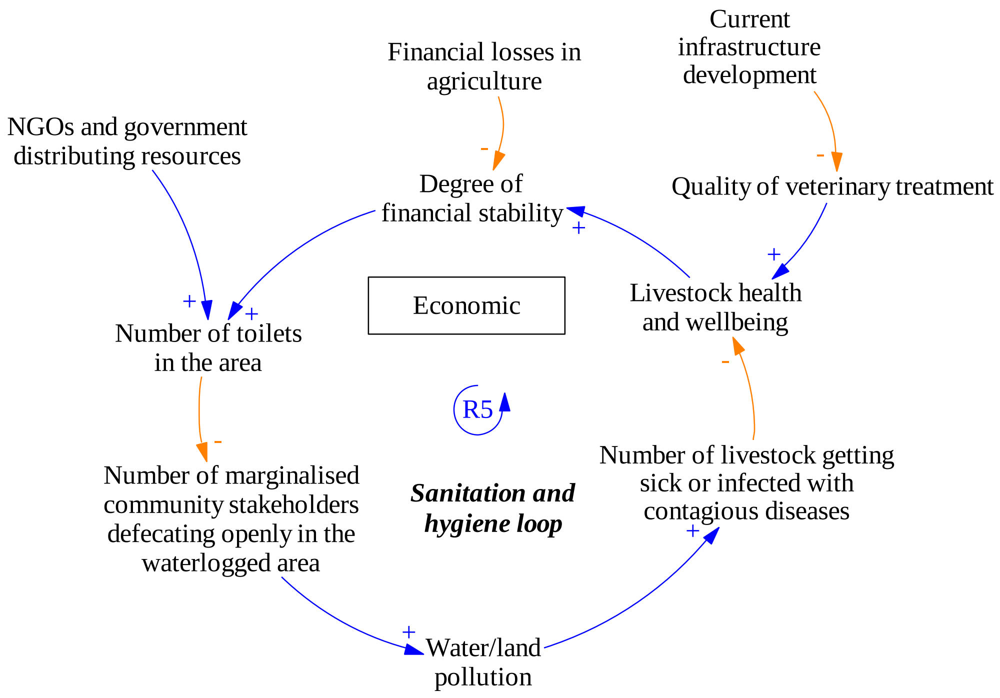


Figure 7-39 Sanitation and hygiene loop

7.6.1.4. Impact of waterlogging on the health and well-being of livestock

Yield or successful harvest of food crops suffers from the delay in agricultural opportunities due to waterlogging, as seen in the hyacinth as fodder (R6) loop (Figure 7-40). The community members use water hyacinths to feed their livestock because of the low yield of food crops, making the livestock sick. The low health and well-being of the livestock negatively impact the communities' degree of financial stability, reducing their capacity to buy agricultural implements. The reduced capacity to buy agricultural implements results in a low yield of food crops. Moreover, there is a lack of veterinary treatment options available to people due to the lack of current infrastructure development in the area. Usually, people have to go to the city to bring medication for the livestock, which is not feasible for most marginalised community stakeholders. Therefore, the death rate of livestock is high in the area, leading to low financial stability for the community members. However, if the quality of veterinary treatment improves, the livestock's health and well-being can be maintained.

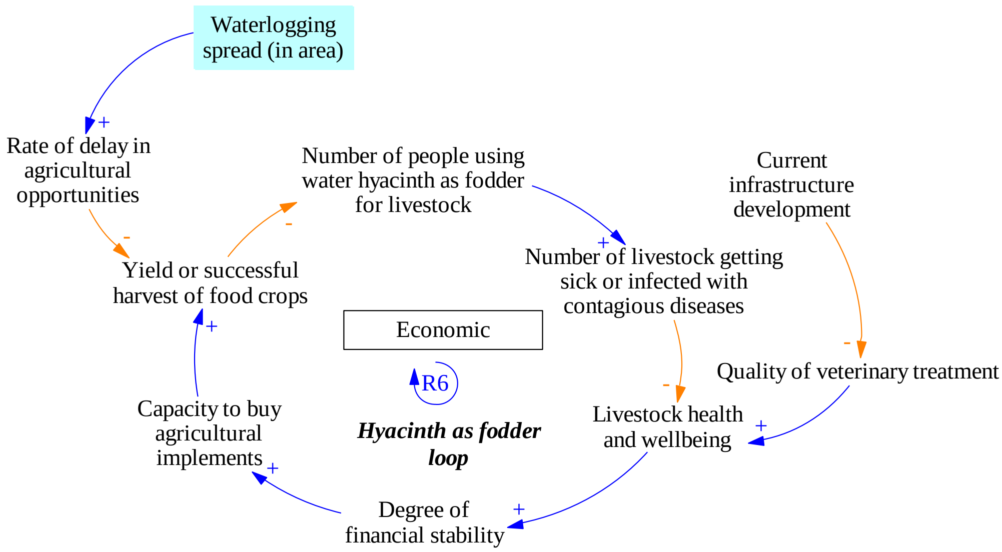


Figure 7-40 Hyacinth as fodder loop

The growth of invasive species such as water hyacinth has severe social and economic impacts on the community members' lives (Figure 7-41). It increases the commute time as it is difficult to row a boat in the water hyacinth. The increase in commute time limits the ability of the community members to reach their workplace. Moreover, it also delays agricultural opportunities because it slows the water evaporation from the waterlogged area. Also, the water hyacinth creates water pollution, negatively impacting the health and well-being of the community members and livestock. Delay in agricultural activities also results in community members using water hyacinth as fodder for livestock (Figure 7-40).

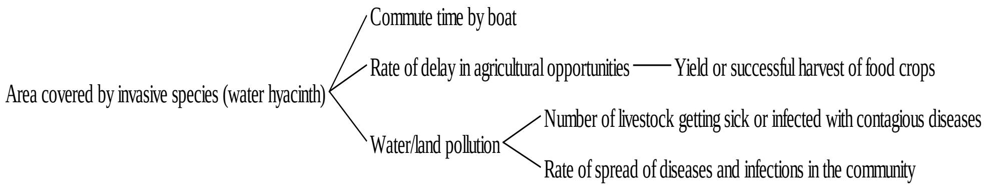


Figure 7-41 Impact of water hyacinth growth

7.6.2. Analysis of vulnerability characteristics identified in the non-monsoon waterlogged sub-system

The dimensional analysis (Appendix D Table D - 5) shows that economic (= 13), social (= 5), and physical (= 5) categories are dominant in the reinforcing loops. In balancing, the economic category (=4) is the most dominant category, followed by the social (=1) and physical (=1) categories. This dimensional analysis suggests that the economic category dominates the non-monsoon sub-system. This finding suggests that the waterlogging in the area highly impacts the financial stability of the community residing in the waterlogged area.

7.7. Monsoon waterlogged sub-system interrogation

The monsoon waterlogged sub-system is similar to the monsoon within embankments sub-system (Section 7.5). Both these communities are evacuating their homes and facing financial losses due to surface water floods. The feedback-only causal loop diagram for the monsoon waterlogged sub-system has five feedback loops: three reinforcing and two balancing loops (Figure 7-42). The key variable identified in this sub-system is crop compensation, discussed in detail in Section 7.7.1, followed by the analysis of vulnerability categories identified in the sub-system (Section 7.7.2).

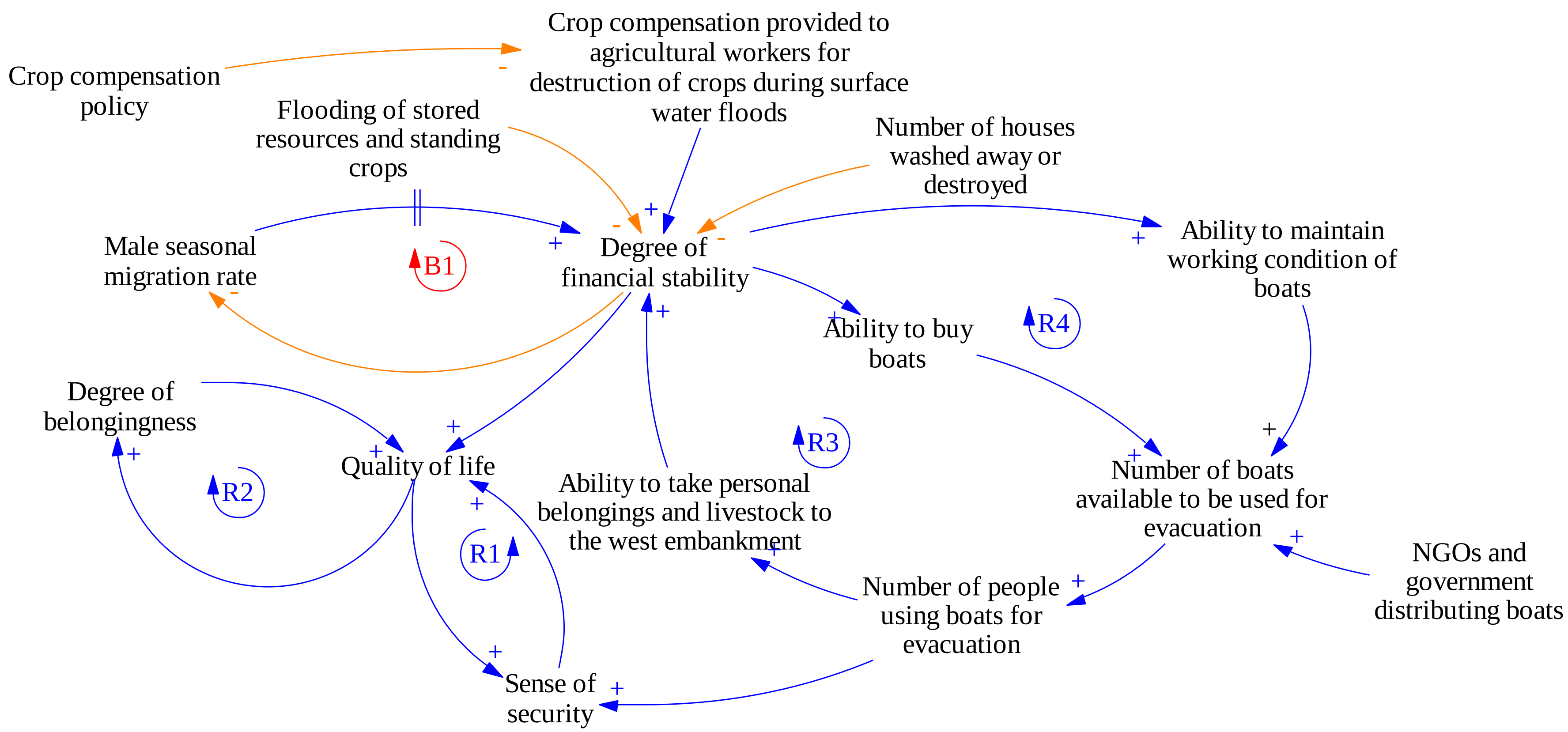


Figure 7-42 Feedback-only causal loop diagram for monsoon waterlogged sub-system

7.7.1. Analysis of feedback loops in the monsoon waterlogged sub-system

As mentioned earlier (Section 7.7), the waterlogged and within embankments sub-systems behave similarly during monsoon season and therefore have common feedback loops (Section 7.5.1), which are not mentioned here to avoid repetition.

7.7.1.1. Crop compensation

The government provides some incentives to compensate for the agricultural and livestock losses caused by surface water flooding, but it fails to raise the marginalised communities' financial stability, as discussed below.

No crop compensation for agricultural workers - The impact of crop compensation on the financial stability of agricultural workers is a critical finding. The agricultural labourers work on the dominant community stakeholders' land on the condition that the crop yield will be divided between the agricultural labourer and the dominant community stakeholders. However, if the crop is destroyed due to surface water floods, only the landowners are eligible for crop compensation under the current crop compensation scheme. The crop compensation is provided under the 'Bihar Rajya Fasal Sahayata yojna-2022', a state government scheme under the cooperative department of the government of Bihar (GoB, 2022). Under this compensation scheme, a relief fund is provided to the farmers for crop loss due to unseasonal rainfall, weather conditions, or other natural calamities for the community members to qualify for crop compensation. The relief fund includes ₹7500/hectare (~£78/hectare) for less than

20% crop damage to ₹10,000/hectare (~£104/hectare) for more than 20% crop damage for up to 2 hectares of land.

Therefore, there is no provision for compensation for agricultural labourers who work on agricultural lands (Figure 7-43). This situation highly impacts these people's financial stability. Even though there is a chance that these agricultural labourers would not be able to get the agricultural yield in the next farming season, they still wait for the next farming season to earn a livelihood because there are rarely any other alternative livelihood opportunities (Kumar et al., 2013).

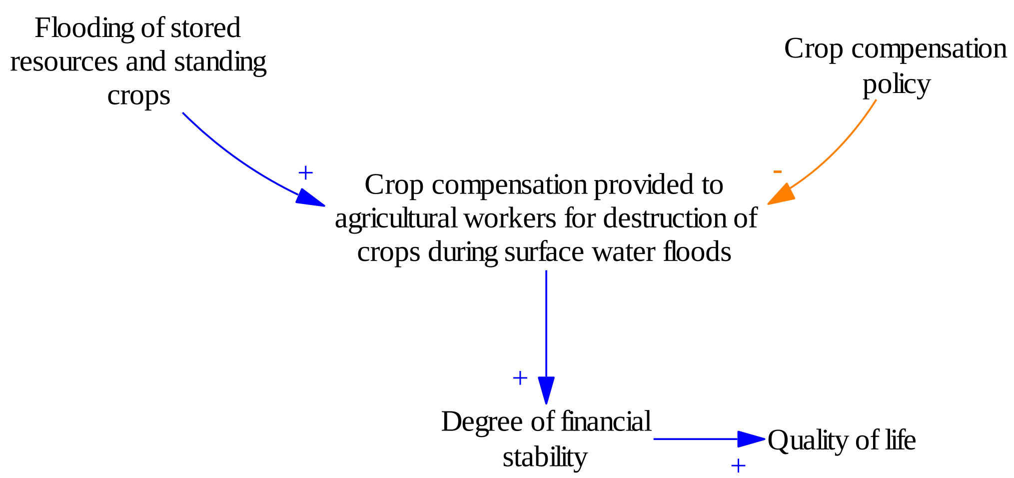


Figure 7-43 Impact of current crop compensation policy on agricultural workers

No crop compensation for waterlogging - Singh et al. (2014) calculated the waterlogging spread in Bihar using satellite image-based evaluation. The results showcase that waterlogging constitutes an area of 1881 sq km, 1.82% of the total area of Bihar and 94% of the total waterlogging is in the North Bihar region where the researcher's study site is located. Using remote sensing and geographical information system, Pandey et al. (2012) calculated an increase of 330% from 31 sq km in 1925 to 103 sq km in 2006 in the total waterlogged area in Bihar. Waterlogging is concomitant to recurrent surface water flooding, and due to waterlogging, most land with agricultural potential has become a wasteland in North Bihar (Singh et al., 2014). Therefore, waterlogging impacts the financial capacity of waterlogged community members to sustain life significantly (Figure 7-44). Even though waterlogging results from surface water flooding, it is currently not considered a form of flooding, so the government has no policy to compensate the community members for the agricultural losses due to waterlogging.

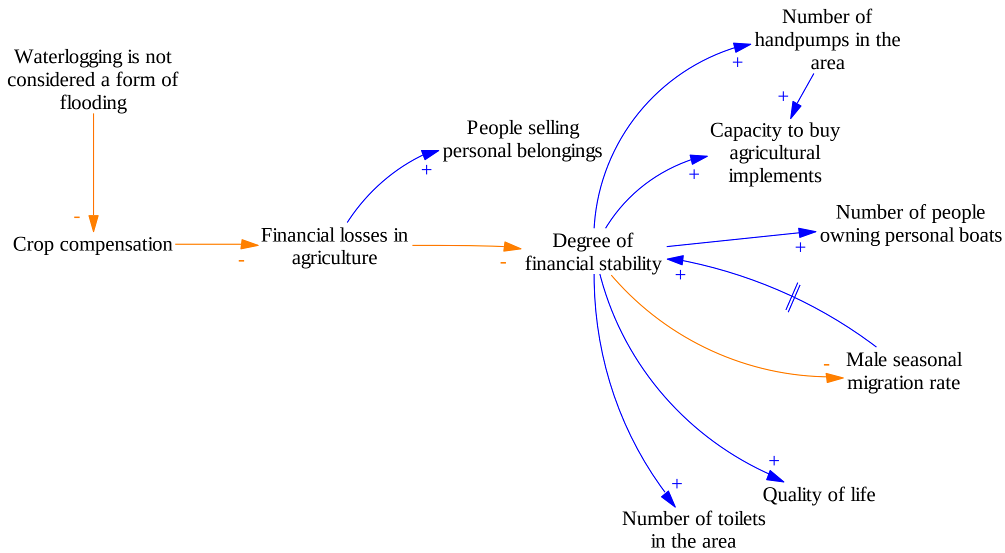


Figure 7-44 Agricultural losses and crop compensation

7.7.2. Analysis of vulnerability characteristics identified in monsoon waterlogged sub-system

The dimensional analysis (Appendix D Table D - 6) for the monsoon waterlogged sub-system suggests that the dominant categories are economic (= 8) and social (= 6). Similarly to the monsoon within embankments sub-system (Section 7.5), the social and economic dimensions govern the feedback loops in this sub-system.

7.8. Key biophysical factors causal loop diagram

This causal loop diagram in Figure 7-45 depicts the key biophysical factors in the Kosi Basin. The pink colour variable represents the social and economic variables.

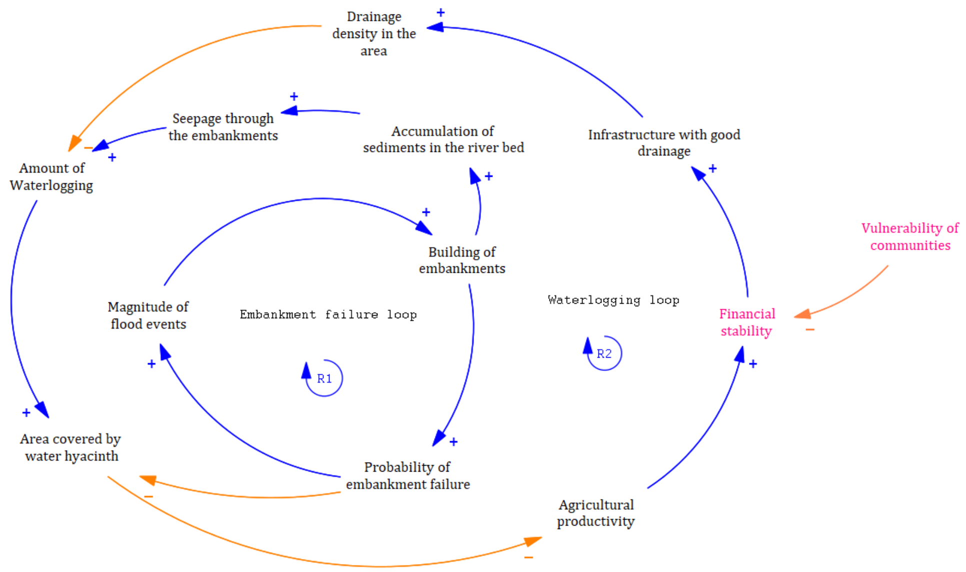


Figure 7-45 Biophysical factors causal loop diagram

7.8.1. Key biophysical causal loops

7.8.1.1. Embankment failure

R1 is positively reinforcing loop. As the magnitude of flood events increases, more embankments are being built to restrict the river flow. Building more embankments results in increased number of embankments which increases the probability of embankment failures.

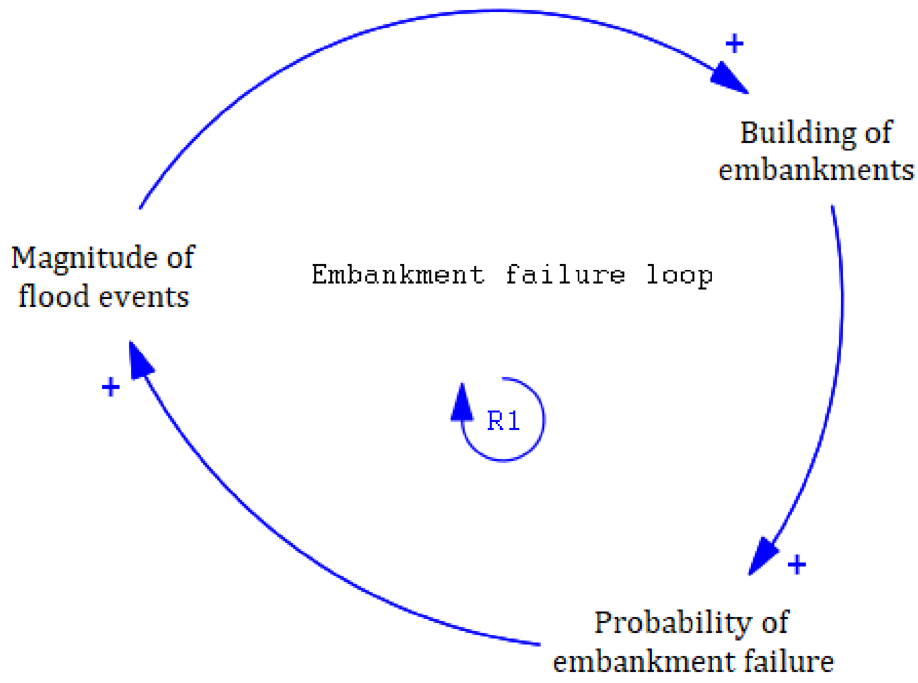


Figure 7-46 Embankment failure loop

7.8.1.2. Waterlogging loop

R2 is a negatively reinforcing loop in which waterlogging, and growth of water hyacinth is impacting the agricultural productivity in the waterlogged area. The amount of waterlogging is increasing due to poor drainage density of the area. This poor drainage density is the result of infrastructure with poor drainage resulting from financial instability which is due to the reduced agricultural production.

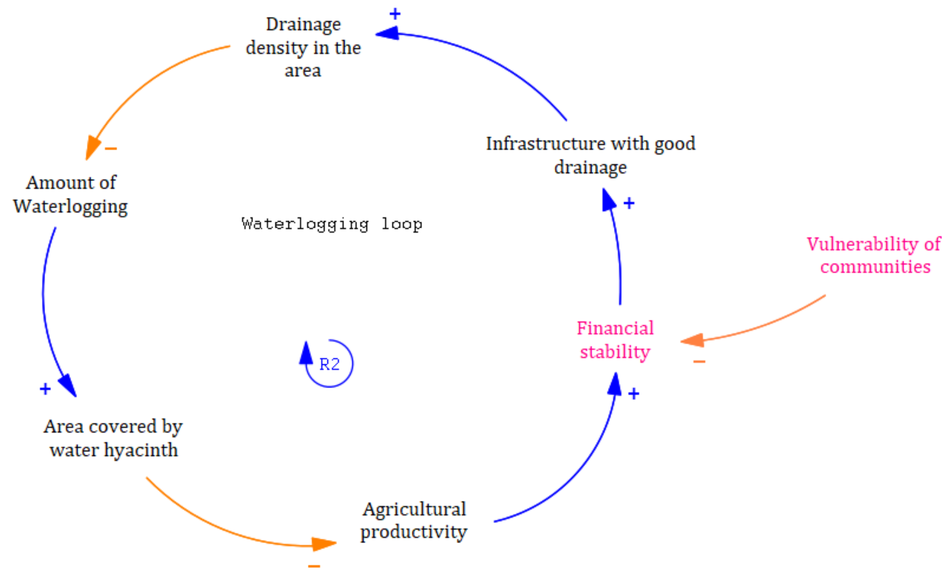


Figure 7-47 Waterlogging loop

7.9. Abstracted key system characteristics

This section reports the main drivers responsible for the current system behaviour in the Kosi Basin.

7.9.1. Degree of belongingness, sense of security and quality of life

These three variables play a significant role in understanding the system's dynamics in the sub-systems identified in the Kosi Basin system. In the sub-systems, the sense of security (R1) and degree of belongingness (R2) reinforcing loops (Figure 7-4) are central to the quality of life of the communities living in the Kosi Basin. Issues such as the impact of floods on the quality of life of people have also been studied in the field of flood risk. Purba et al. (2018) conducted a study in a rural setting in Jakarta, Indonesia and reported that living on the banks of polluted rivers with yearly flooding negatively impacts these people's health and quality of life. French et al. (2019) also stressed the repeat floods highly impact mental health and quality of life.

These variables are qualitative in nature and are complicated to quantify by traditional engineering methods, yet the vast majority of the identified feedback loops signify the crucial role these variables play in this annual flood system. Kabisch (2019) also highlighted the importance of quality of life being a significant dimension when devising sustainability solutions to floods. This finding is critical as these variables have a controlling influence on the dynamics of this sub-system. These three variables, i.e., degree of belongingness, sense of security and quality of life, comprises material as well as immaterial, individual as well as collective, and objective as well as subjective elements of welfare, happiness and satisfaction (Marans and Stimson, 2011). The occurrence of these variables pinpoints the direction of the importance of the system representation and formalisation technique used in this research. However, flood risk management in Bihar relies heavily on physical factors (Page 106) and qualitative variables such as quality of life, degree of belongingness and sense of security are neglected.

7.9.2. Caste dynamics and power politics

Central to the system dynamics described in this chapter is the impact of the caste system on the societal status of vulnerable communities. The history of caste dynamics in India is presented in Box 4-1. The caste system, i.e., a stratified social hierarchy based on caste, distinguishes India from most other countries (Gang et al., 2017). The marginalised communities (majority of the research participants) expressed that belonging to the lower caste has suppressed their voices. They feel that the responsiveness of government officials is biased against them due to these communities belonging to lower castes and also because the majority of these people are illiterate and poor.

7.9.2.1. Land rights

The power dynamics due to caste dynamics put different pressures on these marginalised community stakeholders. At the bottom of the power ladder, Dalits often suffer from bullying due to caste-based violence (Ramesh, 2008, IDSN, 2013). The dominant community stakeholders forcefully occupy their ancestral lands, and if these communities complain to the government officials, they bribe them (Mishra et al., 2008). This situation leaves the marginalised community stakeholders landless with no or little formal assets (IDSN, 2013, UNDP, 2009). Due to this caste-based violence, Dalits are often seen living in the marginal lands on the periphery of settlements (IDSN, 2013), such as Kosi west embankment.

These marginalised stakeholders residing on the Kosi west embankment are also forced to move from the embankment by these dominant community stakeholders because of the increasing property value since the Supaul-Kasraur road in built in the area. Therefore, power politics plays a significant role in making the already vulnerable section of the Kosi Basin community more vulnerable by leaving them with little or no land rights.

7.9.2.2. Livelihood opportunities

The caste dynamics have a tremendous impact on the lives of these marginalised community members, even impacting their livelihood. In countries like Nepal and India, occupational segregation is witnessed due to lower caste status people are still used to doing caste-based traditional work (Katuwal, 2008, Gang et al., 2017), enforcing Dalits to resort to menial jobs (e.g. manual scavenging, removing human waste and dead animals, sewage disposal). Dar et al. (2013) conducted a study in Odisha, India and showcased that in case of crop loss due to surface floods, the marginalised community stakeholders sustain the most financial losses and are unable to cope with them in the longer term.

Especially after the dominant community stakeholders forcefully occupy their lands, the marginalised community stakeholders resort to working as share-croppers or manual labourers ultimately to meet livelihood needs (UNDP, 2009). However, due to groundwater and surface water flooding, the agricultural losses are high, impacting the livelihood opportunities present in the area, especially for marginalised community stakeholders (Singh et al., 2009).

Also, the crop compensation policy 'Bihar Rajya Fasal Sahayata yojna-2022' developed by the government of Bihar provides compensation to the landowners in case of extreme flood events (GoB, 2022). The marginalised community stakeholders who work on the lands of dominant community stakeholders as agricultural labourers are unable to receive any crop compensation. This loss of livelihood opportunities in the area has left the marginalised community stakeholders financially unstable, ultimately decreasing their quality of life by pushing them into a poverty trap.

7.9.2.3. Relief distribution

The discrepancy in relief distribution is based on power politics (Figure 7-21) and is rooted in the socio-political dimension of vulnerability. In the case of relief distribution, this solution to flood hazard is only during the impact stage of extreme surface water flooding events. The magnitude and intensity of relief distribution are highly influenced by new coverage (Kouser-Asif, 2022). Providing resources and financial aid is far from an ideal solution to reduce flood risk as it creates a false sense of security and might contribute to the community's reliance on flood relief for future flood events, as reported by Mai et al. (2020) from their study in Queensland, Australia. Secondly, providing monetary incentives through policies is reactive, showcasing that the government only acts once a disaster occurs (Shafiai and Khalid, 2016).

Jha (2015) conducted a study in Kosi, India which demonstrated the existence of social exclusion during the rescue, relief and rehabilitation process. Rahman et al. (2017) conducted an empirical study to showcase that extreme rainfall-driven floods increase corruption in post-disaster recovery efforts and emergency response. Power politics plays a vital role in relief distribution. The influence of social and political standing leads to discrepancies in relief distribution (Page 128), impacting the ability of marginalised community stakeholders to have adequate nutritious food. Therefore, the relief measures fail to reach the most vulnerable community members.

According to a report by IDSN (2013:5), "Dalits (marginalised community stakeholders) often receive relief materials of a poorer quality or lesser quantity compared to other recipients." The long-term implications of relief distribution also led to malnutrition, declining the quality of life of these Kosi Basin communities. The discrepancy in relief distribution impacts the women or the women-headed households the worse because of the prevalent patriarchal norms (Madhuri, 2016). In these patriarchal norms, men are considered the head of the household, and women have no power in the household decision-making; therefore, women are usually neglected in relief distribution (Madhuri, 2016). The corruption resulting as a result of caste-based politics has also created distrust in the government by marginalised communities. This discrepancy in relief distribution results in a low sense of security among the marginalised community stakeholders. Moreover, caste discrimination plays a major role in influencing the relief distribution process (IDSN, 2013).

7.9.3. Male seasonal migration

Migration is a common practice observed in the Kosi Basin due to the loss of livelihood opportunities in the area. Other studies conducted by Gray and Mueller (2012) in Bangladesh, Ocello et al. (2014) in Tanzania and Mueller et al. (2014) in Pakistan showcase that the loss of livelihood opportunities due to floods forces people to migrate for basic sustenance.

Warner et al. (2012) and Warner and Afifi (2014) describe migration as a maladaptation practice. It is important to understand that male seasonal migration might help the communities deal with the immediate pressures, but it undermines resilience in the long term. Adger et al. (2011:20) argue that migration "cannot be considered successful if they result in damage to people's traditions, knowledge, social orders, identities, and material cultures". Moreover, climate-induced migration results in the loss of labour, knowledges and skills within a community (Warner and Afifi, 2014). Therefore, male seasonal migration results in the loss of social and economic capital and cannot be considered a sustainable practice.

7.9.4. Vulnerability in women

Parameters such as the impacts on physical and mental health (Tapsell et al., 2002, Rufat et al., 2015), sanitation (Giannini and Giupponi, 2011), spread of infections during floods (Madhuri, 2016), coping capacity (Rufat et al., 2015), risk perception (Miceli et al., 2008, Kellens et al., 2011), patriarchal norms (Madhuri, 2016), caste dynamics (Singh et al., 2009, Madhuri, 2016) and gender discrimination (Pritchard and Thielemans, 2014) makes women more vulnerable to floods than men. In Kosi Basin, Singh et al. (2009), and Madhuri (2016) stress that migration of men puts extra pressure on women, leaving them with household responsibilities.

7.10. Chapter summary

This chapter investigated the feedback loops to communicate the complex system dynamics present in the developed causal loop diagrams in a simplified way. Assessing these complex dynamics helped identify key system characteristics responsible for the current system behaviour. The deeper cause of the system behaviour was recognised as the caste dynamics, resulting in corruption and power politics, causing loss of land rights, decreased livelihood opportunities and discrepancy in relief distribution. Maladaptation practice of male seasonal migration is also reported as a key activity leading to loss of social and economic capital. Ultimately, the key system characteristics identified, such as caste dynamics and male seasonal migration, are linked and result in low quality of life marginalised community stakeholders experience in Kosi Basin.

The system interrogation carried out in this chapter suggests cross-boundary interactions between the sub-systems, and all three spatial communities are connected through time and space. The next chapter, i.e., Chapter 8, compares the identified sub-systems and conceptualises the spatial and temporal interaction in the Kosi Basin system. Moreover, Chapter 8 also covers identifying the leverage point drivers of vulnerability in the Kosi Basin system based on the interrogation and abstracted system characteristics presented in this chapter.

Chapter 8. System synthesis

The aim of this chapter is to perform system synthesis. The synthesis involved 1) comparing identified sub-systems, 2) conceptualising the Kosi Basin system to illustrate the spatial and temporal scale of human-flood interactions and 3) identifying the leverage point drivers of vulnerability in the Kosi Basin system. This chapter helps in answering the fourth research question (Page 11), i.e., How do the systems of causality reveal and characterise flood risk and vulnerability?

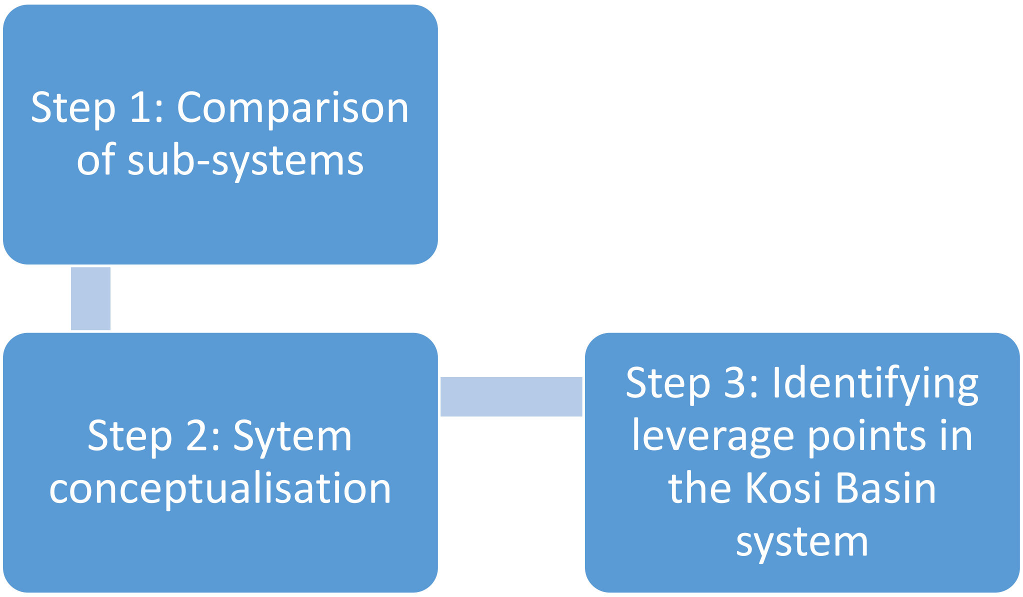


Figure 8-1 Steps adopted for system synthesis

Step 1: Comparison of sub-systems (Section 8.1)

This step compares the dimension analysis carried out in different sub-systems. This comparison would be instrumental in understanding if the spatial and temporal characteristics of the sub-systems distinguish their behaviour from each other. Determining the dominant dimensions would allow us to understand the nature of flood risk management solutions required in the Kosi Basin sub-system.

Step 2: System conceptualisation of Kosi Basin (Section 8.2)

The previous analytical steps performed in Chapter 7 broke the Kosi Basin system into smaller sub-systems and individual causal loops to aid the identification of key individual drivers of community vulnerability. However, it is essential that these are brought together at a whole-system scale. This step is essential to view the Kosi Basin system as whole, adopting a systemic view of the system (Koskinen, 2013). Specifically, this required integration of human and physical dimensions, sub-systems defined by spatial location (i.e., embankment, waterlogged and within-embankment sub-systems) and temporal phase (i.e., monsoon and non-monsoon periods). This allowed feedback between variables from different stages to be identified.

Step 3: Identifying leverage points in the Kosi Basin system (Section 8.3)

The leverage point is a conceptual heuristic which is proposed in this research to identify critical places in the Kosi Basin socio-environmental system where changes can be introduced to make the at-risk communities resilient over time. Leverage points are places in a complex system where introducing a relatively small intervention can significantly change other parts of the system (Meadows, 1999). There are 12 different hierarchal intervention points proposed by Meadows (1999) for leveraging change in a complex system (Figure 8-2). Meadows (1999) suggested that an intervention's capacity to bring a systemic change in a system directly depends on the characteristics of that system. Therefore, the interventions differ in terms of the leverage they produce, which can be shallow or deep. Shallow leverage points are points at which introducing interventions is easy, but their potential to produce a transformative change is limited. Deep leverage points are places (qualities or characteristics) of a system where change is more difficult and fundamental, but where there is greater transformative change potential. The leverage points from 1- 6 are deep, and 6-12 belong to the shallow leverage point category (Figure 8-2).

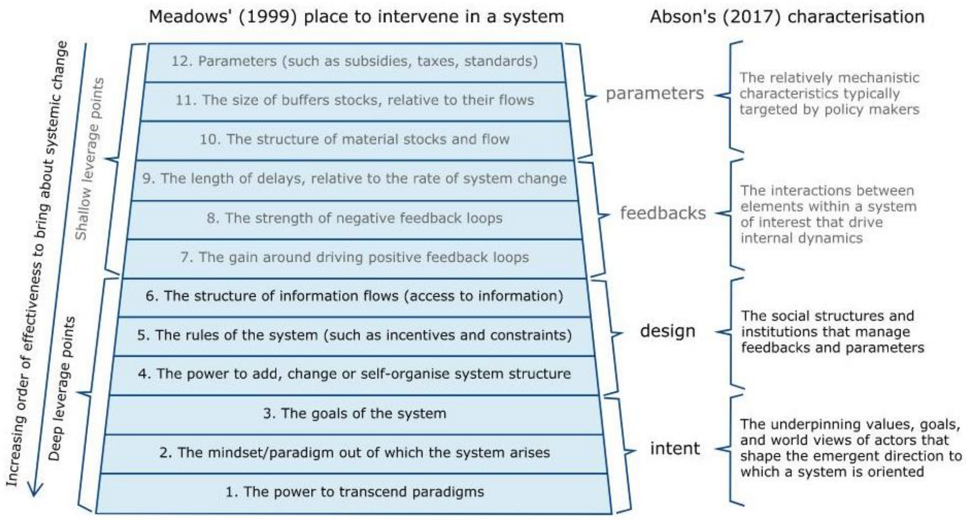


Figure 8-2 Leverage points characterisation (after Abson et al., 2017)

Abson et al. (2017) categorised this hierarchy of leverage points into four groups (Intent, Design, Feedback, and Parameters) to simply the categorisation. Parameters are shallow leverage points where the quantitative variables in a system can be adjusted to alter system behaviour. Feedbacks are also shallow leverage points focusing on the managing the variables or connections in 1) balancing loops to help the system at/near its goals or 2) reinforcing loops to control its damaging behaviour. Feedbacks also include providing information to achieve a desired outcome (e.g., effectiveness of an incentive policy such as crop compensation).

Design is a deep leverage point which focuses on self-organising the current system behaviour. It deals with altering the structure, capacities and rules to refine the behaviour of feedbacks and variables in the system. Structural changes include altering the information flow by introducing new feedbacks to alter the information where it was unable to reach before. Intent is a deep leverage point which involves introducing new goals to the system. It focuses on values, norms and goals of the system and the paradigms which underpins them. It deals with changing the mindset which has resulted in the current state of the system.

The shallow leverage points have been the primary focus of most of the research and policies on sustainability as argued by Abson et al. (2017). The policies mainly focus on providing incentives because these changes are easier to implement. However, by focusing on such shallow leverage points, they fail to address the deep leverage points. The key system characteristics and interrogation presented in Chapter 7 presented opportunities for both shallow and deep leverage points which are synthesised in this chapter. The categorisation was done based on the system as a whole i.e. the conceptual diagram (Figure 8-4) rather than parts i.e. the sub-systems interrogated in Chapter 7. This step was taken with regard to the interconnectedness of the vulnerability dimensions discussed in step 1 and conceptualised in step 2. It is important to note that only the broad categories of leverage points i.e., shallow and deep are used in this chapter, which are further discussed in detail with some possible solutions in Chapter 10.

8.1. Comparison of sub-systems

A comparison of the sub-systems with respect to the dimensional characteristics was carried out to identify the dimensions which dominate the Kosi Basin system (Figure 8-3). The comparison helps to understand which dimensions are dominant in the different sub-systems. The dimensional analysis suggests that the social variable is the most dominant in all the sub-systems. The social variable appears 109 times in total, with a maximum appearance in the monsoon embankment sub-system (=59). This result reflects that during their temporary stay on the Kosi embankment, these communities face the social aspect of the Kosi Basin sub-system, which is significantly impacted by flooding in the area. The second most predominant dimension is economic, appearing 52 times in the feedback loops, with the most appearance in the non-monsoon waterlogged sub-system (=17). The appearance of economic variables showcases that the economic aspect of the life of the waterlogged communities is most disrupted due to the annual flood cycle of the Kosi Basin sub-system.

During surface water flooding, both the waterlogged and within embankment communities temporarily settle on the Kosi west embankment to live with the embankment community, forming the monsoon embankment sub-system. In the monsoon embankment sub-system, social, economic, political, physical and technological are distributed 94.5%, 12.3%, 4.1%, 2.7% and 0.0%, respectively. Therefore, the occurrence of both social and economic variables is the highest. This result indicates that the social and economic dimensions are greatly impacted, lowering the quality of life of all three spatial communities.

However, in the non-monsoon embankment sub-system, the dominant dimensions are social and political, with 16 (57.1%) and 8 (28.6%) occurrences, respectively. The non-monsoon embankment sub-system is when only the embankment community reside on the Kosi west embankment during non-monsoon. The results suggest that the most dominating variables are social and political. Compared to the monsoon embankment sub-system, the monsoon waterlogged sub-system is dominated by social and economic variables. The monsoon waterlogged sub-system has 7 (43.8%) social and 9 (56.2%) economic variables, whereas the non-monsoon waterlogged sub-system has 6 (20.7%) social, 17 (58.6%) economic and 6 (20.7) physical variables. This result suggests that during the non-monsoon temporal variation in the waterlogged sub-system, the physical dimension also plays a significant role in the feedback loops. Nonetheless, the impacted dimensions are both social and economic in this sub-system during monsoon and non-monsoon temporal variations.

The monsoon variation in the within embankments sub-system is similar to the monsoon variation of the waterlogged sub-system. These sub-systems have same dimension occurrence, i.e., 43.8% social and 56.2% economic. This data suggests that during the monsoon variation, the waterlogged and within embankments area are dimensionally impacted similarly. However, the non-monsoon variation is dominant with the social, political and economic dimensions with 14 (48.3%), 9 (31.0%), and 6 (20.7%) occurrences, respectively. This result suggests that the social and political dimension plays a vital role in the non-monsoon temporal variation in the within embankments sub-system. Moreover, both the non-monsoon within embankments and non-monsoon embankment sub-systems are dominant with social and political dimensions suggesting that the caste dynamics play a significant role in these areas during non-monsoon.

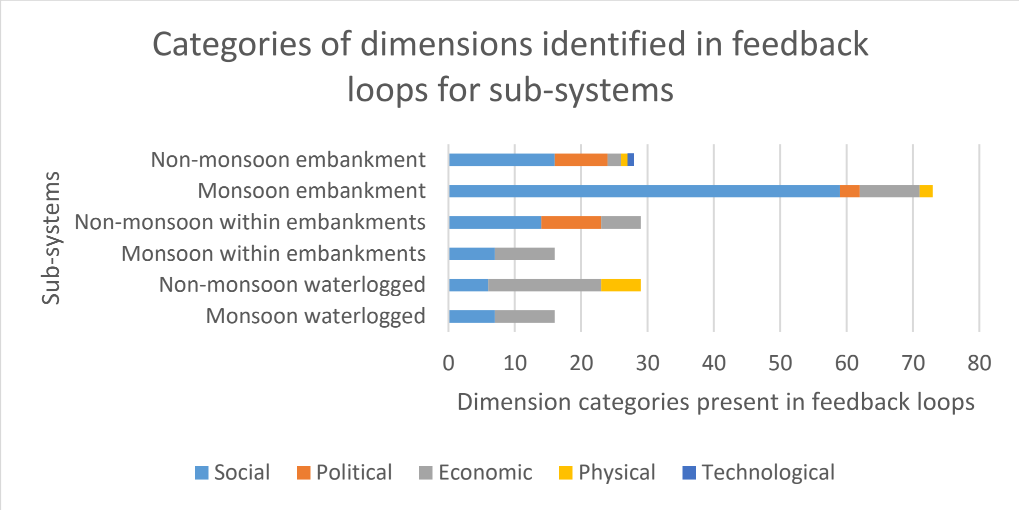


Figure 8-3 Dimension categories identified in feedback loops

The patterns emerged while comparing the sub-systems suggests that the dominant variable dimensions in the Kosi Basin sub-system are social, political and economic. These patterns showcase that Kosi Basin socio-environmental system is a systemically governed by social, political and economic dimensions of vulnerability. At the policy level scale, currently, the knowledges used to develop flood management policies are scientific expert knowledges that usually focus on hazard management rather than community resilience. Therefore, the vulnerability dimensions identified, i.e., social, political and economic dimensions are not involved in the policies.

There are policies in place such as crop compensation aimed at providing help to the communities to minimise crop damage (GoB, 2022), however, these policies only increase financial instability in the marginalised community stakeholders. The reason behind this is that these policies are devised in isolation of the political and social dimensions of vulnerability. However, as identified by the system interrogation in Chapter 7, all these dimensions of vulnerability interact with each other. Solutions to provide resilience to Kosi Basin communities lie in devising strategies which look at the whole system systemically and not parts of the system (Dyball and Newell, 2014, Rehman et al., 2019). Therefore, it is high time to evaluate the effectiveness of existing flood risk management policies and involve the local knowledges in the decision-making process of flood risk management. Understanding the feedback between the river environmental health and community health is pertinent. The details are present in Section 9.2.3.

8.2. System conceptualisation of Kosi Basin

The system thinking approach for understanding the system dynamics focuses on the underlying structure, i.e., understanding the 'wholes rather than parts' (Richmond, 1994). Moreover, a better understanding of these complex behaviours can aid in predicting them and eventually adjusting their outcomes (Arnold and Wade, 2015). Therefore, to view the Kosi Basin system as a whole, a conceptual model for the Kosi Basin socio-environmental system was generated. The Ensure model was adopted and modified to conceptualise the Kosi Basin system. The Ensure model was developed to demonstrate the time and space dimensions of a flood hazard cycle and was used as a 'vulnerability and resilience framework tool' to indicate a relationship between resilience and vulnerability (Twigger-Ross et al., 2014). The model was modified to accommodate the three spatial communities and the local migration in the Kosi Basin communities due to their interaction with floods.

The risk of flooding for the communities living in the Kosi Basin changes during the year. Figure 8-4 shows how the communities are distributed along the at-risk cycle, assuming high surface flood intensity. The at-risk range is the highest in the outermost circle to the least in the innermost circle; Communities living in the waterlogged area (outermost circle), Communities living within the embankments (middle circle), Communities living on the Kosi west embankment (innermost).

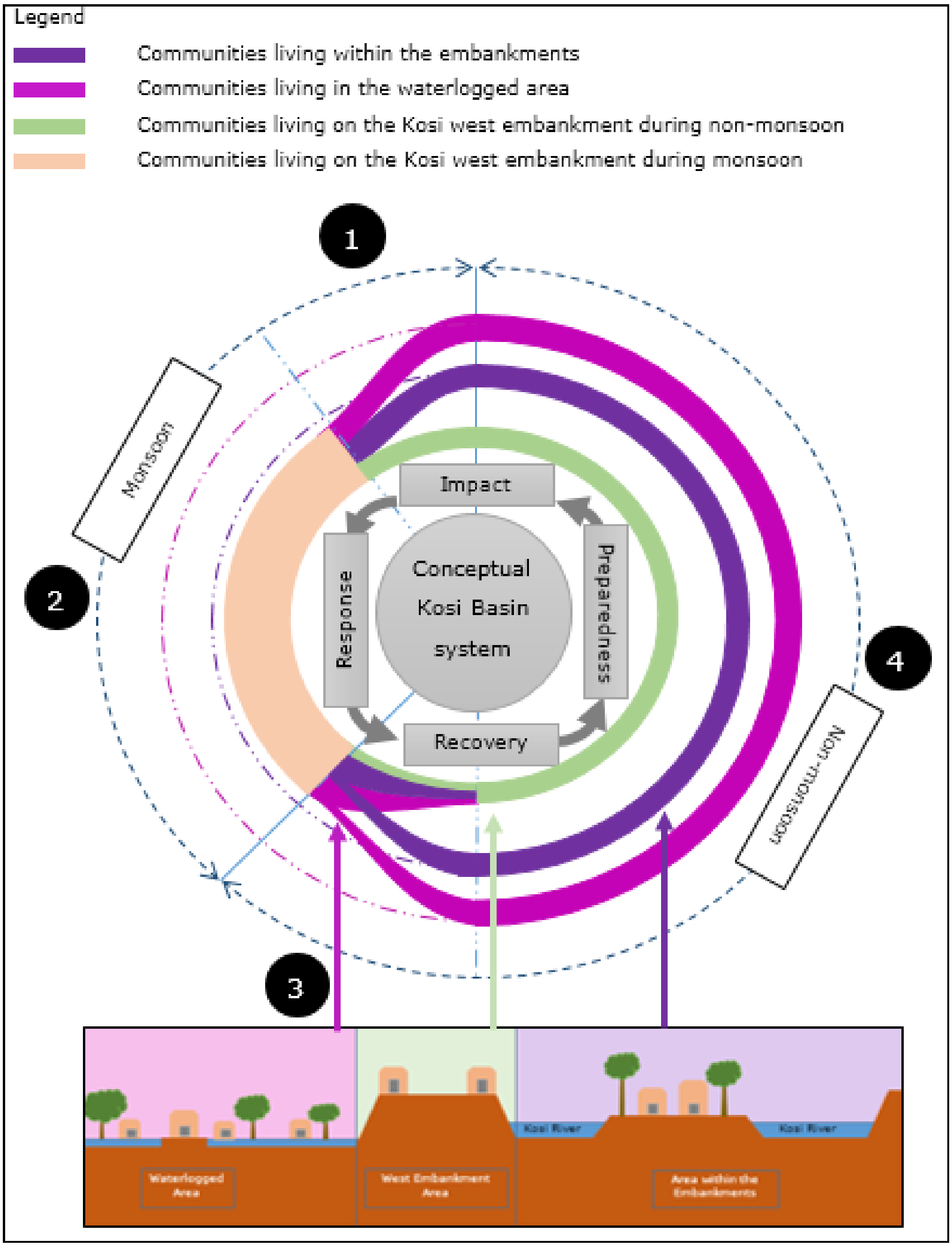


Figure 8-4 Conceptual socio-environmental system of Kosi Basin

This at-risk cycle is based on communities' residence location, and the risk is distributed based on their interaction with floods (Table 8-1). The temporal and spatial characteristics of the area play a significant role in the distribution of flood risk in the Kosi Basin, i.e., the area where these communities live and how these areas interact with surface or groundwater flooding. The communities in the waterlogged area are most at risk because they interact with both surface water flooding during the monsoon and groundwater flooding during the non-monsoon. The communities within the embankments are in the middle of the at-risk cycle because they only interact with surface water flooding. Finally, communities living on the embankment are least vulnerable to floods due to no direct interaction with either surface or groundwater flooding.

Table 8-1 Distribution of Flood Risk based on the interaction of areas with flooding

Spatial Location	**Temporal Variation**		**At-risk of flooding**
	Surface water flooding	**Groundwater flooding**	
Waterlogged area	✓	✓	High
The area within the embankments	✓	X	Medium
Kosi west embankment area	X	X	Low

The annual cycle for all communities has been divided into four sections explained in Table 8-2 for all three areas, i.e., waterlogged area, area within the embankments and west embankment area. The four elements of the risk are divided into four sections. Section 1 covers the impact stage (the period of acute flooding), section 2 response stage, section 3 is the recovery stage, and section 4 is the preparedness stage.

- Section 1 (Impact): Temporary local migration is created when the monsoon period starts. Communities from the waterlogged area and area within the embankments temporary move to the Kosi west embankment.
- Section 2 (Response): All three communities (waterlogged communities, communities from within the embankments and communities already living on the west embankment) stay on the Kosi west embankment for the monsoon period.
- Section 3 (Recovery): As the monsoon ends, the communities from the waterlogged area and area within the embankments return to their houses. However, the people who suffered severe losses from floods permanently migrate on the Kosi west embankment (permanent local migration).
- Section 4 (Preparedness): All three communities return to normal lives. Normal life for the waterlogged communities means they live with groundwater flooding during the non-monsoon period, and the communities on the embankment suffer due to having no land rights in the area they are living in now. On the other hand, the communities residing in the area within the embankment

carry on with agricultural activities. Furthermore, as the monsoon period approaches again, these communities start preparing for the surface water flooding.

Figure 8-5 shows the cross-sectional view of the at-risk cycle of communities. The local migration created by the temporal and spatial characteristics puts the three communities in different sub-systems annually. The at-risk cycle has been created separately for each community. These separate cycles were created to demonstrate the local migration in the Kosi Basin communities concerning their interaction with floods.

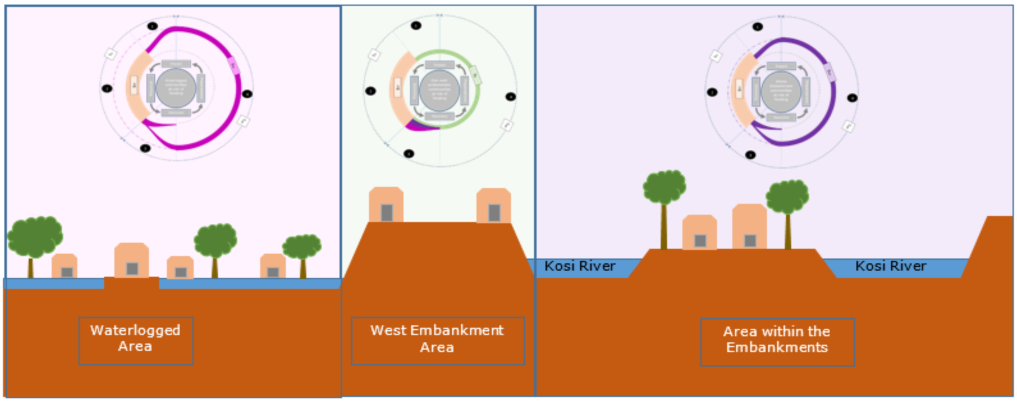


Figure 8-5 Cross-sectional diagram of at-risk cycles for communities

To conclude, the embankment area comprises permanent during non-monsoon and temporary local migration during monsoon from the two spatial areas i.e., waterlogged and within embankment.

Table 8-2 Interaction of areas with flooding

Area	Annual at-risk cycle stages			
	Impact	Response	Recovery	Preparedness
Waterlogged area	Local temporary migration: Communities from the waterlogged area temporarily migrate to the Kosi west embankment due to surface water flooding.	Waterlogged area interacts with surface water flooding. (Communities from the waterlogged have already shifted to Kosi west embankment temporarily).	Communities move back to their homes (in the waterlogged area), but some people stay on the Kosi west embankment permanently due to worst impacts of surface and ground water flooding (Permanent local migration).	Waterlogged communities interact with groundwater flooding.
Area within the embankments	Local temporary migration: Communities from the area within the embankments move to the Kosi west embankment temporary	The area within the embankments interacts with surface water flooding. (Communities from the area within the embankments have already	Communities move back to their homes (in the area within the embankments), but some people permanently stay on the Kosi west embankment	Communities within the embankments focus on their agriculture, yielding the benefits of new fertile soil brought by the Kosi River

Area	Annual at-risk cycle stages			
	Impact	Response	Recovery	Preparedness
	due to surface water flooding.	moved temporarily to Kosi west embankment).	after facing worst impacts of surface water flooding (Permanent local migration).	
West embankment area	Communities from waterlogged and within the embankment area temporary migrate and reside with the communities already settled on the Kosi west embankment.	All three communities interact with surface water flooding for the period of surface water flooding (3 months, i.e., July-September)	Communities from waterlogged and within the embankment area permanently move to live with the communities already settled on the Kosi west embankment.	Communities living on the embankment face problems due to having no land rights in the area where they are living now (after permanently moving from their ancestral land either from the area within embankments or waterlogged area)

8.3. Leverage points in the Kosi Basin

8.3.1. Shallow leverage points

The shallow leverage points provide points in the system where short-term solutions can be provided to make positive changes in the system. However, in order to make the communities resilient over time, there is a need to explore possible solutions for the deep leverage points identified in the system. The shallow leverage points identified in the Kosi Basin system are:

1. **Usage of boats:** Provision of more boats and financial aid for maintaining the boats by the government and NGOs can help increase the boat usage for evacuation for the communities in the waterlogged area (Figure 7-42) and within the area of embankments (Figure 7-31). It will also help the waterlogged communities to commute during extensive waterlogging period.

2. **Advance flood warning:** Provision of advance warning by the government about the Kosi River water being released from the Kosi Barrage can be beneficial to provide adequate time to evacuate (Figure 7-11).

3. **Crop compensation:** There should be provisions to provide crop compensation (Figure 7-43) to the agricultural labourers through either a) financial help or b) agricultural implements and food grains for crop damage caused by surface water flooding. Moreover, consideration should be given to waterlogging as a form of flooding. In the case of Kosi Basin, this groundwater flooding is induced by building the Kosi embankments and, therefore, there is a need to provide crop

compensation to the waterlogged community for agricultural losses caused by waterlogging (Figure 7-44).

4. **Veterinary treatment gap:** Providing quality veterinary treatment to the livestock (Figure 7-40) to ensure the health and well-being of the livestock.

5. **Number of people temporarily living in plastic or slum huts on the Kosi west embankment:** Building and allocating community shelters with basic facilities such as clean drinking water and toilets on high grounds for the duration of surface floods might be a viable solution to safeguard these communities from surface water floods (Figure 7-12).

6. **Frequency of embankment works:** The marginalised community stakeholders can be employed to carry on these embankment works. This solution will help to provide them with livelihood opportunities (Figure 7-3).

The shallow leverage points mentioned above will not be able to provide deep transformations in the system. The lessons learnt from the Kosi Basin system dynamic model are that flood risk management should focus on long-term sustainable solutions, and short-term goals should only be applied to gain the required time needed to implement long-term solutions to manage flood risk (Harris, 1990). In long-term, the short-term solutions may foster unintended consequences. These short-term solutions are described as 'fixes that backfire' in the 'system archetypes' (Stroh, 2015). System archetypes describe recurring patterns of system behaviour. They can be explored to identify the deep levels of the systemic structure that drives the system behaviour and are beneficial for developing interventions focused on identifying and resolving the problem sources (McLean et al., 2019). In the case of Kosi Basin, these 'system archetypes' are the construction of Kosi embankments and relief distribution, fixes adopted by the government to manage floods in Kosi Basin, which resulted in increase in vulnerability in the Kosi Basin communities. Implementing short-term solutions based on shallow leverage points would not result in providing sustainability to the system, and therefore, should be avoided or implemented to gain time for deep levers.

8.3.2. Deep leverage points

The deep leverage points and key system characteristics of the Kosi Basin system (Section 7.8) are:

1. **Power politics:** Power politics comes under the intent category in deep leverage points as it describes the prevalent values and norms of the system.
2. **Male seasonal migration:** Male seasonal migration relates to the design category as it demands an alteration in the structure of the system to refine the behaviour of feedback between male seasonal migration and degree of financial stability (Figure 7-5). There is a need to develop sustainable livelihood opportunities in the area to reduce this maladaptation.
3. **Vulnerability in women:** Vulnerability in women belongs to the intent category as vulnerability in women is predominantly due to patriarchal norms present in the society, exuberated by floods in Kosi Basin. There is a need to address the vulnerable state of these women by empowering them.

Altering these system characteristics have the potential to provide deep transformations in the system and have been discussed in detail in Section 9.2.1, with some possible lever (solutions) in Section 9.2.2.

8.4. Chapter summary

In this chapter, a comparison of the identified sub-systems was carried out. As a result of this comparison, the emerging patterns suggested that Kosi Basin socio-environmental system is a systemically governed by social, political and economic dimensions of vulnerability. However, the current flood risk management policy structure does not include these dimensions of vulnerability and primarily focuses on flood hazard. Therefore, it was pointed out that a need to assess the effectiveness of existing policies and understand the value local knowledges in the decision-making process of flood risk management. Moreover, a conceptual diagram was developed to stress the important of looking at 'whole' and not 'parts' when attempting to understanding the system dynamics. Afterwards, shallow and deep leverage points were identified, which are to be discussed in the detail in the next chapter, i.e., Chapter 9.

Chapter 9. Discussion

This chapter summarises and discusses the research findings (Section 9.1) and their implications for flood risk management in India (Section 9.2). It also explores broader implications of the developed methodology for flood risk management paradigm research (Section 9.3.1) and policymaking (Section 9.3.2). Afterwards, limitations of the research (Section 9.4) and future recommendations (Section 9.5) are discussed.

9.1. Research findings

The aim of this research, as presented in Chapter 1, is to understand flood risk by analysing complex human-flood interactions and feedbacks through a socio-environmental systems lens using local knowledges. The aim was addressed by answering these four research questions mentioned below.

9.1.1. Research question one

What are the local knowledges present in a socio-environment system?

As presented in Chapter 1, Local knowledges are defined as "understandings, skills and philosophies developed by societies with long histories of interaction with their natural surroundings" (UNESCO, 2017). In the context of flood risk, the knowledge of the impact of floods, consequences, exposure and vulnerability has been present in the at-risk communities facing floods over several years. i.e. years of lived experiences of communities with floods (Robertson and McGee, 2003). Therefore, these local knowledges are enriched with grounded perspective of flood risk. It is essential to understand these local knowledges and where they exist as a first step toward bridging the gap between local and scientific knowledges, which is integral to holistically understand flood risk. In Chapter 5, a stakeholder spectrum for Kosi Basin flood risk management was developed by modifying the stakeholder spectrum by Hart and Sharma (2004). These stakeholders were then mapped on an interest influence matrix to classify the wide range (consisting of local and scientific knowledges) of stakeholders based on their local flood interest, experience and expertise (Maskrey et al., 2016). The stakeholder spectrum and mapping facilitated the identification of the local knowledges present in the area and helped identify the research participants.

9.1.2. Research question two

How can these knowledge be elicited based on the socio-demographics of a local context?

It is important to use tools and techniques which can provide opportunities to the participants to express their experiences, feelings and emotions towards a certain problem situation. Qualitative methods provide more opportunities to engage with the stakeholders, especially the marginalised sub-groups, to conduct holistic research in comparison to quantitative methods (Denzin et al., 2008, Dennis and Horn, 2011). Qualitative methods are rooted in generating knowledge elicited from human experiences (Sandelowski, 2004). However, selection of appropriate qualitative method needs to be rigorous as the quality of research (Kallio et al., 2016) and trustworthiness (Kallio et al., 2016) depends on the methods used for system representation. In this research, a vast majority of the participants involved were marginalised stakeholder and illiteracy was a predominant characteristic. The qualitative methods, i.e., semi-structured interviews and rich pictures used for system representation in this research, were instrumental in engaging the marginalised stakeholder in flood risk management. The semi-structured interview process was an effective tool to elicit perceptions of at-risk communities of Kosi. It allowed us to capture the emotional sensitivity (Åstedt-Kurki and Heikkinen, 1994, Barriball and While, 1994) and helped the stakeholders to communicate the complexities of human-flood interactions (Barriball and While, 1994) present in the Kosi Basin.

The rich picture workshops were an effective tool for participatory modelling as they were highly engaging and surpassed the barriers of illiteracy (Bell et al., 2016). Rich pictures allowed the researcher to visualise the map Kosi Basin system through the participants' perception, enabling the researcher to gain an entry point into the multifaceted, complex flood system (Conte and Davidson, 2020). The combination of video recordings and rich pictures was critical in grasping the participants' perception in their own words (Warren, 2005, Loizos, 2000), thus minimising viewer bias (Warren, 2005).

Therefore, using semi-structured interviews and rich picture technique for system representation helped gather valuable raw data regarding the human-flood interactions through the narrations and stories of the at-risk communities. Moreover, these techniques are easy to use, providing a powerful opportunity for social learning and capacity building of stakeholders to work with complex socio-environmental systems (Bell et al., 2019, Conte and Davidson, 2020).

9.1.3. Research question three

What systems of causality exist within the flood-prone Kosi Basin?

The system of causality within the Kosi Basin showcases high complexity, interconnectedness and non-linear nature of systemic flood risk (Schweizer and Renn, 2019). The results of the system interrogation showcase that the Kosi Basin is a tightly coupled system and the variables are not isolated and independent but are interlinked dynamically (Mai et al., 2020). Therefore, change in one key element such as power politics, male seasonal migration, vulnerability in women can have cascading effect on the quality of life, sense of security and degree of belongingness (Schweizer and Renn, 2019). However, if the current behaviour of system continues, with climate change, it might lead to unprecedented increase in vulnerabilities in the communities (IPCC, 2022).

9.1.4. Research question four

How do the systems of causality reveal and characterise flood risk and vulnerability?

The causal loops revealed the key characteristics such as power politics, male seasonal migration, vulnerability in women and quality of life are important characteristics of Kosi Basin system. These key findings helped to conceptualise the system and determine leverage points where positive transformation in the system can be introduced to make the communities resilient with time (Abson et al., 2017). Moreover, understanding implications for research and planning is a subsequent application of having answered this question. These findings are key to justifying the need for flood risk policies to include these dimensions rather than focusing on only the physical system, as is commonly the case in flood management in the Global South (Mohanty et al., 2020). The modelled causal loop diagrams and deep leverage points identified can be used as a platform for stakeholders to open discussion, collaborate, and determine flood risk policies (Mai et al., 2020, Schweizer and Renn, 2019), in the particular local context of Kosi Basin. Henceforth, the system dynamics conceptualisation offers a potential technique for practitioners and policymakers as it can be used to design policies acceptable amongst at-risk communities (Head, 2014, Osberghaus, 2015, Schweizer and Renn, 2019). The implications of this research are presented in Section 9.2 in Indian context and Section 9.3 in broader context.

9.2. Implications of research findings to flood risk management policy in India

This section focuses on the results generated by answering the research question four (Table 1-1). Focusing on controlling the flood hazard, the construction of Kosi embankments by the government has increased the vulnerability of the Kosi Basin communities over time. The sediment deposition within the embankments has led the riverbed to rise, reducing the relative height of adjacent areas, thereby increasing waterlogging in the flood plain and increasing the vulnerability of the communities substantially year around. Moreover, in case of an extreme flood event, especially with climate change, the chances of flood water overtopping the levees increase the residual risk over time (Zischg et al., 2018, Di Baldassarre et al., 2013). The long-term impacts of building embankments, as found by this research, are 1) disruption of agricultural activity, which is the primary source of livelihood of communities in the area, 2) migration, both local and seasonal, which has resulted in a loss of social and economic capital, and 3) low sanitation and hygiene, especially among women and girls. All these three impacts are exacerbated by (i) land insecurity, (ii) caste discrimination, and (iii) weak governance processes as discussed in Section 9.2.1.

Understanding the management implications of the deep leverage points identified to be introduced in the system is pertinent. Deep leverage points are important as they identify places in a system to introduce deep transformative change. These deep leverage points are place where introducing change is hard but harness great potential to bring transformative change (Abson et al., 2017). According to Internal Displacement monitoring centre, 10.1 million people are displaced as a result of floods in 104 countries and territories worldwide (IDMC, 2022). 80% of the internal displacements out of the 23.7 million are reported in South Asia and East Asia and the Pacific (IDMC, 2022). The Internal Displacement monitoring centre has proposed that "More efforts are needed to understand the different drivers and triggers of displacement, and to assess for how long people remain displaced. Filling these persistent data gaps is vital to inform policy making and action for displacement risk reduction and durable solutions." (IDMC, 2022:78).

9.2.1. Root cause of vulnerability – deep leverage points

9.2.1.1. Power politics

In the context of Kosi Basin, power politics emerging from caste dynamics is an important factor leading to internal displacement as found out from the causal loop analysis. As such, the social norms and cultural beliefs regarding caste and social status represent a root cause of community vulnerability and a deep leverage point for system change. In any society, power politics lead to corruption and bribery. In case of Kosi Basin, it has resulted in 1) loss of land rights (Section 7.9.2.1), 2) loss of livelihood opportunities (Section 7.9.2.2), and 3) discrepancy in relief distribution (Section 7.9.2.3).

Caste-based power politics is deep rooted in India. Jeffrey (2002) reported that in rural north India, caste based corruptions allow rich farmers to gain access to lucrative marketing opportunities. Pankaj (2019) stressed that due to caste discrimination, Dalits are unable to access government funded welfare schemes such as employment opportunities and poverty eradication. He argued that the discrimination in welfare schemes is not only a result of corruption and favouritism but results from the socio-political structure of the society.

Nordin et al. (2018) conducted a study in Malaysia and concluded that floods provide opportunities for corruption especially in the response and recovery phase, which subsequently impacts the effectiveness of flood risk management. Asri et al. (2019) recognised that in Indonesia corruption negatively impacts the governance and results in poor disaster management. Pathak and Schundeln (2022) the relationship between caste-hierarchies and distribution of aid after the 2015 earthquake in Nepal. They concluded that upper caste people received more aid than lower caste community members due to favouritism. The upper caste people were benefitted by upper caste aid workers, but it is not the case with lower caste aid workers.

Ray-Bennett (2009) conducted a study in Odisha and concluded that for effective disaster management, there is a need to provide considerations to caste and class. Addressing issues of bribery and corruption could represent a lever for change in Kosi Basin. Some possible levers are mentioned in Section 9.2.2.1.

9.2.1.2. Male seasonal migration

Male seasonal migration is a maladaptation adopted by the Kosi Basin communities due to the loss of livelihood opportunities and has resulted in a loss of social and economic capital (Page 328). Human migration as a response to environmental stress has been observed in many parts of the world, and studies have been carried out to explore the causes and implications of this movement. For example, Mueller et al. (2014) conducted a quantitative study in rural Pakistan, showing that heat stress increases long-term human migration. Another quantitative study in Bangladesh suggests that crop failure, along with flooding, is a fundamental reason for migration due to the loss of financial stability (Gray and Mueller, 2012). An empirical study carried out in Tanzania by Ocello et al. (2014) shows that migration is a crucial livelihood strategy for individuals without education in response to floods and droughts.

Moreover, waterlogging is a major form of groundwater flooding impacting countries around the world, such as the Kosi Basin and Indian Sundarban delta (Ghosh and Mistri, 2020) in India, Padma Basin in Bangladesh (Awal and Islam, 2020), Indus Basin in Pakistan (Qureshi et al., 2008) and Awash Basin in Ethiopia (Gebrehiwot, 2018). The livelihood opportunities of at-risk communities are negatively affected by the period of waterlogging (Alam et al., 2017, Nithila et al., 2022, Chakravorty and Jha, 2022). Therefore, loss of livelihood opportunities is a major factor forcing the marginalised community stakeholders to migrate within the country in search of daily wage opportunities.

However, studies such as Warner et al. (2012) and Warner and Afifi (2014) have described migration as maladaptation or erosive. Male seasonal migration might help the communities to deal with the immediate pressures but in long term, it undermines resilience. Climate induced migration results in loss of labour, knowledges and skills within a community (Warner and Afifi, 2014). Moreover, Adger et al. (2011:20) argues that migration "cannot be considered successful if they result in damage to people's traditions, knowledge, social orders, identities, and material cultures". Therefore, male seasonal migration does not necessarily provide food security, resulting in climate-induced poverty trap in the long term as evident from the studies conducted by Jacobson et al. (2019).

9.2.1.3. Vulnerability in women

Flood risk is not homogenously distributed among communities, and women are more vulnerable to floods than men (IPCC, 2022). Actions such as male seasonal migration put extra pressure on women to take care of the household while the men migrate (Section 7.3.1.2). However, the women are paid less for the same labour, agricultural or masonry (Page 132), leaving them more vulnerable to floods.

Azad et al. (2013) conducted a study in Bangladesh and concluded that women are more vulnerable to disasters than men due to poverty, inability to maintain personal hygiene and sanitation, unemployment, domestic violence. Othman et al. (2017) assessed flood vulnerabilities in women and concluded that prevalent social norms that makes women the responsible individual to take care of the households during disaster make them more vulnerable to hazards. Hudson et al. (2021) conducted a study in Vietnam and the results showcased that gender-based inequalities result in a slower rate of recovery for women after floods.

Therefore, gender-based vulnerability to floods has been observed in different parts of the world. The social and patriarchal norms exist especially in the Global south makes the women more vulnerable to flooding. It is crucial to empower these women (IPCC, 2022), which will help improve their quality of life and will be a step in the direction to make them resilient towards floods. Some levers for empowering women are presented in Section 9.2.2.3.

9.2.2. Potential solutions (levers)

Some examples of good practices from around the world are presented in this section in an attempt to emphasise the importance of inclusion of local knowledges in flood risk planning and promoting integrated flood risk management. It is important to note that providing these examples are a speculative exercise and considered important to mention, but it is more forward looking, and this research work does not directly inform this.

9.2.2.1. Land rights

Lessons can be learnt from the impact of human rights watch organisation on Zambia's forcefully evicted villages. Some commercial farmers converted the traditional land of these villagers into farm blocks. In their news article, human rights watch mentioned that after they published their results in 2013, the displaced community filed a complaint to the Zambian high court with the help of Southern Africa Litigation Centre. The court ruled in their favour, and the attorney general, the local government and the private company at issue were to deliver relief to these communities. The relief included the provision of alternate land and compensation for violating the rights of these villagers (Nnoko-Mewanu, 2020). Therefore, a potential solution (lever) that can be deployed to tackle systemic injustice is the provision of legal aid, which when institutionalised in disaster risk policies can enable positive social transformation. Legal aid can help the marginalised community members raise their voices to uphold their land rights. Moreover, Groundswell report part II 2021 is a report prepared by the World Bank focusing on actions that need to be taken on internal climate migration. In the report, the recommendation for policymakers stresses the need to build an effective land administration system which will ensure the security of tenure, reduction in informal tenure and recognition of customary land practices (Clement et al., 2021).

9.2.2.2. Sustainable livelihood opportunities

Long-term solutions lie in providing long-term sustainable livelihood opportunities for Kosi Basin communities. Addressing the issue of migration in policies is becoming more prominent with climate change. The importance of addressing the issue of human migration is also reported on the international scale by the Intergovernmental Panel on Climate Change, the Adaptation report 'Summary for policy makers' (IPCC, 2022). In their groundswell report, which focuses on internal climate migration, the World Bank has pointed out that stakeholder engagement, including international, national and local stakeholders, is the key to pursuing and achieving holistic and sustainable solutions to migration (Rigaud, 2018). World Bank Policy Research Working Paper 427 mentioned that "A relevant area of policy-oriented research is the interaction of migration with existing government programs" (McKenzie and Sasin, 2007: 13). Therefore, there is a need to include the issue of migration in flood risk policies, working with the relevant actors at the local, national and international scale.

With respect to waterlogging, there has been advancement in research to improve drainage in waterlogged areas. Such examples include installing vertical drains in the waterlogged areas to minimise seasonal waterlogging (Prathapar et al., 2018) and dry drainage, in which part of the land is set aside as a sink for excess groundwater and salt transport with the groundwater. Therefore, dry drainage requires providing a pathway from irrigated land to fallow land (Konukcu et al., 2006). It is crucial to consider waterlogging as groundwater flooding and devise policies to build resilience in the communities residing in the waterlogged area rather than focusing only on surface water flooding. This waterlogging has resulted from the hard engineering solution (the Kosi embankments) devised by the government to manage flood hazards. Therefore, there is a need to ensure ecological balance in the area so that the communities have agricultural lands as a source of income during the non-monsoon period.

Additionally, there is a requirement to generate a viable livelihood system by focusing on integrated management of natural resources and landscapes, providing diversified livelihood opportunities to at-risk communities (Clement et al., 2021), in the waterlogged area. It is noteworthy that research efforts are being made to develop drought and waterlogging-tolerant crop plants. Bashar et al. (2020) researched the science behind developing waterlogging tolerant crop plants and concluded that there is a need to devote research in this direction. Another study focused on creating tropical maize which can tolerate waterlogging and drought stresses (Das et al., 2021). Moreover, Ghosh and Mistri (2020) advocate that crop diversification has the potential to become the alternative way forward for building a self-resilient farming system. This research direction has the potential to provide livelihood opportunities to waterlogged communities and reduce migration.

In its national strategy on internal displacement management 2021, the Ministry of Disaster Management and Relief, Bangladesh, has focused on social security and resilience of internally displaced communities. The internal displacement in Bangladesh is majorly due to tidal floods, followed by tropical cyclones and storm surges. The solutions to be introduced focus on livelihood diversification, including off-farm livelihood and providing skills training to marginalised community stakeholders, adopting/upscaling hazard-resistant agricultural practices such as drought-tolerant crop varieties (MoDMR, 2021).

9.2.2.3. Empowerment of women

World Bank conducted an experiment in Tunisia that provided women cash grants and financial training to women. The results show that it was a highly cost-effective program and stimulated women's ability to generate income, but only when their partners were not involved (Gazeaud et al., 2022). This program recommended that careful considerations should be undertaken not to alter the societal norms and traditional gender roles in the area, which applies to a rural context like Kosi.

Furthermore, UN Women has started an initiative called fund for gender equality that has been working in different parts of the world. They are working towards offering systematic support for the livelihood of rural women, land rights, and representation in government elections (UNWomen, 2019). In the policy brief 'Gender-responsive disaster risk reduction', the United Nations office for disaster risk reduction provided policy recommendations that stresses to "address structural gender inequality as an underlying driver of risk in disaster risk reduction laws, policies, programs and governance" (UNDRR, 2022:3).

9.2.3. Systemic approach for deep transformation

It is vital to understand that the deep levers mentioned above cannot be used in seclusion because 1) flood risk in Kosi Basin is multi-faceted, consisting of social, political and economic dimensions and 2) systemic, i.e., there exists interactions among all these domains of action, as assessed by Kosi Basin system dynamics. Therefore, a gender-equality focused response will not be effective without also dealing with crop vulnerabilities to flooding, impacts of male seasonal migration, and cultural perceptions of caste. Moreover, it is not only essential that land rights are recognised in the Kosi Basin, which is a political issue, but also the considerations of the land which itself is at risk from flooding (an environmental issue) should be considered. These interactions highlight the importance of coordinating solutions and thinking systemically. In order to provide sustainable solutions to address the flood risk drivers present in Kosi, there is a need to build inclusive flood risk policies, laws, program and governance.

Lessons can be learnt from Fiji, where the social, political and economic dimensions such as gendered risk, relocation, and displacement concerning flood risk have been integrated into the climate change bill and national disaster management act (UNWomen, 2020). The government of Fiji released the plan in 2018, 'Republic of Fiji: National adaptation plan, a pathway towards climate resilience', in which they stressed the importance of 1) horizontal and vertical integration and 2) focusing on the whole system rather than interventions (Government of the Republic of Fiji, 2018). In their reforms, horizontal integration means including climate change issues in national development planning processes. This integration will increase the robustness of the planning process, strengthen coordination between different actors and can be instrumental in preventing maladaptive outcomes. Vertical integration relates to the integration of climate change issues in planning processes at the sub-national level. This integration gives opportunities to include local-level experiences to inform national policies and help reduce risks where they are experienced. "The focus on systems and processes – rather than simply interventions – enables the potential for paradigmatic change where actions trigger broader changes throughout the country." (Government of the Republic of Fiji, 2018:3).

In Bihar, the Ministry of rural development launched a social welfare program 'Pradhan Mantri Gramin Awas Yojna' (housing scheme for rural India) in 2015, a project aiming to provide planned residences to people residing in informal settlements (Ministry of Rural Development India, 2022). Other schemes include Mahatama Gandhi National Rural Employment Guarantee Scheme, under the Ministry of Rural Development, which works on providing livelihood opportunities to rural households (Ministry of Rural Development India, 2022). The flood risk managers can collaborate with these experts in housing informalities to look for solutions for the flood-affected landless community members in Kosi Basin and also to incorporate flood-induced loss of agricultural opportunities in policies to devise livelihood opportunities for the Kosi Basin at-risk communities.

This collaborative working environment will require bridging the gap between local and scientific knowledges. The deep levers identified in this research can act as a platform for different actors focusing on different issues such as land reforms, livelihood opportunities, women empowerment to come together and collaborate (Mai et al., 2020) to provide pathways for deep transformational systemic changes. However, to devise and implement systemic transformation, an attempt of interdisciplinary collaboration might result in different options on how the transformation arises or recognised (Feola, 2015). Nonetheless, having a platform to discuss and communicate provides opportunities to widen our perceptions and understandings towards option appraisal to implement policy reforms (Fisher et al., 2022).

Furthermore, policy implementation has a pivotal role to play. There needs to be a way to cross-check the policy implementation. The policies should be area-specific, and not all central policies can be implemented effectively in places with different spatial and temporal dimensions. Therefore, linking the management infrastructure of the authorities to the needs of the communities is required. This linkage will ensure the effective transference of local knowledges to ensure that the policy in place is implemented as intended and required.

9.3. Broader implications of developed methodology on the flood risk management paradigm

The socio-environmental system perspective advanced in this thesis challenges prevailing norms in river management and research. This section is directly related to the research question four posed in the beginning of the research, i.e., How do the systems of causality reveal and characterise flood risk and vulnerability? The sections below showcase the advancement of the current research and management policies concerning flood risk.

9.3.1. Contributions in the field of flood risk research

Flood risk research is currently dominated by quantitative assessment of hazards (Cardona, 2003) (Section 2.2). However, such quantitative methods have limited ability to model social systems (Mount et al., 2016). Panta Rhei (Page 46) advocates that an interdisciplinary approach is required to develop and explore new methodologies which can model the interactions and feedbacks between physical and social systems (Mount et al., 2016). This challenging task has opened up opportunities for developing methodologies that can capture new knowledge forms to improve our understanding of these complex systems, thus helping us improve our knowledge about flood risk.

There has been substantial evidence demonstrating that local communities have the potential to play a prominent role in building governance strategies to sustainably manage natural resources (Blom et al., 2010, Voß and Bornemann, 2011). In the context of policy-making, the role of local knowledges is still undermined, although these knowledges have the potential to help plan governance and management of socio-environmental systems (Mistry et al., 2016a). Mistry and Berardi (2016) suggested that to bridge the gaps between local and scientific knowledges, there is a requirement to understand the problem situation at the ground level by engaging with the at-risk communities and then seek relevant scientific expert knowledges to devise actions to solve the problem. Additionally, Raymond et al. (2010) argue that there is no optimum way to integrate local and scientific knowledges, and there needs to be a scientific shift from developing integrated knowledge products to developing problem-focused knowledge integration processes.

The thesis began with the assumption that soft system thinking is critical to understanding the complex socio-environmental flood system as the conventional hard system methods involving scientific knowledges alone are insufficient to address this complex phenomenon (Suriya and Mudgal, 2013). The methodology used in this research was adopted from the soft system technique devised by Checkland and Scholes (2001) and multimethod approach (Jackson, 2019). The soft system methodology was tailored for the field setting, i.e., Kosi Basin and was used in conjunction with the system dynamic approach. The methodology was devised to enable the researcher to gather rich qualitative data from local knowledges and then analyse it to understand the system's dynamic behaviour. This methodological framework developed in this thesis is one of the key contributions of this research.

However, conducting such research has its challenges. Capturing human dimensions includes deriving flood risk based on the flood experiences from the perspective of the at-risk people. These experiences are qualitative in nature and hard to quantify without losing valuable information. The adopted methodology in this research reflects how these local knowledges consists of rich information that can be captured, shared and harnessed for flood risk management at a local scale. The role of the researcher was to help elicit and organise knowledge from local perspectives and to bring these into conversation with other forms of knowledges present in the flood system. Therefore, the role of scholarly research is paramount in exploring the importance of local knowledges for identifying solutions for flood risk management solutions, especially in a local context.

The approach used in this thesis is not proposed to replace the prevailing and existing methods for assessing flood risk based on scientific, biophysical knowledge, but rather to complement and enrich them (Fisher et al., 2022). Therefore, the approach adopted in this research i.e., participatory modelling can be utilised to bridge the gap between local and scientific knowledges. The deep leverage points identified in the research can serve as a platform for relevant actors to collaborate and identify ways to incorporate these deep leverage point to develop sustainable and effective strategies.

9.3.2. Flood risk management implications around the world

There have been many cases around the world where interventions based on the traditional flood hazard paradigm, which has privileged knowledge from physical and engineering sciences, have unintentionally exacerbated the physical risk posed by flooding and reinforced social vulnerabilities. Key examples are covered here, with comparisons made to the Kosi Basin. Cases such as the Kosi floods in 2008 (Mishra et al., 2008), the Oder floods in central Europe in 1997 (Kundzewicz et al., 1999), the Yangtze River flood in 1998 (Zong and Chen, 2000), and the New Orleans flood in 2005 (Andersen and Buhrman, 2007) showcase scenarios where the physical engineered structural measures have failed to control floods, disturbing the socio-environmental system. Building levees permits more housing development on the floodplain but reduces community resilience to flooding longer term (Di Baldassarre et al., 2013). In Kosi Basin, building embankments led to more significant problems, such as waterlogging and displacement of communities. Physical engineered structural measures can unintentionally undermine social resilience because these communities are losing agricultural opportunities and being displaced based on the system’s hydrology. With technological advancement, flood hazard/risk assessment has been used to reduce flood losses by providing a way for decision-makers to predict, analyse, and manage the impacts of floods (Zhou et al., 2021, Duan et al., 2012). However, the limitations of such techno-scientific methods are (i) marginalisation of stakeholders, and (ii) mismatch of scales (i.e., catchment processes vs. local communities' responses), discussed below:

Marginalisation of stakeholder: The techno-scientific approach is a powerful tool well-suited for modelling and appraising hazards (Jonkman et al., 2008, Dawson and Hall, 2006) and participation in understanding the flood problem is mainly limited to scientific experts (e.g. Suriya and Mudgal (2013), Bunch (2003) and Mai et al. (2020)). Neglecting the participation of marginalised stakeholders leaves them struggling to understand the different options identified, appraised and prioritised. This inaccessibility leaves the marginalised stakeholders on the periphery of the decision-making process without necessary information to respond and adapt to future flood events. Moreover, As a result, neglected participation of marginalised stakeholders leads to a) a lack of support for the intervention options, b) dissatisfaction in the decision-making process, and c) distrust in scientific experts (Maskrey et al., 2016).

Mismatch of scales (i.e., catchment processes vs. local communities' responses): The policies and intervention options are proposed and implemented by international and national governments and are not always well-suited to the ground realities in every local context (Mistry et al., 2016a). Both the hard defences approach and flood maps privilege scientific and expert knowledges in the decision-making process, neglecting local knowledges. On the international scale, the Adaptation report ‘Summary for policy makers’ published by the

Intergovernmental Panel on Climate Change argues that "Inclusive planning initiatives informed by cultural values, Indigenous knowledge, local knowledge, and scientific knowledge can help prevent maladaptation" IPCC (2022: 47). The maladaptation refers to using hard defences against flooding. The local knowledges bring crucial information about flood experiences and the learning these communities have derived over the years facing floods (Evans and Plows, 2007). Moreover, hard defence approaches focus fail to accommodate a complex, relational, and systemic ontology of flood systems, instead assuming linear relationships between floods and humans. They rarely grapple with the complex feedbacks and interactions between the social and physical systems, which are crucial in understanding system behaviour.

The United Nations Office for Disaster Risk Reduction adopted the Sendai Framework 2015-2030 during the third UN world conference on disaster risk reduction. The goal of the Sendai Framework is to "Prevent new and reduce existing disaster risk through the implementation of integrated and inclusive economic, structural, legal, social, health, cultural, educational, environmental, technological, political and institutional measures that prevent and reduce hazard exposure and vulnerability to disaster, increase preparedness for response and recovery, and thus strengthen resilience" (UNDRR, 2015). Therefore, the Sendai Framework advocates for a systems perspective for strengthen resilience against disasters and there is a need to translate the Sendai framework to the Kosi context, i.e., by focusing on the economic, structural, legal, social, health, cultural, educational, environmental, technological, political and institutional characteristics to improve the community resilience.

It is important to stress that the answer is not to abolish the use of flood maps but to integrate them into a more holistic flood management process. Community participation is the way forward to understand the system characteristics mentioned in the Sendai Framework as these communities are a part of the human-flood interactions taking place in these socio-environmental systems. When considering the flood risk management strategies in the western developed countries, there has been prevalent community participation in countries like the UK, the Netherlands and Italy under the European flood directive (Wehn et al., 2015). The community role and influence in participation are based on the different authorities' varied perceptions, focusing on either prevention, mitigation, preparedness, or response stage of the flood cycle (Wehn et al., 2015). However, in Kosi Basin, the political and social context fails to recognise the value of local perspectives, and the hard science holds a privileged position in policy formulation and decision-making.

In the Global South countries, there occurs an annual cyclicity of floods which defines and drives the flood risks of communities. The annual cyclicity of the socio-environmental system is a phenomenon observed in the global south, which is on the frontline of climate change and is environmentally vulnerable (IPCC, 2022). The participatory approach adopted in this research to build a socio-environmental system model can be used in countries where such cyclic system behaviour occurs. The main message is that in regions where there is an acute cyclical nature to hydrological dynamics, it is also necessary to understand social vulnerabilities in a more nuanced temporal context. Some examples include Padma Basin in Bangladesh (Alam et al., 2017), where communities face surface water and groundwater flooding problems, Indus Basin in Pakistan (Mueller et al., 2014), and Sri Lanka (Dasandara et al., 2022).

Moreover, the methodological framework adopted in this research can be applied to other socio-environmental systems and disasters. This research uncovered a need to understand how social vulnerability to flooding changes over time according to human responses to risk. This principle is applicable everywhere but is especially important in India due to the negligence of the social vulnerability dimension in the flood risk policy framework.

9.3.3. Impacts on existing geographical research

This research helps to bridge critical perspectives on vulnerability (e.g., foregrounding importance of gender, religion, caste and power) (UNESCO, 2017) and practical solutions (e.g., language and methodology that are interpretable by policymakers).

Geographers such as Phillip et al. (2023) have carried out a similar project in Malawi and mentioned how the quantitative data clarifies the extent of a problem and, on the other hand, participatory approaches help in exploring the practices and attitudes in a community. The multimethod approach (Jackson, 2019) aided in utilising different methods in conjuncture with SSM which helped in extending our knowledge of Kosi Basin flood system and also benefitted in addressing the issues of power dynamics resulting from gender and caste. Moreover, the participatory approach used in this thesis emphasises the importance of co-construction of knowledge. However, the researcher was only able to involve the participants till the workshops due to the COVID-19 pandemic, it is pertinent to stress the importance of co-construction of knowledge with the participants rather than treating them as research subjects (Given, 2008).

This research also points out the importance of inclusion of gendered experiences (of women) in understanding a system, which is currently negligible in Kosi Basin. Similar findings have been presented by Rissgaard et. al (2010) in value chains. The findings in this research suggest that women play an important role in running the household and have invaluable knowledge which can help us develop our knowledge of systems, especially in rural context.

The multimethod approach helped in identifying deep leverage points. These deep leverage points showcase the importance of interdisciplinary intervention designs based of human-flood interactions which aligns with the finding of Sovacool et.al (2015). These interdisciplinary interventions are important to be implemented in such systems where hard engineering solutions have been failing these communities.

Finally, this thesis makes a step in providing a practical solution towards methodology and language. This thesis can be easily interpreted by policy makers and researchers in the field of geography to explore the vulnerabilities existing in a community.

9.4. Limitations

Abstraction of knowledge: The abstraction of complex and specific issues the researcher gathered during the interview and workshop stage has led to converting people’s lives into variables. While converting the gathered information into variables helps us understand the system dynamics, the system's formalisation loses the nuance required to illustrate the participants' feelings, emotions and individual perspectives (Tapsell et al., 2010, Adger, 2006, Alwang et al., 2001). However, the purpose of the research is to communicate the findings to decision-makers and academic researchers; therefore, the techno-scientific approach was used to convey the participants' understandings, experiences and fears.

Quantifying variables and representing uncertainties and sensitivities: The causal loop diagrams are suitable for understanding the feedback and existing interactions in the system (Barbrook-Johnson and Penn, 2022). However, they have limited ability to provide information, i.e., the interactions present in the causal loop diagrams cannot be quantified, and only the direction of change between two variables can be represented. Therefore, causal loop diagrams lack representation of uncertainties and sensitivities in the system (Barbrook-Johnson and Penn, 2022). The sensitivity analysis can be performed using a system dynamic model (Di Baldassarre et al., 2015). The research acknowledges that it is important to address the uncertainties and sensitivities while understanding system dynamics. However, a systems dynamics model would not have been able to quantify the qualitative variables identified in this research, such as quality of life, degree of belongingness and sense of security. Therefore, using causal loop diagrams in conjecture with leverage points heuristics allowed the researcher to identify the drivers of vulnerability in the Kosi Basin.

9.5. Recommendations

Based on the findings of this thesis, the leverage points defined suggest the entry points for 1) future research focus and 2) the practice of flood risk planning and policymaking for sustainable flood risk management are as follows:

Recommendation for future research:

1. The causal loop diagrams used in this research identified deep leverage points such as caste dynamics and economic paradigms. Future research should be invested in exploring these leverage points in detail, identifying sustainable pathways in which these leverage points can be explored and addressed in flood risk policy in Kosi Basin. This future work will require action-oriented research, working with the policy-makers to identify possible levers to bring deep transformational changes in the system, as suggested by Mistry and Berardi (2016) as a way forward to bridge the gap between local and scientific knowledges.

2. The methodological framework developed to conceptualise the socio-environmental system can be applied and tested in other case studies, especially in the field of disaster. The risks and vulnerabilities in any disaster are generated as a result of that disaster interacting with communities at-risk. Therefore, the tools and techniques used to represent local knowledges and formalise the system behaviour used in this research can be easily transferred to other disaster management in local context.

3. Due to Covid-19, the researcher was unable to organise field visits to verify the generated system causal loop diagrams. Therefore, the future research direction can include working with the Kosi communities to verify that the generated causal loop diagrams fulfil their expectations and represent the real-world situation.

Due to the field-based exploratory nature of this research, further refining and testing of the methodological framework are required. Applying the techniques and tools used in this research across different field settings in socio-environmental systems would help refine the methodological framework.

Recommendations for policymakers:

1. Acknowledging the importance of local knowledges would lead to developing flood risk policies which are well suited to the needs of at-risk communities. The prevalent hard defence and techno-scientific approaches assume linear relationships between floods and humans (Levin et al., 2013) and fail to accommodate a complex, relational, and systemic ontology of flood systems (Mount et al., 2016). In the context of flood risk, local knowledges are enriched with grounded realities of flood risk, i.e., the knowledge of the impact of floods, consequences, exposure and vulnerability established with years of lived experiences with floods (Robertson and McGee, 2003). The local knowledges were crucial in understanding that the vulnerabilities present in Kosi are not physical but are deep-rooted in social, political and economic dimensions of vulnerabilities. These knowledges can be incorporated with the already well-established scientific knowledges used in policy making, especially in a local context, to

devise holistic sustainable solutions to flood risk, understanding its dynamic nature (Fisher et al., 2022).

2. As found in this research, the key areas to reduce Kosi Basin communities’ vulnerability are land rights, alternative livelihood opportunities, internal migration, women empowerment, and waterlogging-resistant crops. Therefore, integration of different local, national and international policymakers is required to devise a holistic solution. The key areas identified requires an integrated approach because the deep leverage points are all connected to each other and a deep transformation of the system cannot be devise while looking at the parts rather than the whole system (Riechers et al., 2022).

   However, when the transformational change required is non-linear and non-teleological, i.e., the societal changes identified in this research then different stakeholders might feel differently about how the transformation arises or recognised (Feola, 2015). These different ways of understanding transformation provides opportunities for identifying new insights and advocacy for different policy actions (Fisher et al., 2022). Systems model created in this research can therefore be used as a platform for communication, dialogue and collaboration between different government and non-government agencies (Mai et al., 2020). In case of Kosi Basin, Ministry of Rural development (national), Bihar state disaster management authority (local), National disaster management authority (national), local and regional NGO and international agencies like the World Bank can collaborate to propose inclusive flood risk management policy.

In the context of governance and policymaking, these critical system-based heuristics will 1) allow for further testing and refining of the system conceptualisation methodology and 2) pave the way to exchange knowledge and learning with a theoretically grounded approach (Mai et al., 2020). Moreover, exploring their application in different types of systems (e.g., other natural disasters) can assist in verifying the transferability of the conceptual framework to different governance and policy-making context.

Chapter 10. Conclusion

The flood management strategies in India focus on minimising flood impacts by emphasising physical structural measures and emergency responses (Mohanty et al., 2020). In the case of the Kosi Basin, the Kosi embankments were built in the 1960s as a physical structural response to control Kosi floods. However, in the long term, these embankments have increased the vulnerability of the communities. Due to sediment deposition within the embankments, the riverbed has risen, reducing the relative height of the adjacent areas (Pandey et al., 2012). Waterlogging has become a common phenomenon in these flood plains due to the low relative height in the adjacent areas, increasing the vulnerability of the communities substantially year around (Mishra et al., 2008, Kumar et al., 2016). This case, interrogated in detail in this thesis, exemplifies the complexity and often unpredictability of flooding, the profound impacts it has on social vulnerability (Mustafa et al., 2015), and the perverse unintended consequences (Johnson et al., 2007, Kundzewicz et al., 1999, Sinha, 2009b) of linear scientific and mechanical paradigms of thinking when applied to socio-environmental systems.

The probability of extreme flooding is increasing with climate change. The extreme flood event includes flood water overtopping the levees, increasing the residual risk over time (Zischg et al., 2018, Di Baldassarre et al., 2013). The findings of this research indicate that the building of Kosi embankments has resulted in long-term impacts on the lives of the Kosi Basin communities by exacerbating the social, political and economic dimensions of vulnerability. The primary source of livelihood for these communities is agriculture, which has been disrupted, making these communities financially unstable. The financial instability has resulted in the maladaptation practice of male seasonal migration, a solution adopted by the Kosi communities to earn a livelihood. Moreover, both temporary and permanent local migration has resulted in social and economic capital loss. During temporary migration, the sanitation and hygiene standards amongst the communities are quite low, especially among women and girls. All these three impacts are exacerbated by land insecurity, caste discrimination, and weak governance processes.

In conclusion, inclusive flood risk management policies with a focus on providing sustainable solutions are needed to make at-risk communities resilient. The policies' ultimate goal should be improving these communities' quality of life, as identified in this research. Therefore, there is a need to look at the whole system and not the parts in isolation (Dyball and Newell, 2014, Rehman et al., 2019). In the context of Kosi Bain, variables such as male seasonal migration, waterlogging, forced land acquisition and gendered vulnerability are not included in policy responses. Yet these variables were shown to lead to a low sense of security, degree of belongingness and degree of financial stability, ultimately lowering the quality of life of the Kosi Basin communities. There is therefore a need to integrate and incorporate these social, political and economic dimensions of vulnerability along with physical vulnerabilities.

The need for capacity building in at-risk communities has been recognised, but there is a lack of proper implementation of the designed flood schemes (Mohanty et al., 2020). Moreover, these programs and aid, such as crop compensation or relief aid, rarely reach the most vulnerable community members, i.e., the marginalised community stakeholders, as observed in the causal loop diagrams. This research highlights the need to close this gap in designing and implementing flood risk management policies, especially at a local scale. The results of this research indicate that local knowledges play a crucial role in identifying the dimensions of vulnerabilities present in any system. However, marginalised stakeholders are often on the periphery of the decision-making process. This is due to (i) lack of political will to include other voices (Warner, 2006), and (ii) methodological challenges in representing these perspectives and integrating them with other kinds of knowledge (Mount et al., 2016). This research does not provide advancement to address political will to include other voices, but it does focus on the methodological challenges.

The tools and techniques used to represent, formalise, interrogate and synthesise the system used in this research were a key contribution of this research. The methodology adopted in this thesis was the foundation of identifying the deep leverage points and the social, political and economic vulnerabilities generated due to current flood management policies. These results were achieved by understanding the 'wholes rather than parts' (Richmond, 1994) i.e. by focusing on understanding the whole system rather than devising interventions for parts of the system. For looking at the system as a whole, local knowledges were used. Local knowledges bring crucial information about flood experiences and the learning these communities have derived over the years facing floods (Evans and Plows, 2007), which can enhance existing flood risk knowledge holistically. It is crucial to understand that this research does not propose to replace the prevailing and existing methods for assessing flood risk based on scientific knowledge but rather to complement and enrich them (Fisher et al., 2022). The research addresses the need articulated by environmental scholars for new systems based perspectives that allow integration of different forms of knowledge related to physical and social systems (Liu et al., 2007).

Therefore, there is a need to bridge this gap between local and scientific knowledges. This research stresses the value of participatory modelling to bridge this gap by incorporating local knowledges with the already present expert scientific knowledges. Participatory modelling can be useful when used with techniques such as rich picture workshops for generating collaborative knowledge about system behaviour. In the decision-making process, this generated knowledge can be used to inform the policy structure and devise actions to solve the root causes of the identified problems (Mistry and Berardi, 2016). As Mosse (2001) pointed out, these local knowledges can be more accurately viewed as 'planning knowledges', as they are generated as a result of the planning processes. Therefore, the new knowledges about the socio-environmental system acquired from eliciting these local knowledges can be used to inform the local flood risk management decision-making (Raymond et al., 2010, Haughton et al., 2015), hence completing the loop.

This research also demonstrates the essential importance of understanding the local context (Khalafzai et al., 2019) because the solutions to provide resilience might differ in different local contexts; it is essentially accurate regarding the social, political and governance structure concerning a particular local context. Therefore, flood risk management solutions and strategies might vary in different parts of the world, depending on the social, political and governance structure. However, the basic principles and definitions of flood risk and vulnerability are universal. The methodology adopted in this research helped demonstrate the importance of understanding the interactions and feedbacks amongst the system variables and the generation of flood risk due to the system dynamics. Therefore, this methodological framework can be easily transferred to different parts of the world to understand flood risk and also in different complex socio-environmental systems to identify the root causes of system behaviour.

There is a need to develop a fundamental understanding of flood vulnerabilities and resilience worldwide. The novel methodological framework adopted in this research and the resulting generated knowledge about system conceptualisation and deep leverage points can be a step forward in the direction of building a fundamental understanding of flood vulnerabilities and resilience at local, national and international scales. Therefore, there is a need for local perspectives to be well established as vital to the future of flood risk research and practice.

References

ABSON, D. J., FISCHER, J., LEVENTON, J., NEWIG, J., SCHOMERUS, T., VILSMAIER, U., VON WEHRDEN, H., ABERNETHY, P., IVES, C. D., JAGER, N. W. & LANG, D. J. 2017. Leverage points for sustainability transformation. *Ambio,* 46**,** 30-39.

ACKERMANN, F. & EDEN, C. 2011. Strategic Management of Stakeholders: Theory and Practice. *Long Range Planning,* 44**,** 179-196.

ADGER, W., BARNETT, J., CHAPIN III, F. S. & ELLEMOR, H. 2011. This Must Be the Place: Under Representation of Identity and Meaning in Climate Change Decision-Making. *Global Environmental Politics,* 11**,** 1-25.

ADGER, W. & KELLY, P. 1999. Social Vulnerability to Climate Change and the Architecture of Entitlements. *Mitigation and Adaptation Strategies for Global Change, Springer,* 4**,** 253-266.

ADGER, W. N. 2006. Vulnerability. *Global Environmental Change,* 16**,** 268-281.

ALAM, M., KHAN, M. K., PATIL, S., MISHRA, G. C., PARWEEN, M. H., KUMAR, M. & SINGH, A. 2016. Working to Build Livelihood Opportunities for the Elderly.

ALAM, M. S., SASAKI, N. & DATTA, A. 2017. Waterlogging, crop damage and adaptation interventions in the coastal region of Bangladesh: A perception analysis of local people. *Environmental Development,* 23**,** 22-32.

ALBRIS, K., LAUTA, K. C. & RAJU, E. 2020. Disaster Knowledge Gaps: Exploring the Interface Between Science and Policy for Disaster Risk Reduction in Europe. *International Journal of Disaster Risk Science,* 11**,** 1-12.

ALEXANDER, D. 1991. Natural Disasters: A Framework for Research and Teaching. *Disasters,* 15**,** 209-226.

ALHO, P. & AALTONEN, J. 2008. Comparing a 1D hydraulic model with a 2D hydraulic model for the simulation of extreme glacial outburst floods. *Hydrological Processes,* 22**,** 1537-1547.

ALMOTAIRI, B. & LUMSDEN, K. 2009. Port logistics platform integration in supply chain management. *INTERNATIONAL JOURNAL OF SHIPPING AND TRANSPORT LOGISTICS,* 1**,** 194-210.

ALTUNKAYNAK, A. 2009. Sediment load prediction by genetic algorithms. *ADVANCES IN ENGINEERING SOFTWARE,* 40**,** 928-934.

ALWANG, J., SIEGEL, P. B. & JORGENSEN, S. L. 2001. Vulnerability : a view from different disciplines.: The World Bank.

ANANDA, J. & HERATH, G. 2003. Incorporating stakeholder values into regional forest planning: a value function approach. *Ecological Economics,* 45**,** 75-90.
ANDERSEN, C. F. & BUHRMAN, J. The New Orleans hurricane protection system : what went wrong and why. 2007.
ANDERSSON, E., TENGO, M., MCPHEARSON, T. & KREMER, P. 2015. Cultural ecosystem services as a gateway for improving urban sustainability. *ECOSYSTEM SERVICES,* 12**,** 165-168.
ARIYABANDU, M. M. & FONSEKA, D. 2009. Do Disasters Discriminate? A Human Security Analysis of the Impact of the Tsunami in India, Sri Lanka and of the Kashmir Earthquake in Pakistan. *In:* BRAUCH, H. G., SPRING, Ú. O., GRIN, J., MESJASZ, C., KAMERI-MBOTE, P., BEHERA, N. C., CHOUROU, B. & KRUMMENACHER, H. (eds.) *Facing Global Environmental Change: Environmental, Human, Energy, Food, Health and Water Security Concepts.* Berlin, Heidelberg: Springer Berlin Heidelberg.
ARNOLD, R. D. & WADE, J. P. 2015. A Definition of Systems Thinking: A Systems Approach. *Procedia Computer Science,* 44**,** 669-678.
ARNOLD, S., ATTINGER, S., FRANK, K. & HILDEBRANDT, A. 2015. Assessing the structural adequacy of alternative ecohydrological models using a pattern-oriented approach. *ECOLOGICAL MODELLING,* 316**,** 52-61.
ASLAM, K., RASHID, S., SALEEM, R. & ASLAM, R. F. M. 2015. Use of Geospatial Technology for Assessment of Waterlogging & Salinity Conditions in the Nara Canal Command Area in Sindh, Pakistan. *Journal of Geographic Information System,* 07**,** 438-447.
ASRI, M., ALI, M. & IOP 2019. Transparency, ethical disaster and public sector corruption control in Indonesia. *1ST INTERNATIONAL CONFERENCE ON GLOBAL ISSUE FOR INFRASTRUCTURE, ENVIRONMENT & SOCIO-ECONOMIC DEVELOPMENT.*
ÅSTEDT-KURKI, P. & HEIKKINEN, R.-L. 1994. Two approaches to the study of experiences of health and old age: the thematic interview and the narrative method. *Journal of Advanced Nursing,* 20**,** 418-421.
ATTEFALK, L. & LANGERVIK, G. 2001. *Socio technical soft systems methodology – A sociotechnical approach to Soft Systems Methodology. .* Master, University of Gothenburg.
AUGUSTSSON, H., CHURRUCA, K. & BRAITHWAITE, J. 2019. Re-energising the way we manage change in healthcare: the case for soft systems methodology and its application

to evidence-based practice. *BMC Health Services Research,* 19**,** 666.

AWAL, M. & ISLAM, A. F. M. T. 2020. Water Logging in South-Western Coastal Region of Bangladesh: Causes and Consequences and People's Response. *Asian Journal of Geographical Research***,** 9-28.

AZAD, A. K., HOSSAIN, K. M. & NASREEN, M. 2013. Flood-Induced Vulnerabilities and Problems Encountered by Women in Northern Bangladesh. *INTERNATIONAL JOURNAL OF DISASTER RISK SCIENCE,* 4**,** 190-199.

BALICA, S. F., WRIGHT, N. G. & VAN DER MEULEN, F. 2012. A flood vulnerability index for coastal cities and its use in assessing climate change impacts. *Natural Hazards,* 64**,** 73-105.

BALLESTEROS-CANOVAS, J. A., SANCHEZ-SILVA, M., BODOQUE, J. M. & DIEZ-HERRERO, A. 2013. An Integrated Approach to Flood Risk Management: A Case Study of Navaluenga (Central Spain). *WATER RESOURCES MANAGEMENT,* 27**,** 3051-3069.

BANKOFF, G. F., G.

HILHORST, D 2004. *Mapping Vulnerability: Disasters, Development and People*, Routledge.

BARBROOK-JOHNSON, P. & PENN, A. S. 2022. Causal Loop Diagrams. *Systems Mapping: How to build and use causal models of systems.* Cham: Springer International Publishing.

BARRIBALL, K. L. & WHILE, A. 1994. Collecting data using a semi-structured interview: a discussion paper. *Journal of Advanced Nursing,* 19**,** 328-335.

BASHAR, K. K., TAREQ, M. Z. & ISLAM, M. S. 2020. Unlocking the mystery of plants' survival capability under waterlogging stress. *PLANT SCIENCE TODAY,* 7**,** 142-153.

BASKERVILLE, R. & WOOD-HARPER, T. 1996. A Critical Perspective on Action Research as a Method for Information Systems Research. *Journal of Information Technology,* 11**,** 235-246.

BAUMBUSCH, J. 2010. Semi-structured interviewing in practice-close research. *J Spec Pediatr Nurs,* 15**,** 255-8.

BDMA. 2014. *State Disaster Management Plan* [Online]. Government of Bihar. Available: http://www.bsdma.org/DMP.aspx?id=1 [Accessed 18/01/2021 2021].

BELL, S., BERG, T. & MORSE, S. 2016. Rich Pictures: Sustainable Development and Stakeholders - The Benefits of Content Analysis. *SUSTAINABLE DEVELOPMENT,* 24**,** 136-148.

BELL, S., BERG, T. & MORSE, S. 2019. Towards an Understanding of Rich Picture Interpretation. *Systemic Practice and Action Research,* 32**,** 601-614.

BERGSTRAND, K., MAYER, B., BRUMBACK, B. & ZHANG, Y. 2015. Assessing the Relationship Between Social Vulnerability and Community Resilience to Hazards. *Social Indicators Research,* 122**,** 391–409.

BHATT, C. M., GUPTA, A., ROY, A., DALAL, P. & CHAUHAN, P. 2021. Geospatial analysis of September, 2019 floods in the lower gangetic plains of Bihar using multi-temporal satellites and river gauge data. *Geomatics, Natural Hazards and Risk,* 12**,** 84-102.

BINDER, C., HINKEL, J., BOTS, P. & PAHL-WOSTL, C. 2013. Comparison of Frameworks for Analyzing Social-ecological Systems. *Ecology and Society,* 18**,** art26.

BIRKMANN, J. 2006. Measuring vulnerability to natural hazards: Towards disaster resilient societies. New York: United Nations University Press.

BJERKLIE, D. M., DINGMAN, S. L., VOROSMARTY, C. J., BOLSTER, C. H. & CONGALTON, R. G. 2003. Evaluating the potential for measuring river discharge from space. *JOURNAL OF HYDROLOGY,* 278**,** 17-38.

BLAIR, P. & BUYTAERT, W. 2016. Socio-hydrological modelling: a review asking "why, what and how?". *Hydrol. Earth Syst. Sci.,* 20**,** 443-478.

BLOM, B., SUNDERLAND, T. & MURDIYARSO, D. 2010. Getting REDD to work locally: lessons learned from integrated conservation and development projects. *Environmental Science & Policy,* 13**,** 164-172.

BLÖSCHL, G., SIVAPALAN, M., WAGENER, T., VIGLIONE, A. & SAVENIJE, H. H. G. Runoff prediction in ungauged basins: Synthesis across processes, places and scales. 2013.

BODOQUE, J. M., AMÉRIGO, M., DÍEZ-HERRERO, A., GARCÍA, J. A., CORTÉS, B., BALLESTEROS-CÁNOVAS, J. A. & OLCINA, J. 2016. Improvement of resilience of urban areas by integrating social perception in flash-flood risk management. *Journal of Hydrology,* 541**,** 665-676.

BOELENS, R. 2014. Cultural politics and the hydrosocial cycle: Water, power and identity in the Andean highlands. *Geoforum,* 57**,** 234–247.

BOGARDI, J. & BIRKMANN, J. 2004. Vulnerability Assessment: The First Step towards Sustainable Risk Reduction. *In:* MALZAHN, D. & PLAPP, T. (eds.) *Disaster and Society – From Hazard Assessment to Risk Reduction.* Berlin: Logos Verlag Berlin.

BOHLE, H.-G. 2001. Vulnerability and Criticality: Perspectives from Social Geography. *IHDP Update,* 2**,** 1-7.

BOHMANN, J. 1996. *Public Deliberation: Pluralism, Complexity and Democracy.,* Cambridge, MIT Press.
Bosch X, Titus SL (2009) Cultural challenges and their effect on international research integrity. The Lancet 373(9664): 610–612.
BOWEN, M. G. 1992. Feedback thought in social science and systems theory, George P. Richardson Philadelphia: University of Pennsylvania Press, 1991. *System Dynamics Review,* 8**,** 105-107.
BRAUN, V. & CLARKE, V. 2006. Using thematic analysis in psychology. *Qualitative Research in Psychology,* 3**,** 77-101.
BRIERLEY, G. J. & FRYIRS, K. 2000. River styles, a geomorphic approach to catchment characterization: Implications for river rehabilitation in Bega catchment, New South Wales, Australia. *ENVIRONMENTAL MANAGEMENT,* 25**,** 661-679.
BRONTE-STEWART, M. 1999. Regarding rich pictures as tools for communication in information systems development. *Comput Inf Syst,* 6**,** 104.
BROWN, J. D. & DAMERY, S. L. 2002. Managing flood risk in the UK: towards an integration of social and technical perspectives. *Transactions of the Institute of British Geographers,* 27**,** 412-426.
BRUGHA, R. & VARVASOVSZKY, Z. 2000. Stakeholder Analysis: A Review. *Health policy and planning,* 15**,** 239-46.
BRYSON, J. M. 2004. What to do when Stakeholders matter. *Public Management Review,* 6**,** 21-53.
BUBECK, P., KREIBICH, H., PENNING-ROWSELL, E. C., BOTZEN, W. J. W., DE MOEL, H. & KLIJN, F. 2017. Explaining differences in flood management approaches in Europe and in the USA - a comparative analysis. *Journal of Flood Risk Management,* 10**,** 436-445.
BUNCH, M. J. 2003. Soft Systems Methodology and the Ecosystem Approach: A System Study of the Cooum River and Environs in Chennai, India. *Environmental Management,* 31**,** 0182-0197.
BUSETTO, L., WICK, W. & GUMBINGER, C. 2020. How to use and assess qualitative research methods. *Neurological Research and Practice,* 2**,** 14.
BYE, P. & HORNER, M. 1998. Easter 1998 Floods: Final Assessment by the Independent Review Team. Bristol: EA.
CALLON, M. 1999. The Role of Lay People in the Production and Dissemination of Scientific Knowledge. *Science, Technology and Society,* 4**,** 81-94.

CANNON, T. & TWIGG, J. 2003. Social Vulnerability, Sustainable Livelihoods and Disasters. *Report to DFID Conflict and Humanitarian Assistance Department (CHAD)*.
CARDONA, O. D. 2003. The need for rethinking the concepts of vulnerability and risks from a holistic perspective a necessary review and criticism for effective risk management. Red de Estudios Sociales en Prevencion de Desastres en América Latina (LA RED), Facultad Latinoamericana de Ciencias Sociales (FLACSO).
CARREÑO, M., CARDONA, O. & BARBAT, A. 2007. A disaster risk management performance index, Natural Hazards. *Natural Hazards,* 41**,** 1-20.
CASSIDY, R., SINGH, N. S., SCHIRATTI, P.-R., SEMWANGA, A., BINYARUKA, P., SACHINGONGU, N., CHAMA-CHILIBA, C. M., CHALABI, Z., BORGHI, J. & BLANCHET, K. 2019. Mathematical modelling for health systems research: a systematic review of system dynamics and agent-based models. *BMC Health Services Research,* 19**,** 845.
CENSUS, I. 2011. Census 2011. India: Indian Government.
CHAKRAVORTY, B. & JHA, R. 2022. Assessment of Spatio-Temporal Variation of Waterlogged Areas Lying Between Lower Gandak and Burhi Gandak Basins, India. *JOURNAL OF THE INDIAN SOCIETY OF REMOTE SENSING,* 50**,** 583-596.
CHECKLAND, P. 2000. Soft systems methodology: a thirty year retrospective. *Systems Research and Behavioral Science,* 17**,** S11-S58.
CHECKLAND, P. B. 1981. *Systems thinking, Systems practice,* Chichester, Wiley.
CHECKLAND, P. B. & HAYNES, M. G. 1994. Varieties of systems thinking: The case of soft systems methodology. *System Dynamics Review,* 10**,** 189-197.
CHECKLAND, P. B. & SCHOLES, J. 2001. Soft Systems Methodology in Action. *In:* ROSENHEAD, J. & MINGERS, J. (eds.) *Rational Analysis for a Problematic World Revisited.* Chichester: Wiley.
CHENAIL, R. 2011. Interviewing the Investigator: Strategies for Addressing Instrumentation and Researcher Bias Concerns in Qualitative Research. *The Qualitative Report,* 16**,** 255-262.
CHILVERS, J. 2008. Environmental Risk, Uncertainty, and Participation: Mapping an Emergent Epistemic Community. *Environment and Planning A,* 40**,** 2990 - 3008.
CINDERBY, S. & FORRESTER, J. 2005. Facilitating the Local Governance of Air Pollution Using GIS for Participation. *Applied Geography - APPL GEOGR,* 25**,** 143-158.

CLAYTON, T., CLAYTON, A. M. H. & RADCLIFFE, N. J. 1996. *Sustainability: A Systems Approach*, Earthscan Publications.

CLEAVER, F. 2001. Institutions, Agency and the Limitations of Participatory Approaches to development. *In:* COOKE, B. & KOTHARI, U. (eds.) *Participation. The New Tyranny?* London: Zed Books.

CLEMENT, V., RIGAUD, K. K., SHERBININ, A., JONES, B., ADAMO, S. S., J. & SADIQ, N. S., E. 2021. Groundswell Part 2: Acting on Internal Climate Migration. Washington, DC: The World Bank.

CONTE, K. P. & DAVIDSON, S. 2020. Using a 'rich picture' to facilitate systems thinking in research coproduction. *Health Research Policy and Systems,* 18**,** 14.

CRIDLAND, L., JONES, S., CAPUTI, P. & MAGEE, C. 2015. Qualitative research with families living with autism spectrum disorder: Recommendations for conducting semistructured interviews. *Journal of Intellectual and Developmental Disability,* 40**,** 78-91.

CROSBY, B. 1991. Stakeholder Analysis: A Vital Tool for Strategic Managers.

CUTTER, S. L. 1996. Vulnerability to environmental hazards. *Progress in Human Geography,* 20**,** 529-539.

CUTTER, S. L., BARNES, L., BERRY, M., BURTON, C., EVANS, E., TATE, E. & WEBB, J. 2008. A place-based model for understanding community resilience to natural disasters. *Global Environmental Change,* 18**,** 598-606.

CUTTER, S. L., BORUFF, B. J. & SHIRLEY, W. L. 2003. Social Vulnerability to Environmental Hazards*. *Social Science Quarterly,* 84**,** 242-261.

CUTTER, S. L. & EMRICH, C. T. 2006. Moral Hazard, Social Catastrophe: The Changing Face of Vulnerability along the Hurricane Coasts. *The ANNALS of the American Academy of Political and Social Science,* 604**,** 102-112.

DAR, M. H., DE JANVRY, A., EMERICK, K., RAITZER, D. & SADOULET, E. 2013. Flood-tolerant rice reduces yield variability and raises expected yield, differentially benefitting socially disadvantaged groups. *Scientific Reports,* 3**,** 3315.

DAS, R. R., VINAYAN, M. T., SEETHARAM, K., PATEL, M., PHAGNA, R. K., SINGH, S. B., SHAHI, J. P., SARMA, A., BARUA, N. S., BABU, R. & ZAIDI, P. H. 2021. Genetic gains with genomic versus phenotypic selection for drought and waterlogging tolerance in tropical maize (Zea mays L.). *The Crop Journal,* 9**,** 1438-1448.

DAS, T. K., HALDAR, S. K., GUPTA, I. D. & SEN, S. 2014. River Bank Erosion Induced Human Displacement and Its Consequences. *Living Rev. Landscape Res.,* 8.

DASANDARA, M., ERNST, R., KULATUNGA, U. & RATHNASIRI, P. 2022. Investigation of Issues in Structural Flood Management Measures in Sri Lanka. *JOURNAL OF CONSTRUCTION IN DEVELOPING COUNTRIES,* 27**,** 65-78.

DAWSON, R. & HALL, J. 2006. Adaptive Importance Sampling for Risk Analysis of Complex Infrastructure Systems. *Proceedings: Mathematical, Physical and Engineering Sciences,* 462**,** 3343-3362.

DCTFP 1933. Thames Flood Prevention (Departmental Committee on Thames Flood Prevention). *NATURE.* MacMillan and Co., LTD., London.

DE BRITO, M. M., EVERS, M. & ALMORADIE, A. D. S. 2018. Participatory flood vulnerability assessment: a multi-criteria approach. *Hydrol. Earth Syst. Sci.,* 22**,** 373-390.

DE LOPEZ, T. T. 2001. Stakeholder management for conservation projects: a case study of Ream National Park, Cambodia. *Environ Manage,* 28**,** 47-60.

DEARNLEY, C. 2005. A reflection on the use of semi-structured interviews. *Nurse Res,* 13**,** 19-28.

DENNIS, L. R. & HORN, E. 2011. Strategies for Supporting Early Literacy Development. *Young Exceptional Children,* 14**,** 29-40.

DENZIN, N. K., LINCOLN, Y. S. & SMITH, L. T. 2008. Handbook of Critical and Indigenous Methodologies. Thousand Oaks, California: Sage.

DESSAI, S. & HULME, M. 2004. Does climate adaptation policy need probabilities? *Climate Policy,* 4**,** 107-128.

DI BALDASSARRE, G., ELSHAMY, M., VAN GRIENSVEN, A., SOLIMAN, E., KIGOBE, M., NDOMBA, P., MUTEMI, J., MUTUA, F., MOGES, S., XUAN, Y. Q., SOLOMATINE, D. & UHLENBROOK, S. 2011. Future hydrology and climate in the River Nile basin: a review. *HYDROLOGICAL SCIENCES JOURNAL-JOURNAL DES SCIENCES HYDROLOGIQUES,* 56**,** 199-211.

DI BALDASSARRE, G., SCHUMANN, G., BATES, P. D., FREER, J. E. & BEVEN, K. J. 2010. Flood-plain mapping: a critical discussion of deterministic and probabilistic approaches. *Hydrological Sciences Journal,* 55**,** 364-376.

DI BALDASSARRE, G., SIVAPALAN, M., RUSCA, M., CUDENNEC, C., GARCIA, M., KREIBICH, H., KONAR, M., MONDINO, E., MÅRD, J., PANDE, S., SANDERSON, M. R., TIAN, F., VIGLIONE, A., WEI, J., WEI, Y., YU, D. J., SRINIVASAN, V. & BLÖSCHL, G. 2019. Sociohydrology: Scientific

Challenges in Addressing the Sustainable Development Goals. *Water Resources Research,* 55**,** 6327-6355.

DI BALDASSARRE, G., VIGLIONE, A., C, G., KUIL, L., YAN, K., BRANDIMARTE, L. & BLÖSCHL, G. 2015. Debates—Perspectives on socio-hydrology: Capturing feedbacks between physical and social processes. *Water Resources Research,* 51**,** 4770-4781.

DI BALDASSARRE, G., VIGLIONE, A., CARR, G., KUIL, L., SALINAS, J. L. & BLÖSCHL, G. 2013. Socio-hydrology: conceptualising human-flood interactions. *Hydrol. Earth Syst. Sci.,* 17**,** 3295-3303.

DÍAZ, S., DEMISSEW, S., CARABIAS, J., JOLY, C., LONSDALE, M., ASH, N., LARIGAUDERIE, A., ADHIKARI, J. R., ARICO, S., BÁLDI, A., BARTUSKA, A., BASTE, I. A., BILGIN, A., BRONDIZIO, E., CHAN, K. M. A., FIGUEROA, V. E., DURAIAPPAH, A., FISCHER, M., HILL, R., KOETZ, T., LEADLEY, P., LYVER, P., MACE, G. M., MARTIN-LOPEZ, B., OKUMURA, M., PACHECO, D., PASCUAL, U., PÉREZ, E. S., REYERS, B., ROTH, E., SAITO, O., SCHOLES, R. J., SHARMA, N., TALLIS, H., THAMAN, R., WATSON, R., YAHARA, T., HAMID, Z. A., AKOSIM, C., AL-HAFEDH, Y., ALLAHVERDIYEV, R., AMANKWAH, E., ASAH, S. T., ASFAW, Z., BARTUS, G., BROOKS, L. A., CAILLAUX, J., DALLE, G., DARNAEDI, D., DRIVER, A., ERPUL, G., ESCOBAR-EYZAGUIRRE, P., FAILLER, P., FOUDA, A. M. M., FU, B., GUNDIMEDA, H., HASHIMOTO, S., HOMER, F., LAVOREL, S., LICHTENSTEIN, G., MALA, W. A., MANDIVENYI, W., MATCZAK, P., MBIZVO, C., MEHRDADI, M., METZGER, J. P., MIKISSA, J. B., MOLLER, H., MOONEY, H. A., MUMBY, P., NAGENDRA, H., NESSHOVER, C., OTENG-YEBOAH, A. A., PATAKI, G., ROUÉ, M., RUBIS, J., SCHULTZ, M., SMITH, P., SUMAILA, R., TAKEUCHI, K., THOMAS, S., VERMA, M., YEO-CHANG, Y. & ZLATANOVA, D. 2015. The IPBES Conceptual Framework — connecting nature and people. *Current Opinion in Environmental Sustainability,* 14**,** 1-16.

DICICCO-BLOOM, B. & CRABTREE, B. F. 2006. The qualitative research interview. *Medical Education,* 40**,** 314-321.

DIXIT, A. 2003. Floods and Vulnerability: Need to Rethink Flood Management. *In:* MIRZA, M. M. Q., DIXIT, A. & NISHAT, A. (eds.) *Flood Problem and Management in South Asia.* Dordrecht: Springer Netherlands.

DIXIT, A. 2009. Kosi Embankment Breach in Nepal: Need for a Paradigm Shift in Responding to Floods. *Economic and Political Weekly,* 44**,** 70-78.

DN 1988. Problem of Unity in the Agrarian Struggle: Case of Bihar. *Economic and Political Weekly,* 23**,** 941-943.

DOLOI, H. K. 2011. Understanding stakeholders' perspective of cost estimation in project management. *International Journal of Project Management,* 29**,** 622-636.

DOUGILL, A. J., FRASER, E. D. G., HOLDEN, J., HUBACEK, K., PRELL, C., REED, M. S., STAGL, S. & STRINGER, L. C. 2006. Learning from Doing Participatory Rural Research: Lessons from the Peak District National Park. *Journal of Agricultural Economics,* 57**,** 259-275.

DOUGLAS, I., GARVIN, S., LAWSON, N., RICHARDS, J., TIPPETT, J. & WHITE, I. 2010. Urban pluvial flooding: A qualitative case study of cause, effect and nonstructural mitigation. *Journal of Flood Risk Management,* 3**,** 112-125.

DTLR 2001. Planning Policy Guidance note 25: development and flood risk. Department for Transport, Local Government and The Regions.

DUAN, M., ZHANG, J. & LIU, Z. 2012. USE OF REMOTE SENSING AND GIS FOR FLOOD HAZARD MAPPING IN CHIANG MAI PROVINCE, NORTHERN THAILAND.

DUGGAN, D. E., FARNSWORTH, K. D. & KRAAK, S. B. M. 2013. Identifying functional stakeholder clusters to maximise communication for the ecosystem approach to fisheries management. *Marine Policy,* 42**,** 56-67.

DUNNING, C. M. & DURDEN, S. 2011. Social Vulnerability Analysis Methods for Corps Planning United States of America: Institute for Water Resources

DYBALL, R. & NEWELL, B. 2014. *Understanding Human Ecology: A systems approach to sustainability*.

DZULKARNAIN, A., SURYANI, E. & APRILLYA, M. R. 2019. Analysis of Flood Identification and Mitigation for Disaster Preparedness: A System Thinking Approach. *Procedia Computer Science,* 161**,** 927-934.

EDELENBOS, J., VAN BUUREN, A., ROTH, D. & WINNUBST, M. 2017. Stakeholder initiatives in flood risk management: exploring the role and impact of bottom-up initiatives in three 'Room for the River' projects in the Netherlands. *Journal of Environmental Planning and Management,* 60**,** 47-66.

EDEN, C., ACKERMANN, F., BRYSON, J., FINN, C., ANDERSEN, D. & RICHARDSON, G. 2006. Experiences in attempting to combine group support methods. *Group Decision and Negotiation International Conference.* Karlsruhe, Germany.

EIVAZY, H. & MALEK, M. R. 2019. Flood Management in Aqala through an Agent-Based Solution and Crowdsourcing Services in an Enterprise Geospatial Information System. *ISPRS International Journal of Geo-Information,* 8**,** 420.

EKER, S. & ZIMMERMANN, N. 2016. Using Textual Data in System Dynamics Model Conceptualization. *Systems,* 4.

EM-DAT 2022. EM-DAT: The CRED/OFDA International Disaster Database. Belgium: Université Catholique de Louvain, Brussels.

EMMETT, W. W. & WOLMAN, M. G. 2001. Effective discharge and gravel-bed rivers. *EARTH SURFACE PROCESSES AND LANDFORMS,* 26**,** 1369-1380.

ENSURE 2009. Integration of different vulnerabilities vs. Natural and Na-tech Hazards (Deliverable 2.2). *WP 2: Integration and connection of vulnerabilities.* European Project (2009-2011).

EVANS, R. & PLOWS, A. 2007. Listening Without Prejudice?: Re-discovering the Value of the Disinterested Citizen. *Social Studies of Science,* 37**,** 827-853.

FAZEY, I., PETTORELLI, N., KENTER, J., WAGATORA, D. & SCHUETT, D. 2011. Maladaptive trajectories of change in Makira, Solomon Islands. *Global Environmental Change,* 21**,** 1275–1289.

FEOFILOVS, M., ROMAGNOLI, F., CAMPOS, J. I., GOTANGCO, C. K., JOSOL, J. C., JARDELEZA, J. M. P., LITAM, J. E. & ABENOJAR, K. 2020. Assessing resilience against floods with a system dynamics approach: a comparative study of two models. *INTERNATIONAL JOURNAL OF DISASTER RESILIENCE IN THE BUILT ENVIRONMENT,* 11**,** 615-629.

FEOLA, G. 2015. Societal transformation in response to global environmental change: A review of emerging concepts. *Ambio,* 44**,** 376-390.

FIELDING, J. & BURNINGHAM, K. 2005. Environmental inequality and flood hazard. *Local Environment,* 10**,** 379-395.

FIORINO, D. J. 1990. Citizen Participation and Environmental Risk: A Survey of Institutional Mechanisms. *Science, Technology & Human Values,* 15**,** 226 - 243.

FISHER, E., BRONDIZIO, E. & BOYD, E. 2022. Critical social science perspectives on transformations to sustainability. *Current Opinion in Environmental Sustainability,* 55**,** 101160.

FLEUVRIER, J. P. 1995. Flood Risk: Education and Folk Memory. *EAT***,** 29–34.

FLOOD, R. & CARSON, E. Dealing with Complexity: An Introduction to the Theory and Application of Systems Science. 1988.

FMISC. 2021. *History of flood in Bihar* [Online]. Bihar: Flood management improvement support centre Available: http://fmis.bih.nic.in/history.html [Accessed 08/06/2021 2021].

FORD, J. D., PEARCE, T., MCDOWELL, G., BERRANG-FORD, L., SAYLES, J. S. & BELFER, E. 2018. Vulnerability and its discontents: the past, present, and future of climate change vulnerability research. *Climatic Change,* 151**,** 189-203.

FORDHAM, K. & STEVENSON-HINDE, J. 1999. Shyness, Friendship Quality, and Adjustment During Middle Childhood. *Journal of Child Psychology and Psychiatry,* 40**,** 757-768.

FORRESTER, J. 1958. Industrial Dynamics: A Major Breakthrough for Decision Makers. *Harvard Business Review,* 36**,** 37-66.

FORRESTER, J. W. 1961. *Industrial dynamics,* [Cambridge, Mass., M.I.T. Press.

FREEMAN, R. E. 1984. *Strategic Management: A Stakeholder Approach*.

FRENCH, C. E., WAITE, T. D., ARMSTRONG, B., RUBIN, G. J., BECK, C. R., OLIVER, I. & ENGLISH NATL STUDY FLOODING, H. 2019. Impact of repeat flooding on mental health and health-related quality of life: a cross-sectional analysis of the English National Study of Flooding and Health. *BMJ OPEN,* 9.

GADDIS, E. J. B., FALK, H. H., GINGER, C. & VOINOV, A. 2010. Effectiveness of a participatory modeling effort to identify and advance community water resource goals in St. Albans, Vermont. *Environmental Modelling & Software* 25**,** 1428-1438.

GAILLARD, J. C. & MERCER, J. 2012. From knowledge to action: Bridging gaps in disaster risk reduction. *Progress in Human Geography,* 37**,** 93-114.

GANG, I. N., SEN, K. & YUN, M. S. 2017. Is Caste Destiny? Occupational Diversification among Dalits in Rural India. *EUROPEAN JOURNAL OF DEVELOPMENT RESEARCH,* 29**,** 476-492.

GASSON, S. 2013. *The Purpose of Soft Systems Methodology* [Online]. Drexel University: College of computing and informatics. Available: http://cci.drexel.edu/faculty/sgasson/ssm/Purpose.html [Accessed 8 February 2022].

GAZEAUD, J., KHAN, N., MVUKIYEHE, E. & STERCK, O. 2022. With or Without Him? Experimental Evidence on Gender-Sensitive Cash Grants and Trainings in Tunisia. World Bank.

GEBREHIWOT, K. A. 2018. A review on waterlogging, salinization and drainage in Ethiopian irrigated agriculture. *Sustainable Water Resources Management,* 4**,** 55-62.

GHOSH, S. & MISTRI, B. 2020. Drainage induced waterlogging problem and its impact on farming system: a study in Gosaba Island, Sundarban, India. *Spatial Information Research,* 28**,** 709-721.
GIANNINI, V. & GIUPPONI, C. 2011. Integration by identification of indicators. *Advances in Science and Research,* 7.
Gillard, R., Gouldson, A., Paavola, J. and Van Alstine, J. (2016), Transformational responses to climate change: beyond a systems perspective of social change in mitigation and adaptation. WIREs Clim Change, 7: 251-265.
Given LM (ed) (2008). The sage encyclopedia of qualitative research methods. Sage publications, Thousand Oaks.
Glenzer, K. (2021). Toward equity: Power, cultural hegemony, and organizations. Action Research, 19(4), 609-613.
GNDR 2011. If we do not join hands: Views from the frontline – local reports of progress on implementing the Hyogo Framework for Action, with strategic recommendations for more effective implementation. Teddington: Global Network of Civil Society Organizations for Disaster Reduction.
GOB 2022. Bihar State Crop Assistance Scheme for Kharif 2022 season in the state of Bihar. *In:* DEPARTMENT, C. (ed.). Bihar: Government of BIhar.
GOBER, P. & WHEATER, H. S. 2015. Debates—Perspectives on socio-hydrology: Modeling flood risk as a public policy problem. *Water Resources Research,* 51**,** 4782-4788.
GOLE, C. V. & CHITALE, S. V. 1966. Inland delta building activity of Kosi River. *Journal of the hydraulics division,* 92**,** 111-126.
GOTANGCO, C. K., SEE, J., DALUPANG, J. P., ORTIZ, M., PORIO, E., NARISMA, G., YULO-LOYZAGA, A. & DATOR-BERCILLA, J. 2016. Quantifying resilience to flooding among households and local government units using system dynamics: a case study in Metro Manila. *JOURNAL OF FLOOD RISK MANAGEMENT,* 9**,** 196-207.
GOVERNMENT OF THE REPUBLIC OF FIJI 2018. Republic of Fiji National Adaptation Plan: A pathway towards climate resilience. Suva, Fiji.
GRAY, C. & MUELLER, V. 2012. Natural Disasters and Population Mobility in Rural Bangladesh. *Proceedings of the National Academy of Sciences of the United States of America,* 109**,** 6000-5.
GUEST, G., NAMEY, E. E. & MITCHELL, M. L. 2013. *Collecting qualitative data : a field manual for applied research,* Thousand Oaks, SAGE Publications.

GUNDERSON, L. & HOLLING, C. S. 2002. *Panarchy: Understanding Transformations in Systems of Humans and Nature,* Washington, Island Press.

HAASE, D. 2013. Participatory modelling of vulnerability and adaptive capacity in flood risk management. *Natural Hazards,* 67**,** 77-97.

HAIR, J. F., BUSH, R. P. & ORTINAU, D. J. 2000. *Marketing Research: a Practical Approach for the New Millennium,* Boston, McGraw-Hill.

HARALDSSON, H. 2004. *Introduction to system thinking and causal loop diagrams*.

HARRIS, S. G. 1990. The fifth discipline: The art and practice of the learning organization, by Peter Senge, New York: Doubleday/Currency, 1990. *Human Resource Management,* 29**,** 343-348.

HARRISON, S. R. & QURESHI, M. E. 2000. Choice of stakeholder groups and members in multicriteria decision models. *Natural Resources Forum,* 24**,** 11-19.

Harrowing JN, Mill J, Spiers J, et al. (2010) Culture, context and community: Ethical considerations for global nursing research. International Nursing Review 57(1): 70–77.

HART, S. L. & SHARMA, S. 2004. Engaging fringe stakeholders for competitive imagination. *Academy of Management Executive***,** 7–18.

HARVEY, G. L., THORNE, C. R., CHENG, X., EVANS, E. P., HAN, S., SIMM, J. D. & WANG, Y. 2009. Qualitative analysis of future flood risk in the Taihu Basin, China. *JOURNAL OF FLOOD RISK MANAGEMENT,* 2**,** 85-100.

HAUGHTON, G., BANKOFF, G. & J COULTHARD, T. 2015. In search of 'lost' knowledge and outsourced expertise in flood risk management. *Transactions of the Institute of British Geographers,* 40**,** 375-386.

HEAD, B. 2014. Managing urban water crises: Adaptive policy responses to drought and flood in Southeast Queensland, Australia. *Ecology and Society,* 19.

HEMINGWAY, L. & PRIESTLEY, M. 2006. Natural Hazards, Human Vulnerability and Disabling Societies: A Disaster for Disabled People? *Review of Disability Studies: An International Journal,* 2.

HINKEL, J., LINCKE, D., VAFEIDIS, A. T., PERRETTE, M., NICHOLLS, R. J., TOL, R. S., MARZEION, B., FETTWEIS, X., IONESCU, C. & LEVERMANN, A. 2014. Coastal flood damage and adaptation costs under 21st century sea-level rise. *Proc Natl Acad Sci U S A,* 111**,** 3292-7.

HOFFMANN, R. & MUTTARAK, R. 2017. Learn from the Past, Prepare for the Future: Impacts of Education and

Experience on Disaster Preparedness in the Philippines and Thailand. *World Development,* 96**,** 32-51.
HOLLOWAY, I. & TODRES, L. 2003. The Status of Method: Flexibility, Consistency and Coherence. *Qualitative Research,* 3**,** 345-357.
HORNER, R. W. 1976. The Thames tidal flood prevention scheme. *Long Range Planning,* 9**,** 78-83.
HUANG, D., ZHANG, R., HUO, Z., MAO, F., YOUHAO, E. & ZHENG, W. 2012. An assessment of multidimensional flood vulnerability at the provincial scale in China based on the DEA method. *Natural Hazards,* 64.
HUDSON, P., PHAM, M., HAGEDOORN, L., THIEKEN, A., LASAGE, R. & BUBECK, P. 2021. Self-stated recovery from flooding: Empirical results from a survey in Central Vietnam. *JOURNAL OF FLOOD RISK MANAGEMENT,* 14.
Hutcheson, M., Morton, A. & Blair, S. Critical Systems Heuristics: a Systematic Review (2023). Syst Pract Action Res.
IDMC 2022. Grid 2022: Children and youth in internal displacement. Internal displacement monitoring centre.
IDSN 2013. Equality in Aid: Addressing Caste Discrimination in Humanitarian Response.
IFRC 2020. World Disaster Report 2020.
IHA. 2018. *The Caste System* [Online]. ushistory.org. Available: http://www.ushistory.org/civ/8b.asp [Accessed 12 December 2018].
IMD 2011. Climate of Bihar. *CLIMATOLOGICAL SUMMARIES OF STATES SERIES - No. 18.* Pune: India Meteorological Department.
IPCC 2014. Summary for policymakers. In: Climate Change 2014: Impacts,Adaptation, and Vulnerability.Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. *In:* FIELD, C. B., BARROS, V. R., DOKKEN, D. J., MACH, K. J., MASTRANDREA, M. D., BILIR, T. E., CHATTERJEE, M., EBI, K. L., ESTRADA, Y. O., GENOVA, R. C., GIRMA, B., KISSEL, E. S., LEVY, A. N., MACCRACKEN, S., MASTRANDREA, P. R. & L.L., W. (eds.). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA,.
IPCC 2022. Summary for Policymakers. *In:* TIGNOR, H.-O. P. D. C. R. E. S. P. K. M. M. & OKEM, A. A. M. C. S. L. S. L. V. M. A. (eds.) *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel*

on Climate Change. Cambridge, UK and New York, NY, USA.
JACKSON, G., MCNAMARA, K. & WITT, B. 2017. A Framework for Disaster Vulnerability in a Small Island in the Southwest Pacific: A Case Study of Emae Island, Vanuatu. *International Journal of Disaster Risk Science,* 8**,** 358-373.
Jackson, Michael. (2019). Critical Systems Thinking and the Management of Complexity.
JACOBSON, C., CREVELLO, S., CHEA, C. & JARIHANI, B. 2019. When is migration a maladaptive response to climate change? *Regional Environmental Change,* 19.
JEFFREY, C. 2002. Caste, class, and clientelism: A political economy of everyday corruption in rural north India. *ECONOMIC GEOGRAPHY,* 78**,** 21-41.
JHA, M. K. 2015. Liquid disaster and frigid response: Disaster and social exclusion. *International Social Work,* 58**,** 704-716.
JHA, M. K. & RAGHAVAN, V. 2008. Disaster in Bihar: A Report from the TISS Assessment Team. Mumbai: Tata Institute of Social Sciences.
JHA, R. K. & GUNDIMEDA, H. 2019. An integrated assessment of vulnerability to floods using composite index – A district level analysis for Bihar, India. *International Journal of Disaster Risk Reduction,* 35**,** 101074.
JOHNSON, C., PENNING-ROWSELL, E. & PARKER, D. 2007. Natural and imposed injustices: the challenges in implementing 'fair' flood risk management policy in England. *GEOGRAPHICAL JOURNAL,* 173**,** 374-390.
JOHNSON, C. L., TUNSTALL, S. M. & PENNING-ROWSELL, E. C. 2005. Floods as Catalysts for Policy Change: Historical Lessons from England and Wales. *International Journal of Water Resources Development,* 21**,** 561-575.
JONGMAN, B., HOCHRAINER-STIGLER, S., FEYEN, L., AERTS, J. C. J. H., MECHLER, R., BOTZEN, W. J. W., BOUWER, L. M., PFLUG, G. C., ROJAS, R. & WARD, P. J. 2014. Increasing stress on disaster-risk finance due to large floods. *Nature Climate Change,* 4**,** 264-268.
JONKMAN, S. N., KOK, M. & VRIJLING, J. 2008. Flood Risk Assessment in the Netherlands: A Case Study for Dike Ring South Holland. *Risk analysis : an official publication of the Society for Risk Analysis,* 28**,** 1357-74.
JUNTTI, M., RUSSEL, D. & TURNPENNY, J. 2009. Evidence, politics and power in public policy for the environment. *Environmental Science & Policy,* 12**,** 207-215.
KABISCH, S. 2019. URBAN TRANSFORMATIONS TO PURSUE SUSTAINABILITY THROUGH RESOURCE EFFICIENCY,

QUALITY OF LIFE AND RESILIENCE: A CONCEPTUAL APPROACH. *GEOGRAPHIA TECHNICA,* 14**,** 98-107.

KALLIO, H., PIETILÄ, A.-M., JOHNSON, M. & KANGASNIEMI, M. 2016. Systematic methodological review: developing a framework for a qualitative semi-structured interview guide. *Journal of Advanced Nursing,* 72**,** 2954-2965.

KANDASAMY, J., SOUNTHARARAJAH, D., SIVABALAN, P., CHANAN, A., VIGNESWARAN, S. & SIVAPALAN, M. 2014. Socio-hydrologic drivers of the pendulum swing between agricultural development and environmental health: a case study from Murrumbidgee River basin, Australia. *Hydrol. Earth Syst. Sci.,* 18**,** 1027-1041.

KAOJE, I. U., RAHMAN, M. Z. A., TAM, T. H., SALLEH, M. R. M., IDRIS, N. H. & OMAR, A. H. 2021. An Indicator-Based Approach for Micro-Scale Assessment of Physical Flood Vulnerability of Individual Buildings. *INTERNATIONAL JOURNAL OF BUILT ENVIRONMENT AND SUSTAINABILITY,* 8**,** 23-33.

KAR, N. 2006. Psychosocial issues following a natural disaster in a developing country: a qualitative longitudinal observational study. *International Journal of Disaster Medicine,* 4**,** 169-176.

KAR, N. 2009. NATURAL DISASTERS IN DEVELOPING COUNTRIES: MENTAL HEALTH ISSUES. *Indian Journal of Medical Sciences,* 63**,** 327-329.

KARAGIORGOS, K., THALER, T., HÜBL, J., MARIS, F. & FUCHS, S. 2016. Multi-vulnerability analysis for flash flood risk management. *Natural Hazards,* 82**,** 63-87.

KATUWAL, S. B. 2008. The Issues and Concerns of Dalit Labourers in Nepal. *In:* MOHANTY;, P., MALIK;, R. C. & KASI, E. (eds.) *Ethnographic Discourse of the Other: Conceptual and Methodological Issues.* Newcastle, UK: Cambridge Scholars Publishing.

KAUSHIK, A. D. & SHARMA, V. K. 2012. Flood Management in India. *Indian Journal of Public Administration,* 58**,** 119-136.

KELLENS, W., ZAALBERG, R., NEUTENS, T., VANNEUVILLE, W. & DE MAEYER, P. 2011. An Analysis of the Public Perception of Flood Risk on the Belgian Coast. *Risk Analysis,* 31**,** 1055-1068.

KELLY, R. A., JAKEMAN, A. J., BARRETEAU, O., BORSUK, M. E., ELSAWAH, S., HAMILTON, S. H., HENRIKSEN, H. J., KUIKKA, S., MAIER, H. R., RIZZOLI, A. E., VAN DELDEN, H. & VOINOV, A. A. 2013. Selecting among five common modelling approaches for integrated environmental assessment and management. *Environmental Modelling & Software,* 47**,** 159-181.

KHALAFZAI, M.-A. K., MCGEE, T. K. & PARLEE, B. 2019. Flooding in the James Bay region of Northern Ontario, Canada: Learning from traditional knowledge of Kashechewan First Nation. *International Journal of Disaster Risk Reduction,* 36**,** 101100.

KISHORE, K. 2015. Floods turned out to be a great deal harder for people with disabilities. *The Hindu*, DECEMBER 19, 2015 02:00 IST.

KITTO, S., CHESTERS, J. & GRBICH, C. 2008. Quality in qualitative research. *The Medical journal of Australia,* 188**,** 243-6.

KLINKE, A. & RENN, O. 2002. A New Approach to Risk Evaluation and Management: Risk-Based, Precaution-Based, and Discourse-Based Strategies1. *Risk Analysis,* 22**,** 1071-1094.

KONUKCU, F., GOWING, J. & ROSE, D. A. 2006. Dry drainage: A sustainable solution to waterlogging and salinity problems in irrigation areas? *Agricultural Water Management,* 83**,** 1-12.

KOSKINEN, K. U. 2013. Systemic View and Systems Thinking. *Knowledge Production in Organizations: A Processual Autopoietic View.* Heidelberg: Springer International Publishing.

KOUSER-ASIF, S. 2022. Extreme Flood Events in India and Attribution to Climate Change: An Analysis of News Media Coverage from 2013–2019 during Bihar Floods. *Natural Hazards Review,* 23.

KRAUSS, S., HAMZAH, A., OMAR, Z., SUANDI, T., ISMAIL, I. A., ZAHARI, M. & NOR, Z. M. 2009. Preliminary Investigation and Interview Guide Development for Studying how Malaysian Farmers Form their Mental Models of Farming. *The Qualitative Report,* 14**,** 245-260.

KREHER, H. 1994. Some Recurring Themes in Using Soft Systems Methodology. *Journal of the Operational Research Society,* 45**,** 1293-1303.

KUHLICKE, C., CALLSEN, I. & BEGG, C. 2016. Reputational risks and participation in flood risk management and the public debate about the 2013 flood in Germany. *Environmental Science & Policy,* 55**,** 318-325.

KUMAR, S., SAHDEO, A. & GULERIA, S. 2013. Bihar Floods : 2007 (A Field Report). New Delhi: National Institute of Disaster Management.

KUMAR, V., CHENG, S. Y. C. & SINGH, A. K. 2016. Impact of flood on rural population and strategies for mitigation: A case study of Darbhanga district, Bihar state, India. *Contemporary Rural Social Work Journal,* 8.

KUNDZEWICZ, Z., SZAMALEK, K. & KOWALCZAK, P. 1999. The Great Flood of 1997 in Poland. *Hydrological Sciences Journal-journal Des Sciences Hydrologiques - HYDROLOG SCI J,* 44**,** 855-870.

LANE, S. N. 2014. Acting, predicting and intervening in a socio-hydrological world. *Hydrol. Earth Syst. Sci.,* 18**,** 927-952.

LATRUBESSE, E. M. 2015. Large rivers, megafans and other Quaternary avulsive fluvial systems: A potential "who's who" in the geological record. *Earth-Science Reviews,* 146**,** 1-30.

LAUTA, K. C. 2014. New Fault Lines? On Responsibility and Disasters. . *European Journal of Risk Regulation,* 5**,** 137-145.

LAVELL, A. 1996. Degradación Ambiental, Riesgo y Desastre Urbano. Problemas y Conceptos: Hacia la Definición de una Agenda de Investigación. *Fernández, M.A.* USAID: La Red.

LAVELL, A. & MASKREY, A. 2014. The future of disaster risk management. *Environmental Hazards,* 13**,** 267-280.

LE-SAINT, F. 1991. Performance Evaluation Using Soft SystemsMethodology. *Management Accounting,* 69**,** 34-36.

LEACH, W. D., PELKEY, N. W. & SABATIER, P. A. 2002. Stakeholder Partnerships as Collaborative Policymaking: Evaluation Criteria Applied to Watershed Management in California and Washington. *Journal of Policy Analysis and Management,* 21**,** 645-670.

LEAL, M., REIS, E., PEREIRA, S. & SANTOS, P. P. 2021. Physical vulnerability assessment to flash floods using an indicator-based methodology based on building properties and flow parameters. *JOURNAL OF FLOOD RISK MANAGEMENT,* 14.

LENZI, M. A., MAO, L. & COMITI, F. 2003. Interannual variation of suspended sediment load and sediment yield in an alpine catchment. *HYDROLOGICAL SCIENCES JOURNAL-JOURNAL DES SCIENCES HYDROLOGIQUES,* 48**,** 899-915.

LEVIN, S., XEPAPADEAS, T., CRÉPIN, A.-S., NORBERG, J., ZEEUW, A., FOLKE, C., HUGHES, T., ARROW, K., BARRETT, S., DAILY, G., EHRLICH, P., KAUTSKY, N., MÄLER, K.-G., POLASKY, S., TROELL, M., VINCENT, J. & WALKER, B. 2013. Social-Ecological Systems as Complex Adaptive Systems: Modeling and Policy Implications. *Environment and Development Economics,* 18.

LIAMPUTTONG, P. & EZZY, D. 2005. *Qualitative research methods,* South Melbourne, VIC, Oxford University Press.

LINDAHL, T., BODIN, O. & TENGO, M. 2015. Governing complex commons - The role of communication for experimental

learning and coordinated management. *ECOLOGICAL ECONOMICS,* 111**,** 111-120.
LIU, J., DIETZ, T., CARPENTER, S. R., ALBERTI, M., FOLKE, C., MORAN, E., PELL, A. N., DEADMAN, P., KRATZ, T., LUBCHENCO, J., OSTROM, E., OUYANG, Z., PROVENCHER, W., REDMAN, C. L., SCHNEIDER, S. H. & TAYLOR, W. W. 2007. Complexity of Coupled Human and Natural Systems. *Science,* 317**,** 1513-1516.
LIVERMAN, D. M. 1990. Vulnerability to Global environmental change. *Journal of Human Ecology,* 29**,** 47-55.
LOIZOS, P. 2000. Qualitative Researching with Text, Image and Sound. London: SAGE Publications Ltd.
LOUCKS, D. P. 2015. Debates—Perspectives on socio-hydrology: Simulating hydrologic-human interactions. *Water Resources Research,* 51**,** 4789-4794.
LUDWIG, D., MANGEL, M. & HADDAD, B. M. 2001. Ecology, Conservation, and Public Policy. *Annual Review of Ecology, Evolution, and Systematics,* 32**,** 481-517.
MADHURI 2016. The Impact of Flooding in Bihar, India on Women: A Qualitative Study. *Asian Women,* 32**,** 31-52.
MAI, T., MUSHTAQ, S., REARDON-SMITH, K., WEBB, P., STONE, R., KATH, J. & AN-VO, D. A. 2020. Defining flood risk management strategies: A systems approach. *INTERNATIONAL JOURNAL OF DISASTER RISK REDUCTION,* 47.
MALLICK, R. B., TAO, M., DANIEL, J. S., JACOBS, J. & VEERARAGAVAN, A. 2017. Development of a methodology and a tool for the assessment of vulnerability of roadways to flood-induced damage. *JOURNAL OF FLOOD RISK MANAGEMENT,* 10**,** 301-313.
MALTERUD, K. 2001. Qualitative research: standards, challenges, and guidelines. *The Lancet,* 358**,** 483-488.
MANFREDO, M., RECHKEMMER, A. & VASKE, J. 2014. *Understanding Society and Natural Resources: Forging New Strands of Integration Across the Social Sciences*.
MARANS, R. W. & STIMSON, R. Investigating Quality of Urban Life. 2011.
MASKREY, A. 1993. Vulnerability Accumulation in Peripheral Regions in Latin America: The Challenge for Disaster Prevention and Management. *In:* BROWITT, P. A. M. A. C. W. (ed.) *Natural Disasters: Protecting Vulnerable Communities.* Telford: IDNDR, London.
MASKREY, S. A., MOUNT, N. J., THORNE, C. R. & DRYDEN, I. 2016. Participatory modelling for stakeholder involvement in the development of flood risk management intervention options. *Environmental Modelling & Software,* 82**,** 275-294.

MASKREY, S. A., PRIEST, S. & MOUNT, N. J. 2019. Towards evaluation criteria in participatory flood risk management. *Journal of Flood Risk Management,* 12**,** e12462.
MATHESWARAN, K., ALAHACOON, N., PANDEY, R. & AMARNATH, G. 2019. Flood risk assessment in South Asia to prioritize flood index insurance applications in Bihar, India. *Geomatics, Natural Hazards and Risk,* 10**,** 26-48.
MATTHEWS, R. B., GILBERT, N. G., ROACH, A., POLHILL, J. G. & GOTTS, N. M. 2007. Agent-based land-use models: a review of applications. *Landscape Ecology,* 22**,** 1447-1459.
MAVHURA, E., MANYENA, B. & COLLINS, A. E. 2017. An approach for measuring social vulnerability in context: The case of flood hazards in Muzarabani district, Zimbabwe. *Geoforum,* 86**,** 103-117.
MCENTIRE, D., MPH, C. G. C. & PETERS, E. 2010. Addressing vulnerability through an integrated approach. *International Journal of Disaster Resilience in The Built Environment,* 1**,** 50-64.
MCKENZIE, D. & SASIN, M. J. 2007. Migration, Remittances, Poverty, and Human Capital: Conceptual and empirical challenges. World Bank.
MCLEAN, S., READ, G. J. M., HULME, A., DODD, K., GORMAN, A. D., SOLOMON, C. & SALMON, P. M. 2019. Beyond the Tip of the Iceberg: Using Systems Archetypes to Understand Common and Recurring Issues in Sports Coaching. *Front Sports Act Living,* 1**,** 49.
MEADOWS, D. 1999. Leverage Points: Places to Intervene in a System. *Sustainability Institute*.
MEHREGAN, M. R., HOSSEINZADEH, M. & KAZEMI, A. 2012. An application of Soft System Methodology. *Procedia - Social and Behavioral Sciences,* 41**,** 426-433.
MENS, M. J. P., KLIJN, F., DE BRUIJN, K. M. & VAN BEEK, E. 2011. The meaning of system robustness for flood risk management. *Environmental Science & Policy,* 14**,** 1121-1131.
MERZ B., T. A. G. M. 2007. Flood Risk Mapping At The Local Scale: Concepts and Challenges. *In:* J.W., B. S. S. M. J. F. H. (ed.) *Flood Risk Management in Europe. Advances in Natural and Technological Hazards Research.* Dordrecht: Springer.
MICELI, R., SOTGIU, I. & SETTANNI, M. 2008. Disaster preparedness and perception of flood risk: A study in an alpine valley in Italy. *Journal of Environmental Psychology,* 28**,** 164-173.
MICHELS, A. 2011. Innovations in democratic governance: how does citizen participation contribute to a better

democracy? *International Review of Administrative Sciences,* 77**,** 275-293.
MINGERS, J. 2000. An Idea Ahead of Its Time: The History and Development of Soft Systems Methodology. *Systemic Practice and Action Research,* 13**,** 733-755.
Mingers, J. (2015). Helping business schools engage with real problems: the contribution of critical realism and systems thinking. European Journal of Operational Research 242: 316–331.
MINGERS, J. & TAYLOR, S. 1992. The Use of Soft Systems Methodology in Practice. *Journal of the Operational Research Society,* 43**,** 321-332.
MINISTRY OF RURAL DEVELOPMENT INDIA. 2022. *Ministry of Rural Development annual report 2021-22* [Online]. Government of India. Available: https://rural.nic.in/sites/default/files/AnnualReport2021_22_English.pdf [Accessed 2022].
MISHRA, D. K. 1997. The Bihar Flood Story. *Economic and Political Weekly,* 32**,** 2206-2217.
MISHRA, D. K., INSTITUTE, P. S. S., SOUTH ASIA NETWORK ON DAMS, R. & PEOPLE 2008. *Trapped! Between the Devil and Deep Waters*, Peoples' Science Institute.
MISTRY, J. & BERARDI, A. 2016. Bridging indigenous and scientific knowledge. *Science,* 352**,** 1274-1275.
MISTRY, J., BERARDI, A., TSCHIRHART, C., BIGNANTE, E., HAYNES, L., BENJAMIN, R., ALBERT, G., XAVIER, R., ROBERTSON, B., DAVIS, O., JAFFERALLY, D. & DE VILLE, G. 2016a. Community owned solutions: identifying local best practices for social-ecological sustainability. *Ecology and Society,* 21.
MISTRY, J., BILBAO, B. A. & BERARDI, A. 2016b. Community owned solutions for fire management in tropical ecosystems: case studies from Indigenous communities of South America. *Philos Trans R Soc Lond B Biol Sci,* 371.
MODMR 2021. National Strategy on Internal Displacement Management Ministry of Disaster Management and Relief.
MOHANTY, M. P., MUDGIL, S. & KARMAKAR, S. 2020. Flood management in India: A focussed review on the current status and future challenges. *International Journal of Disaster Risk Reduction,* 49**,** 101660.
MOHAPATRA, P. K. & SINGH, R. D. 2003. Flood Management in India. *Natural Hazards,* 28**,** 131-143.
MONDAL, D., CHOWDHURY, S. & DASU, D. 2015. Role of Non Governmental organization in Disaster Management. *Research Journal of Agricultural Sciences,* 6**,** 1485-1489.

MONNIKHOF, R. A. H. & EDELENBOS, J. 2001. Into the fog? Stakeholder input in participatory impact assessment. *Impact Assessment and Project Appraisal,* 19**,** 29-39.
MONTANARI, A., YOUNG, G., SAVENIJE, H. H. G., HUGHES, D., WAGENER, T., REN, L. L., KOUTSOYIANNIS, D., CUDENNEC, C., TOTH, E., GRIMALDI, S., BLÖSCHL, G., SIVAPALAN, M., BEVEN, K., GUPTA, H., HIPSEY, M., SCHAEFLI, B., ARHEIMER, B., BOEGH, E., SCHYMANSKI, S. J., DI BALDASSARRE, G., YU, B., HUBERT, P., HUANG, Y., SCHUMANN, A., POST, D. A., SRINIVASAN, V., HARMAN, C., THOMPSON, S., ROGGER, M., VIGLIONE, A., MCMILLAN, H., CHARACKLIS, G., PANG, Z. & BELYAEV, V. 2013. "Panta Rhei—Everything Flows": Change in hydrology and society—The IAHS Scientific Decade 2013–2022. *Hydrological Sciences Journal,* 58**,** 1256-1275.
MOORE, B., CARVAJAL-LÓPEZ, P., CHAUKE, P. A., CRISTANCHO, M., DOMINGUEZ DEL ANGEL, V., FERNANDEZ-VALVERDE, S. L., GHOUILA, A., GOPALASINGAM, P., GUERFALI, F. Z., MATIMBA, A., MORGAN, S. L., OLIVEIRA, G., RAS, V., REYES, A., DE LAS RIVAS, J. & MULDER, N. 2021. Ten simple rules for organizing a bioinformatics training course in low- and middle-income countries. *PLoS Comput Biol,* 17**,** e1009218.
MOORE, R. J. & JONES, D. A. 1998. *Proceedings of the First European Expert Meeting on River Basin Modelling (RIBAMOD)*, European Commission.
MORRIS, M., DYER, M. & SMITH, P. 2007. Management of Flood Embankments: A good practice review. *Joint Defra/EA Flood and Coastal Erosion Risk Management R&D Programme*
MOSSE, D. 2001. People's knowledge, participation and patronage: Operations and representations in rural development. *Participation: The new tyranny?***,** 16-36.
MOUNT, N. J., DAWSON, C. W. & ABRAHART, R. J. 2013. Legitimising data-driven models: exemplification of a new data-driven mechanistic modelling framework. *Hydrol. Earth Syst. Sci.,* 17**,** 2827-2843.
MOUNT, N. J., MAIER, H. R., TOTH, E., ELSHORBAGY, A., SOLOMATINE, D., CHANG, F. J. & ABRAHART, R. J. 2016. Data-driven modelling approaches for socio-hydrology: opportunities and challenges within the Panta Rhei Science Plan. *Hydrological Sciences Journal,* 61**,** 1192-1208.
MUELLER, V., GRAY, C. & KOSEC, K. 2014. Heat stress increases long-term human migration in rural Pakistan. *NATURE CLIMATE CHANGE,* 4**,** 182-185.

MUSTAFA, A., DEWALS, B., ARCHAMBEAU, P., PIROTTON, M. & TELLER, J. 2015. *Sustainable integrated land-use plan and flood risk management: A review*.

MUSTERS, C. J. M., DE GRAAF, H. J. & TER KEURS, W. J. 1998. Defining socio-environmental systems for sustainable development. *Ecological Economics,* 26**,** 243-258.

MUTTON, D. & HAQUE, C. E. 2004. Human Vulnerability, Dislocation and Resettlement: Adaptation Processes of River-bank Erosion-induced Displacees in Bangladesh. *Disasters,* 28**,** 41-62.

NADERIFAR, M., GOLI, H. & GHALJAEI, F. 2017. Snowball Sampling: A Purposeful Method of Sampling in Qualitative Research. *Strides in Development of Medical Education,* In Press.

NASIRI, H., YUSOF, M. J. M. & ALI, T. A. M. 2016. An overview to flood vulnerability assessment methods. *Sustainable Water Resources Management,* 2**,** 331-336.

NATHALIE, P., PENNING-ROWSELL, E., TUNSTALL, S. & HUBERT, G. 2005. Land Use and Flood Protection: Contrasting Approaches and Outcomes in France and in England and Wales. *Applied Geography,* 25**,** 1-27.

NCDHR. 2018. *WHO ARE DALITS? & WHAT IS UNTOUCHABILITY?* [Online]. National Campaign on Dalit Human Rights (NCDHR). Available: http://ncdhr.org.in/front/dalits_untouchability [Accessed 12 December 2018].

NDMA. 2022. *Floods* [Online]. Available: https://ndma.gov.in/Natural-Hazards/Floods [Accessed].

NGUYEN, C. T. & VAN NGUYEN, B. 2019. Application of flood vulnerability index in flood vulnerability assessment: a case study in Mai Hoa Commune, Tuyen Hoa District, Quang Binh Province. *Sustainable Water Resources Management,* 5**,** 1917-1927.

NITHILA, A. N., SHOME, P. & ISLAM, I. 2022. Waterlogging induced loss and damage assessment of urban households in the monsoon period: a case study of Dhaka, Bangladesh. *NATURAL HAZARDS,* 110**,** 1565-1597.

NITI_AAYOG 2021. National multidimensional poverty index baseline report. Based on National Family Health Survey-4 (2015-16). India: Government of India.

NNOKO-MEWANU, J. 2020. After seven years, displaced Zambian villagers might get land. *Mail and Guardian*.

NORDIN, R. M., LATIP, E., ZAWAWI, E. M. A. & ISMAIL, Z. 2018. Opportunities for corruption across Flood Disaster Management (FDM). *3RD INTERNATIONAL CONFERENCE ON RESEARCH METHODOLOGY FOR BUILT ENVIRONMENT AND ENGINEERING 2017.*

NUSSER, M. & BAGHEL, R. 2014. Governmentality of River Embankment. *RIVER CONTROL IN INDIA: SPATIAL, GOVERNMENTAL AND SUBJECTIVE DIMENSIONS.*

O'CONNOR, J. & MCDERMOTT, I. 1997. *The art of systems thinking : essential skills for creativity and problem solving,* London, Thorsons.

OCELLO, C., PETRUCCI, A., TESTA, M. & VIGNOLI, D. 2014. Environmental aspects of internal migration in Tanzania. *Population and Environment,* 37.

OLIVER-SMITH, A. & HOFFMAN, S. M. 2019. *The Angry Earth: Disaster in Anthropological Perspective*, Routledge.

OPHI 2010. Multidimensional Poverty Index 2010'. *OPHI Briefing 02, Oxford Poverty and Human Development Initiative (OPHI).* University of Oxford.

OSBERGHAUS, D. 2015. The determinants of private flood mitigation measures in Germany — Evidence from a nationwide survey. *Ecological Economics,* 110**,** 36-50.

OTHMAN, A. Z., DAHLAN, A. & MURAD, S. 2017. The Impact of Flood Disaster on Daily Activities and Quality of Life amongst Women Flood Disaster Survivors. *ENVIRONMENT-BEHAVIOUR PROCEEDINGS JOURNAL.*

PAHL-WOSTL, C., BECKER, G., KNIEPER, C. & SENDZIMIR, J. 2013. How Multilevel Societal Learning Processes Facilitate Transformative Change

A Comparative Case Study Analysis on Flood Management. *Ecology and Society,* 18.

PANDEY, A., SINGH, S. & NATHAWAT, M. 2012. Analysing the impact of anthropogenic activities on waterlogging dynamics in Indo-Gangetic Plains, northern Bihar, India. *International Journal of Remote Sensing,* 33**,** 135-149.

PANKAJ, A. K. 2019. Caste and Discrimination in Welfare: Social Exclusion of Dalits in Uttar Pradesh. *CONTEMPORARY VOICE OF DALIT,* 11**,** 139-149.

PARKER, D., TAPSELL, S., HANDMER, S., KIDRON, G., OMER, BENENSON, I., BAKMAN, ZILBERMAN, COSTA, KROPP, MOLINARI, D., BONADONNA, C. & GREGG, C. 2009. *Relations between different types of social and economic vulnerability*.

PATHAK, P. & SCHUNDELN, M. 2022. Social hierarchies and the allocation of development aid: Evidence from the 2015 earthquake in Nepal. *JOURNAL OF PUBLIC ECONOMICS,* 209.

PERRONE, A., INAM, A., ALBANO, R., ADAMOWSKI, J. & SOLE, A. 2020. A participatory system dynamics modeling approach to facilitate collaborative flood risk

management: A case study in the Bradano River (Italy). *Journal of Hydrology,* 580**,** 124354.
Phillip, E., Conroy, R.M., Walsh, A. et al (2023). Using mixed methods and community participation to explore household and ambient air pollution practices in a rural community in Malawi. J Public Health (Berl.).
PLATE, E. 2002. Flood risk and flood management. *Journal of Hydrology,* 267**,** 2-11.
PRASAD, E. & MUKHERJEE, N. 2014. *Situation Analysis on Floods and Flood Management*, IUCN, International Union for Conservation of Nature.
PRASAD, K. 2005. *Manual on Community Approach to Flood Management in India*.
PRATHAPAR, S. A., RAJMOHAN, N., SHARMA, B. R. & AGGARWAL, P. K. 2018. Vertical drains to minimize duration of seasonal waterlogging in Eastern Ganges Basin flood plains: a field experiment. *Natural Hazards,* 92**,** 1-17.
PRELL, C., HUBACEK, K., QUINN, C. & REED, M. 2008. 'Who's in the Network?' When Stakeholders Influence Data Analysis. *Systemic Practice and Action Research,* 21**,** 443-458.
PRITCHARD, B. & THIELEMANS, R. 2014. 'Rising Waters Don't Lift All Boats': a sustainable livelihood analysis of recursive cycles of vulnerability and maladaptation to flood risk in rural Bihar, India. *Australian Geographer,* 45**,** 325-339.
PURBA, F. D., HUNFELD, J. A. M., FITRIANA, T. S., ISKANDARSYAH, A., SADARJOEN, S. S., BUSSCHBACH, J. J. V. & PASSCHIER, J. 2018. Living in uncertainty due to floods and pollution: the health status and quality of life of people living on an unhealthy riverbank. *BMC PUBLIC HEALTH,* 18.
QURESHI, A. S., MCCORNICK, P. G., QADIR, M. & ASLAM, Z. 2008. Managing salinity and waterlogging in the Indus Basin of Pakistan. *Agricultural Water Management,* 95**,** 1-10.
RABIONET, S. E. 2011. How I Learned to Design and Conduct Semi-structured Interviews: An Ongoing and Continuous Journey. *Qualitative Report,* 16**,** 563-566.
RAGHAVENDRA, R. H. 2020. Literacy and Health Status of Scheduled Castes in India. *Contemporary Voice of Dalit,* 12**,** 97-110.
RAHMAN, M. H., ANBARCI, N., BHATTACHARYA, P. S. & ULUBAŞOĞLU, M. A. 2017. Can extreme rainfall trigger democratic change? The role of flood-induced corruption. *Public Choice,* 171**,** 331-358.

RAMESH, R. 2008. India: Untouchables suffer 'relief discrimination' after flood. 3 September 2008 ed. Delhi: The Guardian.

RAPPORT, R. N. 1970. Three dilemmas of action research. *Human Relations,* 23**,** 499-513.

RAY-BENNETT, N. S. 2009. The influence of caste, class and gender in surviving multiple disasters: A case study from Orissa, India. *ENVIRONMENTAL HAZARDS-HUMAN AND POLICY DIMENSIONS,* 8**,** 5-22.

RAYMOND, C. M., FAZEY, I., REED, M. S., STRINGER, L. C., ROBINSON, G. M. & EVELY, A. C. 2010. Integrating local and scientific knowledge for environmental management. *Journal of Environmental Management,* 91**,** 1766-1777.

REED, M. S., GRAVES, A., DANDY, N., POSTHUMUS, H., HUBACEK, K., MORRIS, J., PRELL, C., QUINN, C. H. & STRINGER, L. C. 2009. Who's in and why? A typology of stakeholder analysis methods for natural resource management. *Journal of Environmental Management,* 90**,** 1933-1949.

REHMAN, J., SOHAIB, O., ASIF, M. & PRADHAN, B. 2019. Applying systems thinking to flood disaster management for a sustainable development. *International Journal of Disaster Risk Reduction,* 36**,** 101101.

RENN, O. 2008. *Risk Governance: Coping With Uncertainty in a Complex World*.

RENN, O., WEBLER, T. & WIEDEMANN, P. 2011. The Pursuit of Fair and Competent Citizen Participation.

RICHARDSON, G. P. 1997. Problems in causal loop diagrams revisited. *System Dynamics Review,* 13**,** 247-252.

RICHMOND, B. 1994. Systems thinking/system dynamics: Let's just get on with it. *System Dynamics Review,* 10**,** 135-157.

RIECHERS, M., FISCHER, J., MANLOSA, A. O., ORTIZ-PRZYCHODZKA, S. & SALA, J. E. 2022. Operationalising the leverage points perspective for empirical research. *Current Opinion in Environmental Sustainability,* 57**,** 101206.

RIGAUD, K. K. D. S., ALEX JONES, BRYAN BERGMANN, JONAS CLEMENT, VIVIANE OBER, KAYLY SCHEWE, JACOB ADAMO, SUSANA MCCUSKER, BRENT HEUSER, SILKE MIDGLEY, AMELIA 2018. Groundswell : Preparing for Internal Climate Migration. Washington, DC.: World Bank.

RIIS, T., SUREN, A. M., CLAUSEN, B. & SAND-JENSEN, K. 2008. Vegetation and flow regime in lowland streams. *FRESHWATER BIOLOGY,* 53**,** 1531-1543.

Riisgaard, Lone, Anna Maria Escobar Fibla, and Stefano Ponte. 2010. Evaluation Study: Gender and Value Chain Development. Copenhagen: Ministry of Foreign Affairs of Denmark.

ROBBINS, P. 2000. The Practical Politics of Knowing: State Environmental Knowledge and Local Political Economy. *Economic Geography,* 76**,** 126-144.

ROBERTSON, H. A. & MCGEE, T. K. 2003. Applying local knowledge: the contribution of oral history to wetland rehabilitation at Kanyapella Basin, Australia. *J Environ Manage,* 69**,** 275-87.

RODRIGUEZ-ULLOA, R., MONTBRUN, A. & MARTÍNEZ, S. 2011. Soft System Dynamics Methodology in Action: A study of the Problem of Citizen Insecurity in an Argentinean Province. *Systemic Practice and Action Research,* 24**,** 275-323.

ROSSIGNOL, N., DELVENNE, P. & TURCANU, C. 2015. Rethinking Vulnerability Analysis and Governance with Emphasis on a Participatory Approach. *Risk Analysis,* 35**,** 129-141.

ROULSTON, K. 2001. Data analysis and 'theorizing as ideology'. *Qualitative Research,* 1**,** 279-302.

RUFAT, S., TATE, E., BURTON, C. G. & MAROOF, A. S. 2015. Social vulnerability to floods: Review of case studies and implications for measurement. *International Journal of Disaster Risk Reduction,* 14**,** 470-486.

RWASHANA, A., NAKUBULWA, S., NAKAKEETO-KIJJAMBU, M. & ADAM, T. 2014. Advancing the application of systems thinking in health: Understanding the dynamics of neonatal mortality in Uganda. *Health research policy and systems / BioMed Central,* 12**,** 36.

RYAN, G. W. & BERNARD, H. R. 2003. Techniques to Identify Themes. *Field Methods,* 15**,** 85-109.

SADLER, G. R., LEE, H.-C., LIM, R. S.-H. & FULLERTON, J. 2010. Recruitment of hard-to-reach population subgroups via adaptations of the snowball sampling strategy. *Nursing & health sciences,* 12**,** 369-374.

SANDARAN, S. C. & SELVARAJ, S. 2021. Government Agencies and their Discourses of Flood Disaster Preparedness: Impact on Response, Action and Community Empowerment. *GEMA ONLINE JOURNAL OF LANGUAGE STUDIES,* 21**,** 294-313.

SANDELOWSKI, M. 2004. Using Qualitative Research. *Qualitative Health Research,* 14**,** 1366-1386.

SAYERS, P. B., HALL, J. W. & MEADOWCROFT, I. C. 2002. Towards risk-based flood hazard management in the UK.

Proceedings of the Institution of Civil Engineers - Civil Engineering, 150**,** 36-42.
SCHAFFERNICHT, M. 2007. Causality and diagrams for system dynamics.
SCHNEIDERBAUER, S. & EHRLICH, D. 2004. Risk, hazard and people's vulnerability to natural hazards. *A review of definitions, concepts and data. European Commission Joint Research Centre. EUR,* 21410**,** 40.
SCHWEIZER, P. J. & RENN, O. 2019. Governance of systemic risks for disaster prevention and mitigation. *DISASTER PREVENTION AND MANAGEMENT,* 28**,** 854-866.
SCRIECIU, A., PAGANO, A., COLETTA, V. R., FRATINO, U. & GIORDANO, R. 2021. Bayesian Belief Networks for Integrating Scientific and Stakeholders' Knowledge to Support Nature-Based Solution Implementation. *Frontiers in Earth Science,* 9.
SENGE, P. M. 2006. *The Fifth Discipline: The Art and Practice of the Learning Organization.,* New York, Doubleday (A Division of Random House).
SESYNC. 2012. *Socio-Environmental Systems* [Online]. Available: https://www.sesync.org/socio-environmental-systems [Accessed 16 July 2020].
SHAFIAI, S. & KHALID, M. S. 2016. Flood Disaster Management in Malaysia: A Review of Issues of Flood Disaster Relief during and Post-Disaster. *ISSC 2016 INTERNATIONAL CONFERENCE ON SOFT SCIENCE.*
SHAH, M. 2013. Water: Towards a paradigm shift in the twelfth plan. *Economic and Political Weekly,* 48**,** 40-52.
SIDDIQUI, N. A., RABIDAS, V. N., SINHA, S. K., VERMA, R. B., PANDEY, K., SINGH, V. P., RANJAN, A., TOPNO, R. K., LAL, C. S., KUMAR, V., SAHOO, G. C., SRIDHAR, S., PANDEY, A. & DAS, P. 2016. Snowball Vs. House-to-House Technique for Measuring Annual Incidence of Kala-azar in the Higher Endemic Blocks of Bihar, India: A Comparison. *PLoS Negl Trop Dis,* 10**,** e0004970.
SINGH, A. & ZOMMERS, Z. 2014. *Reducing Disaster: Early Warning Systems For Climate Change,* Netherlands, Springer
SINGH, A. K. 2018. Salinization of agricultural lands due to poor drainage: A viewpoint. *Ecological Indicators*.
SINGH, H., PARKASH, B. & GOHAIN, K. 1993. Facies analysis of the Kosi megafan deposits. *Sedimentary Geology,* 85**,** 87-113.
SINGH, P., GHOSE, N. C., N & HANSDA, R. 2009. Life in the Shadow of Embankments – Turning Lost Lands into Assets in the Koshi Basin of Bihar, India. Kathmandu.

SINGH, S. K., PANDEY, A. C., RATHORE, V. S. & NATHAWAT, M. S. 2014. Evaluating factors responsible for contrasting signature of wasteland development in northern and southern Ganga Plains (Bihar State, India) with focus on waterlogging. *Arabian Journal of Geosciences,* 7**,** 4175-4190.

SINHA, R. Dynamics of a River System- the Case of the Kosi River in North Bihar. 2009a.

SINHA, R. 2009b. *The Great avulsion of Kosi on 18 August 2008*.

SINHA, R. 2014. The Kosi Megafan: The Best-known Himalayan Megafan.

SINHA, R. & FRIEND, P. F. 1994. River systems and their sediment flux, Indo-Gangetic plains, Northern Bihar, India. *Sedimentology,* 41**,** 825-845.

SINHA, R., GAURAV, K., CHANDRA, S. & TANDON, S. K. 2013. Exploring the channel connectivity structure of the August 2008 avulsion belt of the Kosi River, India: Application to flood risk assessment. *Geology,* 41**,** 1099-1102.

SINNAKAUDAN, S. K., AB GHANI, A., AHMAD, M. S. S. & ZAKARIA, N. A. 2003. Flood risk mapping for Pari River incorporating sediment transport. *ENVIRONMENTAL MODELLING & SOFTWARE,* 18**,** 119-130.

SIVAPALAN, M., SAVENIJE, H. H. G. & BLÖSCHL, G. 2012. Socio-hydrology: A new science of people and water. *Hydrological Processes,* 26**,** 1270-1276.

SIVAPALAN, M., TAKEUCHI, K., FRANKS, S. W., GUPTA, V. K., KARAMBIRI, H., LAKSHMI, V., LIANG, X., MCDONNELL, J. J., MENDIONDO, E. M., O'CONNELL, P. E., OKI, T., POMEROY, J. W., SCHERTZER, D., UHLENBROOK, S. & ZEHE, E. 2003. IAHS Decade on Predictions in Ungauged Basins (PUB), 2003–2012: Shaping an exciting future for the hydrological sciences. *Hydrological Sciences Journal,* 48**,** 857-880.

SKAKUN, S., KUSSUL, N., SHELESTOV, A. & KUSSUL, O. 2014. Flood Hazard and Flood Risk Assessment Using a Time Series of Satellite Images: A Case Study in Namibia. *Risk Analysis,* 34.

SLINGERLAND, R. & SMITH, N. 2004. River avulsions and deposits. *Annual Review of Earth and Planetary Sciences,* 32**,** 257-285.

Sovacool BK, Ryan SE, Stern PC, Janda K, Rochlin G, Spreng D, Pasqualetti MJ, Wilhite H, Lutzenhiser L (2015) Integrating social science in energy research. Energy Research & Social Science 6:95–99.

SRINIVASAN, V. 2015. Reimagining the past – use of counterfactual trajectories in socio-hydrological modelling: the case of Chennai, India. *Hydrol. Earth Syst. Sci.,* 19**,** 785-801.

STANGHELLINI, P. & COLLENTINE, D. 2008. Stakeholder discourse and water management - Implementation of the participatory model CATCH in a Northern Italian alpine sub-catchment. *Hydrology and Earth System Sciences,* 12.

STERMAN, J. 2000. *Business dynamics*, McGraw-Hill, Inc.

STERMAN, J. D. 2001. System Dynamics Modeling: Tools for Learning in a Complex World. *California Management Review,* 43**,** 8-25.

STIRLING, A. 1998. Risk at a turning point? *Journal of Risk Research,* 1**,** 97-109.

STIRLING, A. 2006. From Science and Society to Science in Society: Towards a Framework for Co-operative Research, Project Report. European Commission Directorate General for Research.

STROH, D. P. 2015. *Systems thinking for social change,* USA, Chelsea Green Publishing.

SURIYA, S. & MUDGAL, B. V. 2013. Soft systems methodology and integrated flood management: a study of the Adayar watershed, Chennai, India. *Water and Environment Journal,* 27**,** 462-473.

SY, B., FRISCHKNECHT, C., DAO, H., CONSUEGRA, D. & GIULIANI, G. 2019. Flood hazard assessment and the role of citizen science. *Journal of Flood Risk Management,* 12**,** e12519.

TAN, J. W., WAN, X. J., LIU, H. & XIAO, J. G. 2018. QuoteRec: Toward Quote Recommendation for Writing. *ACM TRANSACTIONS ON INFORMATION SYSTEMS,* 36.

TANAKA, K., YAMADA, F., KAKIMOTO, R., MATSUO, K. & OHMOTO, T. 2011. Information support systems for community-based flood risk management. *Journal of Flood Risk Management,* 4**,** 156-164.

TAPSELL, S., MCCARTHY, S., FAULKNER, H. & ALEXANDER, M. 2010. Social vulnerability to natural hazards.

TAPSELL, S., PENNING-ROWSELL, E., TUNSTALL, S. M. & WILSON, T. L. 2002. Vulnerability to Flooding: Health and Social Dimensions. *Philosophical transactions. Series A, Mathematical, physical, and engineering sciences,* 360**,** 1511-25.

TARIQ, M. A. U. R. & NICK, V. D. G. 2012. Floods and flood management in Pakistan. *Physics and Chemistry of the Earth, Parts A/B/C,* 47-48**,** 11-20.

TAYLOR, M. & BHASME, S. 2021. Between deficit rains and surplus populations: The political ecology of a climate-resilient village in South India. *Geoforum,* 126**,** 431-440.

TAYLOR, R. S. 1904. Levees, Outlets and Reservoirs as Means for Protection against Overflow of the Alluvial Lands of the Mississippi Valley Below Cairo. *Science,* 19**,** 601-609.

THALER, T. & LEVIN-KEITEL, M. 2016. Multi-level stakeholder engagement in flood risk management—A question of roles and power: Lessons from England. *Environmental Science & Policy,* 55**,** 292-301.

TIERNEY, K. 2014. *The Social Roots of Risk: Producing Disasters, Promoting Resilience*, Stanford University Press.

TIKUNOV, V. S. & TROFIMOV, A. M. 1995. Complex ecological and economic systems: problems of study. *International Journal of Environmental Studies,* 48**,** 135-147.

TIMMERMAN, P. 1981. *Vulnerability, Resilience and the Collapse of Society: A Review of Models and Possible Climatic Applications.,* Toronto, Canada, Institute for Environmental Studies, University of Toronto.

TROY, T. J., PAVAO-ZUCKERMAN, M. & EVANS, T. P. 2015. Debates—Perspectives on socio-hydrology: Socio-hydrologic modeling: Tradeoffs, hypothesis testing, and validation. *Water Resources Research,* 51**,** 4806-4814.

TURNER, D. 2010. Qualitative Interview Design: A Practical Guide for Novice Investigators. *The Qualitative Report,* 15**,** 754-760.

TURNER II, B. L., ESLER, K. J., BRIDGEWATER, P., TEWKSBURY, J., SITAS, N., ABRAHAMS, B., CHAPIN, F. S., CHOWDHURY, R. R., CHRISTIE, P., DIAZ, S., FIRTH, P., KNAPP, C. N., KRAMER, J., LEEMANS, R., PALMER, M., PIETRI, D., PITTMAN, J., SARUKHÁN, J., SHACKLETON, R., SEIDLER, R., VAN WILGEN, B. & MOONEY, H. 2016. Socio-Environmental Systems (SES) Research: what have we learned and how can we use this information in future research programs. *Current Opinion in Environmental Sustainability,* 19**,** 160-168.

TWIGGER-ROSS, C., KASHEFI, WELDON, BROOKS, K., DEEMING, H., FORREST, S., FIELDING, J., HARRIES, T., MCCARTHY, S., ORR, P., PARKER, D. & TAPSELL, S. 2014. *Flood Resilience Community Pathfinder Evaluation Rapid Evidence Assessment*.

UDNOON, S., PILAILAR, S. & CHITTALADAKORN, S. 2021. Evaluation of Bangkok Flood Vulnerability Index Using Fuzzy Inference System. *KSCE Journal of Civil Engineering*.

Ulrich, W., Reynolds, M. (2020). Critical Systems Heuristics: The Idea and Practice of Boundary Critique. In: Reynolds, M., Holwell (Retired), S. (eds) Systems Approaches to

Making Change: A Practical Guide. Springer, London. https://doi.org/10.1007/978-1-4471-7472-1_6.
UNDDR. 2020. *Disaster risk management* [Online]. United Nations office for Disaster Risk Reduction. Available: https://www.undrr.org/terminology/disaster-risk-management#:~:text=Disaster%20risk%20management%20is%20the,and%20reduction%20of%20disaster%20losses. [Accessed 18/12/2020].
UNDP 2009. Kosi Floods 2008: How we coped! What we need? Perception Survey on Impact and Recovery Strategies.
UNDRO 1980. Natural Disasters and Vulnerability Analysis. Geneva: Office of the United Nations Disaster Relief Co-ordinator.
UNDRR 2015. Sendai Framework for Disaster Risk Reduction 2015 - 2030.
UNDRR. 2022. *Policy brief: Gender-responsive disaster risk reduction* [Online]. Available: https://www.undrr.org/publication/policy-brief-gender-responsive-disaster-risk-reduction [Accessed 2022].
UNESCO 2017. Local and Indigenous Knowledge Systems. United Nations Educational, Scientific and Cultural Organisation.
UNISDR 2005. Hyogo Framework for Action 2005-2015: Building the Resilience of Nations and Communities to Disasters. Geneva: Extract from the final report of the World Conference on Disaster Reduction (A/CONF.206/6).
UNISDR 2014. Living with Disability and Disasters: UNISDR 2013 Survey on Living with Disabilities and Disasters - Key Findings. The United Nations Office for Disaster Risk Reduction.
UNWOMEN 2019. Fund for Gender Equality Annual Report 2018-2019.
UNWOMEN 2020. The world for women and girls, Annual report 2019-2020.
VAN NES, F., ABMA, T., JONSSON, H. & DEEG, D. 2010. Language differences in qualitative research: is meaning lost in translation? *European Journal of Ageing,* 7**,** 313-316.
VILLARINI, G. & SMITH, J. A. 2010. Flood peak distributions for the eastern United States. *Water Resources Research,* 46.
VOINOV, A. & BOUSQUET, F. 2010. Modelling with stakeholders. *Environmental Modelling & Software,* 25.
VOJTEK, M. & VOJTEKOVÁ, J. 2016. Flood hazard and flood risk assessment at the local spatial scale: a case study. *Geomatics, Natural Hazards and Risk,* 7**,** 1973-1992.
VOß, J.-P. & BORNEMANN, B. 2011. The Politics of Reflexive Governance: Challenges for Designing Adaptive

Management and Transition Management. *Ecology and Society,* 16.
WALKER, B. & SALT, D. E. Resilience Thinking: Sustaining Ecosystems and People in a Changing World. 2006.
WALTNER-TOEWS, D., KAY, J. J., NEUDOERFFER, C. & GITAU, T. 2003. Perspective changes everything: managing ecosystems from the inside out. *Frontiers in Ecology and the Environment,* 1**,** 23-30.
WANG, K., YAN, D. H., QIN, T. L., WENG, B. S., WANG, H., BI, W. X., LI, X. N. & DORJSUREN, B. 2020. A new topological and hierarchical river coding method based on the hydrology structure. *JOURNAL OF HYDROLOGY,* 580.
WARNER, J. F. 2006. More Sustainable Participation? Multi-Stakeholder Platforms for Integrated Catchment Management. *International Journal of Water Resources Development,* 22**,** 15-35.
WARNER, K. & AFIFI, T. 2014. Where the rain falls: Evidence from 8 countries on how vulnerable households use migration to manage the risk of rainfall variability and food insecurity. *Climate and Development,* 6**,** 1-17.
WARNER, K., VAN DER GEEST, K., KREFT, S., HUQ, S., HARMELING, S., KUSTERS, K. & DE SHERBININ, A. 2012. *Evidence from the frontlines of climate change: Loss and damage to communities despite coping and adaptation*.
WARREN, S. 2005. Photography and voice in critical qualitative management research. *Accounting, Auditing & Accountability Journal,* 18**,** 861-882.
WEHN, U., RUSCA, M., EVERS, J. & LANFRANCHI, V. 2015. Participation in flood risk management and the potential of citizen observatories: A governance analysis. *Environmental Science & Policy,* 48**,** 225-236.
WEICHSELGARTNER, J. & KASPERSON, R. 2010. Barriers in the science-policy-practice interface: Toward a knowledge-action-system in global environmental change research. *Global Environmental Change,* 20**,** 266-277.
WEICHSELGARTNER, J. & KELMAN, I. 2014. Geographies of resilience: Challenges and opportunities of a descriptive concept. *Progress in Human Geography,* 39**,** 249-267.
WELLS, N. A. & DORR, J. A., JR. 1987. Shifting of the Kosi River, northern India. *Geology,* 15**,** 204-207.
WESTGATE, K. N. & O'KEEFE, P. 1976. *Some definitions of disaster, Occasional Paper 4,* Bradford, Bradford, Eng. : University of Bradford, Disaster Research Unit.
WHITE, G. F. U. O. C. 1945. *Human adjustment to floods : a geographical approach to the flood problem in the United States.*

WHITING, L. S. 2008. Semi-structured interviews: guidance for novice researchers. *Nurs Stand,* 22**,** 35-40.

Wigginton, B., & Lafrance, M. N. (2019). Learning critical feminist research: A brief introduction to feminist epistemologies and methodologies. Feminism & Psychology, 0(0).

Williams R. (2001). Base and superstructure in Marxist cultural theory. In Durham M. G., Kellner D. (Eds.). Media and cultural studies: Keyworks (pp. 130–143). Malden, Oxford: Blackwell Publisher.

WISNER, B., BLAIKIE, P., CANNON, T. & DAVIS, I. At Risk: Natural Hazards, People's Vulnerability and Disasters. 1994.

WISNER, B., BLAIKIE, P., CANNON, T. & DAVIS, I. 2004. *At Risk: Natural Hazards, People's Vulnerability and Disasters,* London, Routledge.

WMO 2013. Integrated flood management tools series: Flood mapping. World meteorological organisation.

WOBUS, C., GUTMANN, E., JONES, R., RISSING, M., MIZUKAMI, N., LORIE, M., MAHONEY, H., WOOD, A. W., MILLS, D. & MARTINICH, J. 2017. Climate change impacts on flood risk and asset damages within mapped 100-year floodplains of the contiguous United States. *Nat. Hazards Earth Syst. Sci.,* 17**,** 2199-2211.

WORLDBANK 1989. Involving Nongovernmental Organizations in World Bank-Supported Activities.

WOS 2021. Web of Science Search. Web of Science.

WYNNE, B. 1992. Misunderstood misunderstanding: social identities and public uptake of science. *Public Understanding of Science,* 1**,** 281-304.

WYNNE, B. 1993. Public uptake of science: a case for institutional reflexivity. *Public Understanding of Science,* 2**,** 321-337.

XU, C. W., FU, H., YANG, J. S. & WANG, L. Y. 2022. Assessment of the Relationship between Land Use and Flood Risk Based on a Coupled Hydrological-Hydraulic Model: A Case Study of Zhaojue River Basin in Southwestern China. *LAND,* 11.

YAEGER, M. A., HOUSH, M., CAI, X. & SIVAPALAN, M. 2014. An integrated modeling framework for exploring flow regime and water quality changes with increasing biofuel crop production in the U.S. Corn Belt. *Water Resources Research,* 50**,** 9385-9404.

ZAMAN, M. Q. 1991. The Displaced Poor and Resettlement Policies in Bangladesh. *Disasters,* 15**,** 117-125.

ZEVENBERGEN, C., VEERBEEK, W., GERSONIUS, B. & VAN HERK, S. 2008. Challenges in urban flood management:

travelling across spatial and temporal scales. *JOURNAL OF FLOOD RISK MANAGEMENT,* 1**,** 81-88.
ZHOU, Q., SU, J., ARNBJERG-NIELSEN, K., REN, Y., LUO, J., YE, Z. & FENG, J. 2021. A GIS-Based Hydrological Modeling Approach for Rapid Urban Flood Hazard Assessment. *Water,* 13**,** 1483.
ZIEGLER, F. 2012. "You have to engage with life, or life will go away": An intersectional life course analysis of older women's social participation in a disadvantaged urban area. *Geoforum,* 43**,** 1296-1305.
ZISCHG, A. P. 2018. Floodplains and Complex Adaptive Systems—Perspectives on Connecting the Dots in Flood Risk Assessment with Coupled Component Models. *Systems,* 6**,** 9.
ZISCHG, A. P., HOFER, P., MOSIMANN, M., RÖTHLISBERGER, V., RAMIREZ, J. A., KEILER, M. & WEINGARTNER, R. 2018. Flood risk (d)evolution: Disentangling key drivers of flood risk change with a retro-model experiment. *The Science of the total environment,* 639**,** 195-207.
ZONG, Y. & CHEN, X. 2000. The 1998 Flood on the Yangtze, China. *Natural Hazards,* 22**,** 165-184.

Appendix A

Table A - 1 Detailed description of workshop participants

No.	Participating Group	Number of Participants	Stakeholder group	Participant characteristics	Age	Village	Moved from	Occupation
Workshop 1 (31/01/20): Men (Waterlogged community workshop group)								
1	Group 1	1	Marginalised community	Elderly man	60	Samani	-	Unskilled Labour (Agriculture or Masonry)
2		2	Marginalised community	Elderly man	61	Samani	-	Unskilled Labour (Agriculture or Masonry)
3		3	Dominant community	Elderly man	77	Khorawartor	-	Farmer and Landowner
4	Group 2	1	Dominant community	Man	50	Samani	-	Farmer and Landowner
5		2	Marginalised community	Elderly Man	55	Samani	-	Unskilled Labour (Agriculture or Masonry)

No.	Participating Group	Number of Participants	Stakeholder group	Participant characteristics	Age	Village	Moved from	Occupation
6		3	Marginalised community	Elderly Man	60	Peeparpati	-	Unskilled Labour (Agriculture or Masonry)
7	Group 3	1	Marginalised community	Man	51	Samani	-	Unskilled Labour (Agriculture or Masonry)
8		2	Marginalised community	Man	27	Samani	-	Unskilled Labour (Agriculture or Masonry)
9		3	Marginalised community	Elderly Man	60	Bhanthi	-	Unskilled Labour (Agriculture or Masonry)
11	Group 4	1	Marginalised community	Man	45	Nawada	-	Unskilled Labour (Agriculture or Masonry)
12		2	Marginalised community	Man	50	Nawada	-	Unskilled Labour (Agriculture or Masonry)

No.	Participating Group	Number of Participants	Stakeholder group	Participant characteristics	Age	Village	Moved from	Occupation
13		3	Marginalised community	Elderly man	62	Nawada	-	Unskilled Labour (Agriculture or Masonry)
14	Group 5	1	Marginalised community	Man	48	Nawada	-	Unskilled Labour (Agriculture or Masonry)
15		2	Marginalised community	Elderly Man	60	Bhanthi	-	Unskilled Labour (Agriculture or Masonry)
16		3	Marginalised community	Elderly man	59	Samani	-	Unskilled Labour (Agriculture or Masonry)
Workshop 2 (31/01/20): Women (Waterlogged community workshop group)								
17	Group 6	1	Marginalised community	Woman	45	Bhanthi	-	Unskilled Labour (Agriculture or Masonry)

No.	Participating Group	Number of Participants	Stakeholder group	Participant characteristics	Age	Village	Moved from	Occupation
18		2	Marginalised community	Woman	40	Bhanthi	-	Unskilled Labour (Agriculture or Masonry)
19		3	Marginalised community	Woman	35	Bhanthi	-	Unskilled Labour (Agriculture or Masonry)
20		4	Marginalised community	Woman	45	Peeparpati	-	Unskilled Labour (Agriculture or Masonry)
21		5	Marginalised community	Woman	45	Samani	-	Unskilled Labour (Agriculture or Masonry)
22	Group 7	1	Marginalised community	Woman	35	Bhanthi	-	Unskilled Labour (Agriculture or Masonry)
23		2	Marginalised community	Woman	40	Bhanthi	-	Unskilled Labour (Agriculture or Masonry)

No.	Participating Group	Number of Participants	Stakeholder group	Participant characteristics	Age	Village	Moved from	Occupation
24		3	Marginalised community	Woman	30	Khorawartor	-	Unskilled Labour (Agriculture or Masonry)
25		4	Marginalised community	Woman	50	Khorawartor	-	Unskilled Labour (Agriculture or Masonry)
26		5	Marginalised community	Woman	30	Khorawartor	-	Unskilled Labour (Agriculture or Masonry)
27	Group 8	1	Marginalised community	Elderly Woman	65	Khorawartor	-	Unskilled Labour (Agriculture or Masonry)
28		2	Marginalised community	Woman	30	Khorawartor	-	Unskilled Labour (Agriculture or Masonry)
29		3	Marginalised community	Woman	50	Khorawartor	-	Unskilled Labour (Agriculture or Masonry)

No.	Participating Group	Number of Participants	Stakeholder group	Participant characteristics	Age	Village	Moved from	Occupation
30		4	Marginalised community	Woman	38	Khorawartor	-	Unskilled Labour (Agriculture or Masonry)
31	Group 9	1	Marginalised community	Woman	30	Nawada	-	Unskilled Labour (Agriculture or Masonry)
32		2	Marginalised community	Woman	40	Nawada	-	Unskilled Labour (Agriculture or Masonry)
33		3	Marginalised community	Elderly woman	55	Nawada	-	Unskilled Labour (Agriculture or Masonry)
34		4	Marginalised community	Elderly woman	70	Nawada	-	Unskilled Labour (Agriculture or Masonry)
35		5	Marginalised community	Elderly woman	75	Nawada	-	Unskilled Labour (Agriculture or Masonry)

No.	Participating Group	Number of Participants	Stakeholder group	Participant characteristics	Age	Village	Moved from	Occupation
36		6	Marginalised community	Woman	25	Khorawartor	-	Unskilled Labour (Agriculture or Masonry)
Workshop 3 (01/02/20): Men (West Embankment community workshop group)								
37	Group 10	1	Marginalised community	Man	52	Bhagwa	Within embankments	Unskilled Labour (Agriculture or Masonry)
38		2	Marginalised community	Man	40	Bhagwa	Within embankments	Unskilled Labour (Agriculture or Masonry)
39		3	Marginalised community	Elderly man	61	Bhagwa	Within embankments	Unskilled Labour (Agriculture or Masonry)
40		4	Marginalised community	Man	40	Bhagwa	Within embankments	Unskilled Labour (Agriculture or Masonry)

No.	Participating Group	Number of Participants	Stakeholder group	Participant characteristics	Age	Village	Moved from	Occupation
41		5	Marginalised community	Man	27	Bhagwa	Within embankments	Unskilled Labour (Agriculture or Masonry)
42	Group 11	1	Marginalised community	Elderly man	60	Bhagwa	Within embankments	Unskilled Labour (Agriculture or Masonry)
43		2	Marginalised community	Elderly man	62	Bhagwa	Within embankments	Unskilled Labour (Agriculture or Masonry)
44		3	Marginalised community	Man	30	Bhagwa	Within embankments	Furniture maker
45		4	Marginalised community	Man	31	Bhagwa	Within embankments	Unskilled Labour (Agriculture or Masonry)
46		5	Marginalised community	Man	40	Bhagwa	Within embankments	Unskilled Labour (Agriculture or Masonry)

No.	Participating Group	Number of Participants	Stakeholder group	Participant characteristics	Age	Village	Moved from	Occupation
47	Group 12	1	Marginalised community	Man	53	Bhagwa	Waterlogged area	Unskilled Labour (Agriculture or Masonry)
48		2	Marginalised community	Man	45	Bhagwa	Waterlogged area	Unskilled Labour (Agriculture or Masonry)
49		3	Marginalised community	Man	35	Bhagwa	Waterlogged area	Unskilled Labour (Agriculture or Masonry)
50		4	Marginalised community	Man	23	Bhagwa	Waterlogged area	Student
Workshop 4 (01/02/20): Women (West Embankment community workshop group)								
51	Group 13	1	Marginalised community	Woman	45	Bhagwa	Within embankments	Unskilled Labour (Agriculture or Masonry)
52		2	Marginalised community	Woman	50	Bhagwa	Within embankments	Unskilled Labour (Agriculture or Masonry)

No.	Participating Group	Number of Participants	Stakeholder group	Participant characteristics	Age	Village	Moved from	Occupation
53		3	Marginalised community	Elderly woman	55	Bhagwa	Within embankments	Unskilled Labour (Agriculture or Masonry)
54		4	Marginalised community	Woman	30	Bhagwa	Within embankments	Unskilled Labour (Agriculture or Masonry)
55		5	Marginalised community	Elderly woman	70	Bhagwa	Within embankments	Housewife
56		6	Marginalised community	Elderly woman	70	Bhagwa	Within embankments	Unskilled Labour (Agriculture or Masonry)
Workshop 5 (02/02/20): Men (Within embankments community workshop group)								
57	Group 14	1	Dominant community	Elderly man	55	Bhagwa	-	Farmer and Landowner
58		2	Marginalised community	Elderly man	55	Bhagwa	-	Unskilled Labour (Agriculture or Masonry)

No.	Participating Group	Number of Participants	Stakeholder group	Participant characteristics	Age	Village	Moved from	Occupation
59		3	Dominant community	Elderly man	60	Bhagwa	-	Farmer and Landowner
60		4	Dominant community	Man	22	Bhagwa	-	Farmer and Landowner
61	Group 15	1	Dominant community	Man	29	Bhagwa	-	Farmer and Landowner
62		2	Dominant community	Elderly man	55	Bhagwa	-	Farmer and Landowner
63		3	Dominant community	Man	32	Bhagwa	-	Farmer and Landowner
64		4	Marginalised community	Elderly man	69	Bhagwa	-	Unskilled Labour (Agriculture or Masonry)
65	Group 16	1	Dominant community	Elderly man	53	Bhagwa	-	Farmer and Landowner
66		2	Dominant community	Elderly man	59	Bhagwa	-	Farmer and Landowner

No.	Participating Group	Number of Participants	Stakeholder group	Participant characteristics	Age	Village	Moved from	Occupation
67		3	Marginalised community	Man	30	Bhagwa	-	Unskilled Labour (Agriculture or Masonry)
68		4	Marginalised community	Man	29	Bhagwa	-	Unskilled Labour (Agriculture or Masonry)
Workshop 6 (02/02/20): Women (Within embankments community workshop group)								
69	Group 17	1	Marginalised community	Woman	40	Bhagwa	-	Unskilled Labour (Agriculture or Masonry)
70		2	Marginalised community	Woman	42	Bhagwa	-	Unskilled Labour (Agriculture or Masonry)
71		3	Marginalised community	Woman	40	Bhagwa	-	Unskilled Labour (Agriculture or Masonry)

No.	Participating Group	Number of Participants	Stakeholder group	Participant characteristics	Age	Village	Moved from	Occupation
72		4	Marginalised community	Woman	35	Bhagwa	-	Unskilled Labour (Agriculture or Masonry)
73		5	Dominant community	Woman	40	Bhagwa	-	Farmer and Landowner
74		6	Dominant community	Woman	20	Bhagwa	-	Farmer and Landowner
75	Group 18	1	Dominant community	Woman	31	Bhagwa	-	Farmer and Landowner
76		2	Dominant community	Woman	22	Bhagwa	-	Farmer and Landowner
77		3	Dominant community	Woman	20	Bhagwa	-	Farmer and Landowner
78		4	Dominant community	Woman	25	Bhagwa	-	Farmer and Landowner
79		5	Dominant community	Woman	30	Bhagwa	-	Farmer and Landowner
Workshop 7 (03/02/20): NGOs								

No.	Participating Group	Number of Participants	Stakeholder group	Participant characteristics	Age	Village	Moved from	Occupation
80	Group 19	1	NGO	Sahbhagi Shikshan Kendra	46	-	-	NGO employee
81		2	NGO	Kosi Seva Sadan	70	-	-	NGO head
82		3	NGO	Megh Payne Abhiyan	40	-	-	NGO employee
83		4	NGO	Megh Payne Abhiyan	35	-	-	NGO employee

Appendix B

Researcher's introduction to the participants

At the beginning of each workshop, the researcher introduced the researcher and research. "First of all, thank you for coming here and being a part of these workshops. I will start by introducing myself and what I came to do here. My name is Pooja Singh, and I visited Saharsa in Oct 2018 and have interacted and interviewed most of the people present here. However, I am a PhD student pursuing my studies at the University of Nottingham in the UK for those who do not know me. (For their reference, I mentioned that it is near London, England). My native place is Bulandshahar, Uttar Pradesh and I live in Haridwar, Uttarakhand. I am not working for any government organisation or NGO (I emphasised this point to make sure they do not expect monetary help or feel I am here as a government official). My research topic is on floods, and it involves understanding human flood interactions- How do people live in flood-affected areas and how their lives/occupations are affected by flooding on a daily basis?

For my research, I selected Bihar as my field area. Today, I am here because I need your help to understand your situation in your own words because you are the people living here in these conditions. Therefore, who can better understand your lives other than you? So, how will we do that? Today we are going to use the rich picture technique. This technique involves drawing a picture which will illustrate your lives in flood-prone areas and how it impacts your lives. The colours and sticky notes can be used to describe the situation/issues. All of you will be divided into groups, and all groups will make their own rich pictures.

However, if anyone needs any help, they can discuss it with me at any point. I will be more than happy to help.”

After the details of the workshop were explained, and handouts were given to the participants. The researcher made sure to get written consent from the participants at the beginning of the workshop.

Participants feedback regarding the workshop

The researcher sought feedback from the participants about their expectations from the workshops. Few participants came to the researcher before, during or after the workshop with their feedback. The feedback was captured in an informal verbal way, and the researcher documented those in the field diary. The responses included:

- They hope that the authority will hear their voices/situations.
- This process will help them express how they live in these adverse conditions.
- They do not want to rehabilitate; they only want the government’s support to provide them with primary education, sanitation, health and transportation facilities.

Appendix C

Non-monsoon waterlogged sub-system variables

Triggers

1) Construction of Kamla Balan embankments – Construction of Kamla Balan embankments in the early 1970s has put extra pressure on the community living in the waterlogged area. The water from the waterlogged area used to drain faster before the Kamla Balan embankments were constructed.

Impacts on the waterlogged community during non-monsoon

2) Current control of sluice gate – Current mechanism of the sluice gate is uncontrolled, which leads the Kamla Balan water to come into the already waterlogged area.

3) Current quality of education opportunities – This variable represents the current quality of education the children in the area receive, which is relatively low.

4) Seepage through the Kosi embankment – This variable represents the seepage occurring through the Kosi embankments into the adjoining areas.

5) Time period of school being open - Due to waterlogging in the area, either some schools do not open because they are surrounded by water, or it is difficult for children and the school staff to reach.

6) Number of children going to school – This variable defines the number of children able to attend school. Due to the waterlogging, the number of children going to school is hugely impacted.

7) Usage of boats – This variable defines the boat usage by the community members.

8) Road connectivity – Road connectivity defines the network of roads that connect these villages.

9) Commute time by boat – It defines the time taken by the people to commute by boat in the waterlogged area. The amount and time duration of waterlogging increases the commute time significantly and the whole work hours would be wasted in commute. Not only waterlogging but the growth of water hyacinth also aided the increase in commute time. The volume of waterlogging changes during the year, creating different problems year-round. For example, during low volume period, the water hyacinth and the depth of water in the waterlogged area makes transportation using boats difficult, leaving people with no choice but to commute by foot which is not only time consuming and but also puts the commuter in danger of water-borne infections and diseases

10) Number of people owning personal boats – This variable defines the number of people who have their personal boats.

11) Area covered by invasive species (water hyacinth) – The area has a high spread of water hyacinth over the

waterlogged area. Water hyacinth has the property of a high spread rate.

12) Rate of delay in agricultural opportunities – This variable defines the delay in agricultural activities the communities face due to waterlogging in the area. Village area being waterlogging around the year left these communities with no land for agriculture. Their agricultural lands are submerged in water for almost the entire year, weakening the socio-economic situation of these communities.

13) Yield or successful harvest of food crops – This variable defines the yield and successful harvest of food crops in the waterlogged area during the non-monsoon season.

14) Number of people using water hyacinth as fodder for livestock – Due to few agricultural opportunities, people use water hyacinth as fodder to feed their livestock.

15) People selling personal belongings – The number of people living in the waterlogged area selling their personal belongings due to the financial impacts of groundwater flooding.

16) Socio-economic status of communities – This variable represents the socio-economic status of the community members.

17) Capacity to buy agricultural implements – This represents the financial capacity of the community members to buy tools and seeds for agriculture.

18) Financial losses in agriculture – The community members suffer losses in agriculture due to waterlogging in the area.

19) Male seasonal migration rate – The young men from the villages migrate to other cities in India to find employment. With fewer agricultural opportunities in the area, the young men from these communities migrate to other cities in search of jobs to fulfil the basic needs of sustenance of their families.

20) Number of livestock getting sick or infected with contagious diseases – This variable defines the spread of infection amongst the livestock.

21) Livestock health and wellbeing – It represents the health and wellbeing of the livestock in the waterlogged area impacted by groundwater flooding.

22) Current quality of veterinary treatment – This variable reflects the current quality of veterinary treatment available in the area for livestock.

23) Household responsibilities on women – This variable amounts to the responsibility to manage the household on women. The household responsibility has severely increased to the male seasonal migration.

24) Standard of care to pregnant women and personal hygiene in women and adolescent girls – The standard is currently not high due to the remoteness and the messy situation of the area where they live.

25) Quality of life – This variable defines the quality of life of the community member, which is severely impacted by the floods.

26) Sense of security – The sense of security of the communities is also highly impacted by the human-flood interaction in the Kosi Basin.

27) Degree of belongingness – The degree of belongingness is highly impacted by the waterlogging in the area.

28) Current quality of healthcare in the area – This variable defines the current quality of healthcare available to these communities.

29) Number of hand pumps in the area – The number of hand pumps have a considerable impact on the quality of clean water these communities can access.

30) NGO and government distributing resources – NGO and government distributes resources such as toilets, handpumps to the flood affected communities.

31) Water/Land pollution – In the waterlogged area, water pollution is high due to the growth of water hyacinth, the stagnancy of water, littering and open defecation. As the stagnant water recedes, the water pollution converts to land pollution in the area.

32) Number of people littering in the water – The community people litter in the area, contributing to water pollution.

33) Health and well-being of community members – This variable defines the impact of floods on the community members' health and well-being of the community members.

34) Number of children learning to swim in the water in the waterlogged area – To be prepared for floods, the children learn to swim in the polluted water in the waterlogged area.

35) Rate of spread of diseases and infections in the community – This variable defines the rate at which the diseases and infections spread in the community.

36) Number of marginalised community stakeholders defecating openly in the waterlogged area – Due to few toilets, it is common to defecate openly in this area. This practice also leads to water pollution.

37) Number of toilets in the area – It defines the total number of toilets in the area, either private or government or NGO aid.

38) Considering impacts of floods in general policy making- The national policy which provides toilets to poor people does not consider the additional cost involved in building a toilet in the waterlogged impacted area.

39) People commuting by foot in the waterlogged area – Due to few boats or if there are enough boats, sometimes due to the low water depth in the area, people go by foot in the stagnant water to reach their destination.

40) Social implication for women – The patriarchal norms significantly impact the women living in the Kosi Basin. Due to this, these women feel shy even to lift their saris (traditional attire) to walk in the stagnant water in the waterlogged area.

41) Waterlogging is not considered as a form of flooding – Even though the waterlogged area suffers from both surface water and groundwater flooding, it is not considered flood-affected.

Kosi Basin surface water and groundwater class of variables involved

42) Kamla Balan River water enters the villages through the sluice gate – The Kamla Balan embankments were built in the 1970s. Since then, the waterlogging problem has increased due to the uncontrolled flow of Kamla Balan River water through the sluice gate in the waterlogged area.

43) Backflow of Kosi River water from the opening at the end of the west embankment – There is an opening at the end of the Kosi west embankment through which the Kosi River water backflows in the waterlogged area.

44) Volume of water entering the villages from Kosi, Kamla and Gehua rivers during surface water flooding – Water from both the rivers, Kosi and Kamla Balan, enters the waterlogged area during surface water flooding.

45) Waterlogging spread (in area) – This variable defines the waterlogging spread in the area.

46) Drainage density in the waterlogged area – The drainage density is the speed at which the water from the waterlogged area drains out.

Interactions with other human-flood interacting sub-systems

47) Number of marginalised community stakeholders moving to live on/near the west embankment permanently - The worst impact of flooding on people living in the waterlogged area and the area within the embankments rendered them with no other choice shift from their home permanently. People chose to move to the Kosi project embankment land as their first choice as this is the only safer option available to them owing to the discrepancy in compensation distribution. Having no other option to explore, these communities have been moving to live on the embankment since it was built in the late 60s. The discrepancy in compensation distribution led to people not getting the promised compensation land for their flooded property. Some people got the compensation land, but the adequacy of the compensation land was not up to the standard, although a few families have moved. The lives of families who have moved to the given compensation are out of the scope of this study.

48) Flood compensation – There is a gap in the flood compensation given to the waterlogged communities as the waterlogged area is not considered flood affected.

Monsoon waterlogged sub-system variables

Impacts on the waterlogged community during monsoon

1) Probability of embankment failure – Because of the unpredictability of the Kosi River, the embankment can break during monsoon.

2) Flooding of houses and assets – Due to surface water flooding, the community people lose their houses and assets.

3) Quality of life - This variable defines the quality of life of the community member, which is severely impacted by the floods.

4) Socio-economic status of the community members– This variable defines the social and economic status of the community members. It also includes the economic losses which the community members endure due to flooding.

5) Number of women with increased household/childcare responsibility – This variable amounts to the responsibility to manage the household on women. The household responsibility has severely increased to the male seasonal migration.

6) Male seasonal migration rate – The young men from the villages migrate to other cities in India to find employment. With fewer agricultural opportunities in the area, the young men from these communities migrate to other cities in search of jobs to fulfil the basic needs of sustenance of their families.

7) Degree of belongingness – During surface water floods, temporarily settling on the embankment experience a low degree of belongingness.

8) Degree of fear – These waterlogged communities live in the constant fear of breaking of Kosi embankments, especially during the monsoon season.

9) Sense of security - The sense of security of the communities is also highly impacted by the human-flood interaction in the Kosi Basin.

10) Destruction of standing crops – Many standing crops get destroyed during the monsoon due to surface water flooding.

11) Current government issued crop compensation shared by the Zamindars with the agricultural workers – In the current scenario, the compensation money given by the government to the landlord does not reach the agricultural workers.

12) Time period of school being open – Due to the surface water flooding in the monsoon, the school remains close for the surface water flood duration.

13) Current quality of education opportunities - This variable represents the current quality of education the children in the area receive, which is relatively low.

14) Current maintenance of boats – This variable defines the current ability of the communities to maintain their boats.

15) Usage of boats for evacuation – This variable defines the importance of boats for evacuation purpose during the monsoon season.

16) Rate of people evacuating – This variable defines the number of people evacuating using the boats.

17) Ability to take personal belongings and livestock to the west embankment – Higher number of boats also allow the communities to take their livestock with them to west embankment during floods.

Kosi Basin surface water and groundwater class of variables involved

18) Waterlogging spread (in area) (non-monsoon waterlogged sub-system) - This variable defines the waterlogging spread in the area.

19) Backflow of Kosi River water from the opening at the end of the west embankment – There is an opening at the end of the Kosi west embankment through which the Kosi River water backflows in the waterlogged area.

20) Rate of surface water flooding – This variable defines the quantity of surface water flooding in the area.

Interactions with other human-flood interacting sub-systems

21) Number of people temporarily settling on the west embankment during the surface water flood period (monsoon embankment sub-system) – Due to the submergence of villages in the area, the community

members temporarily move to the west embankment for the period of flooding.

Non-monsoon within embankments sub-system variables

Impacts on the within embankments community during non-monsoon

1) Number of houses washed away or destroyed (Monsoon within embankments sub-system) – Many houses within embankments get washed away during surface water flooding. Due to scouring, land becomes a pit or Kosi River flows there now.

2) Number of people losing their ancestral property and becoming landless – Because of surface water flooding, the people living within the embankments lose their ancestral property.

3) Socio-economic status of communities - This variable represents the financial capacity of the community members to sustain their lives.

4) Quality of life - This variable defines the quality of life of the community member, which is severely impacted by the floods.

5) Degree of belongingness - During surface water floods, temporarily settling on the embankment experience a low degree of belongingness.

6) Sense of security - The sense of security of the communities is highly impacted by the human-flood interaction in the Kosi Basin.

7) Zamindars acquiring the land where these marginalised community stakeholders used to live – Due to the high fertility of the soil in the area within the embankments, the Zamindars acquire their lands once the marginalised community stakeholders move to the embankment to live there permanently.

8) Number of marginalised community stakeholders who cannot return to their ancestral land – Due to the land now acquired by the Zamindars, the people living on the embankment cannot return to their ancestral land.

9) Number of people able to get government allocated compensation money/land – This variable defines the number of people who are able to get the flood compensation after their house has been destroyed.

10) Current quality of education opportunities - This variable represents the current quality of education the children in the area receive, which is relatively low.

11) Number of children going to school - This variable defines the number of children able to attend school. Due to the low road connectivity, the number of children going to school is hugely impacted.

12) Knowledge about government policies and ability to fill in official forms - Due to the low education rate, the community members have little knowledge about the current government policies related to flood or general.

Low literacy also limits their ability to fill in the official forms.

13) Implementation of government policies - This variable defines the degree to which the flood risk policies are implemented in the area.

14) Current attitude of government authorities - This defines the current attitude of the government authorities towards the problems of the Kosi Basin community members.

15) Number of villages trapped within Kosi River tributaries – The number of villages trapped within the tributaries depends on the Kosi River's meandering nature.

16) Degree of road connectivity – It defines the road connectivity available to these within the embankments community.

Interactions with other human-flood interacting sub-systems

17) Number of marginalised community stakeholders moving to live on/near the Kosi west embankment - The worst impact of flooding on people living in the waterlogged area and the area within the embankments rendered them with no other choice shift from their home permanently. People chose to move to the Kosi project embankment land as their first choice as this is the only safer option available to them owing to the discrepancy in compensation distribution. Having no other option to explore, these communities have been moving to live on

the embankment since it was built in the late 60s. The discrepancy in compensation distribution led to people not getting the promised compensation land for their flooded property. Some people got the compensation land, but the adequacy of the compensation land was not up to the standard, although a few families have moved. The lives of families who have moved to the given compensation are out of the scope of this study.

Monsoon within embankments sub-system variables

Impacts on the within embankments community during monsoon

1) Submergence of villages – Due to the surface water flooding, the villages in the area gets submerged in floodwater.

2) Rate of people evacuating – This defines the time it takes people to evacuate, which is hugely affected by the high current of the Kosi River.

3) Number of people owning personal boats - This variable defines the number of people who have their personal boats.

4) NGO and government distribution of boats – This variable defines the aid the community gets from the NGO and government in the form of boats.

5) Socio-economic status community members - This variable represents the financial capacity of the community members to sustain their lives.

6) Male seasonal migration rate - The young men from the villages migrate to other cities in India to find employment. With fewer agricultural opportunities in the area, the young men from these communities migrate to other cities in search of jobs to fulfil the basic needs of sustenance of their families.

7) Household responsibility on women - This variable amounts to the responsibility to manage the household on women. The household responsibility has severely increased to the male seasonal migration.

8) Rate of dependency of elderly and disabled community members on other community members – Due to high vulnerability, the rate of dependency of elderly and disabled people increases during surface water flooding.

9) Fear of losing vulnerable family members when women are at work – The women during the monsoon period have a constant fear of losing vulnerable family members while at work.

10) Psychological impact – This variable defines the psychological impact flood has on the community members.

11) Number of children going to school - This variable defines the number of children able to attend school. Due to the waterlogging, the number of children going to school is hugely impacted.

12) Current quality of education opportunities - This variable represents the current quality of education the children in the area receive, which is relatively low.

13) Number of houses washed away or destroyed - Many houses within embankments get washed away during surface water flooding.

14) Ability to take livestock to the west embankment – This variable defines the community's ability to take the livestock to the west embankment during surface water flooding to safeguard the livestock from floods.

15) Flooding of stored resources and standing crops – The communities endure losses during surface water flooding due to the loss of stored resources and standing crops.

16) Quality of life - This variable defines the quality of life of the community member, which is severely impacted by the floods.

17) Sense of security - The sense of security of the communities is also highly impacted by the human-flood interaction in the Kosi Basin.

18) Amount of time people have to prepare for floods – This variable defines the time people have to prepare after the Kosi River water is released from the Kosi Barrage.

19) Degree of fear of houses being washed away or destroyed in floods – Degree of fear is the uncertainty of losing their houses which these people face during surface water floods.

20) Resources and infrastructure for advance flood warning - This variable is defined as the resources and infrastructure invested by the government authorities in

advance flood warning given to the Kosi Basin communities living at risk of flooding.

21) Current responsiveness of government officials - The actions taken by the government officials result from the government's willingness to listen to the issues faced by people and the socio-economic status of people. These actions impact the community’s sense of security.

Kosi Basin surface water and groundwater class of variables involved

22) Volume of water released from the Kosi Barrage - This variable defines the volume of water released from the Kosi Barrage during the monsoon period of the year.

23) Velocity of Kosi River water – This variable defines the velocity of Kosi River water during the time of surface floods.

24) Meandering of Kosi River – Meandering is the Kosi River property because of which it changes its flow direction.

25) River erosion – During surface water flooding, the river erodes the riverbed in the area within the embankments.

Interactions with other human-flood interacting sub-systems

26) Number of people temporarily settling on the Kosi west embankment (monsoon embankment sub-system) - Due to the submergence of villages in the area, the

community members temporarily move to the west embankment for the period of flooding.

Non-monsoon embankment sub-system variables

Triggers

1) Construction of Supaul-Kasraur road – The construction of this road acted as a trigger for the embankment communities. Before the Supaul-Kasraur road was built, people lived in peace with the Zamindars. Some people have settled on the embankment for nearly 50 years now. However, as the road bridge was constructed, the system's dynamics changed, making Zamindars interested in the land.

Impacts on the embankment community during non-monsoon

2) Number of marginalised community stakeholders moving to live on/near the Kosi west embankment permanently - The worst impact of flooding on people living in the waterlogged area and the area within the embankments rendered them with no other choice shift from their home permanently. People chose to move to the Kosi project embankment land as their first choice as this is the only safer option available to them owing to the discrepancy in compensation distribution. Having no other option to explore, these communities have been moving to live on the embankment since it was built in the late 60s. The

discrepancy in compensation distribution led to people not getting the promised compensation land for their flooded property. Some people got the compensation land, but the adequacy of the compensation land was not up to the standard, although a few families have moved. The lives of families who have moved to the given compensation are out of the scope of this study.

3) Number of marginalised community stakeholders living in slum huts in a small area on the embankment - The struggles of the community people with belongingness make people not build permanent houses. The community is unsure about their living conditions, so they feel that living in slum huts is better. Also, the low agricultural options and fewer live stocks hinder these communities' growth. Even if they possess livestock, they have nowhere to put them.

4) Number of toilets in the area - As the communities live in slums huts with uncertainty in the degree of belongingness, they do not feel the need to build a toilet in the house.

5) Accessibility of land for agriculture and possession of livestock - Surrounded by Kosi and Gehua leaves significantly less land for the embankment people to perform agricultural activities. Even if they have the land available, it is highly subjected to the dynamics of Kosi River in the area within the embankments and Gehua River in the waterlogged area. Space restriction due to living in slum huts also restricts the ability of the communities to possess livestock.

6) Degree of restriction based on geomorphology - The embankment land is surrounded by the Kosi River on one side and the Gehua River on the other side, which restricts land usage by people for agricultural activities.

7) Socio-economic status of the marginalised community stakeholders - Living on the embankment land with limited agricultural opportunities and livestock, rendering them very few employment opportunities. People engage in fishing, small business, or ancestral trade like bamboo craft.

8) Current responsiveness of government officials to community concerns - The actions taken by the government officials result from the government's willingness to listen to the issues faced by people and the socio-economic status of people. These actions impact people's trust in government, sense of security and the number of people approaching the government for land issues.

9) Resources and infrastructure for advance flood warning – This variable is defined as the resources and infrastructure invested by the government authorities in advance flood warning given to the Kosi Basin communities living at risk of flooding.

10) Amount of time people have to prepare for floods - This variable defines the time people have to prepare after the Kosi River water is released from the Kosi Barrage.

11) Number of marginalised community stakeholders having trust in the government - The actions taken by the

government against the issues/problems faced by the communities, land issues, an advance flood warning is a measure of the number of people having trust in the government.

12) Sense of security - The sense of security of the communities is also highly impacted by the human-flood interaction in the Kosi Basin. The communities on the embankment land face a low sense of security due to the low degree of belongingness. This low sense of security makes the people approach the government for land issues. It is also significantly impacted by the number of people trusting the government.

13) Quality of life - This variable defines the quality of life of the community member, which is severely impacted by the floods.

14) Degree of belongingness - The people living on the embankment forms a new community. This community includes the homeless/landless people from the waterlogged area and the area within the embankments. Settling on the embankment land, the homeless/landless people struggle with the degree of belongingness towards the area. They are now living on government land with no land rights. Having no land rights and the constant fear of being moved at any time hampers the degree of belongingness of these communities to a great extent.

15) Frequency of embankment works - Along with the Zamindars threatening the embankment people, the embankment works also lower the embankment community's degree of belongingness.

16) Number of land claim threats by Zamindars - As the Zamindars feel that the land value near the embankment has increased, more and more Zamindars start claiming land rights.

17) Forced acquisition of land by Zamindars – The number of forced acquisitions of land by Zamindars has increased as the land value became high.

18) Number of marginalised community stakeholders approaching the government for land issues - When the Zamindars threaten the marginalized community stakeholders, their degree of belongingness decreases. The lowered degree of belongingness decreases the sense of security. Moreover, when the sense of security is lowered, the number of people approaching the government for land issues increases.

19) Land value near the Kosi embankment - Construction of Supaul-Kasraur road raised the land value near the embankment, making nearby Zamindars make land claims for the embankment land near their house or connecting their land to the embankment road.

20) Degree of Zamindar's political power – This variable defines the influence of the Zamindars because of their social and political standing.

21) Zamindar bribery of government – This variable defines the degree of corruption that impacts the lives of the community members.

Kosi Basin surface water and groundwater class of variables involved

22) Volume of water released from the Kosi Barrage – This variable defines the volume of water released from the Kosi Barrage during the monsoon period of the year.

Interactions with other human-flood interacting sub-systems

23) Worst effects of human-flood interactions in the within embankment area - The issues within the embankments are quite different from the waterlogged area's situation. These communities face the direct impact of the Kosi River during the monsoon period. This situation leads to three major issues:

a) River erosion cuts down the soil making the houses fall and wash away. This phenomenon makes people homeless. So, to safeguard themselves from this situation happening again during the next monsoon, these people move to the embankment to live permanently.

b) Some people have also become landless because the land they used to live in became a pit due to soil erosion or is now serving as one of the new flow paths for the Kosi River.

c) When the soil bed in the area where these communities used to live has increased over time or the Kosi River has finally decided to change its course, making the communities perceive the situation to be safer for living and providing them with agricultural opportunities. The people relocated on the Kosi west embankment are willing to move back to their ancestral lands. However, the Zamindars or the people with high social and political standing forcefully acquire the land of these communities. The forceful acquisition is due to Kosi River's fertile soil after surface floods and the marginalized community stakeholder's unheard land ownership claims. The new soil increases the fertility of the land, making it suitable for agriculture. So, even if the people residing on the embankment want to relocate to their homes, they cannot.

24) Worst effects of human-flood interactions in the waterlogged area - In the waterlogged area, some families still have homes, but the surrounding land's condition is such that the village becomes like an island, surrounded by water around the year. This situation impacts the lives of the people drastically, raising two significant issues: a) Commute time and b) Land area for agriculture. Therefore, these people move to live on the west embankment permanently.

25) Number of marginalised community stakeholders defecating openly in the waterlogged area - The number of toilets impacts the number of people defecating openly in the waterlogged area, creating problems for the waterlogged community.

26) Number of children going to school - Due to the flooding problems in the waterlogged area and the area within the embankments, the number of days the school opens is limited. The time of school being open depends on groundwater flooding in the waterlogged area during

non-monsoon. Furthermore, during the monsoon, the schools in both the waterlogged area and the area within the embankments are shut. Even connectivity plays a significant role in determining the number of children going to school.

Monsoon embankment sub-system variables

Impacts on the embankment community during monsoon

1) Number of people temporarily living in plastic or slum huts on the Kosi west embankment for the surface water flood period - Due to the submergence of villages and high grounds in the area, the community members temporarily move to the west embankment and live in plastic or slum huts to be safeguarded from surface water flooding.

2) Current distribution of relief goods – During high surface floods, the relief provided in the form of a basic package of food and shelter does not reach all the flood-affected people.

3) Number of dominant community members using their social and political influence - This variable defines the influence of the Zamindars because of their social and political standing.

4) Ability to have adequate nutritious food – Living on the west embankment temporarily, these communities struggle to have adequate nutritious food.

5) Number of malnourished marginalised community members – The inability to have adequate nutritious food, the community members, especially the children, suffer from malnutrition.

6) Human mortality – This variable defines the mortality rate of the community member during the surface water flooding period.

7) Psychological impact - This variable defines the psychological impact flood has on the community members.

8) Degree of belongingness – During surface water floods, temporarily settling on the embankment experience a low degree of belongingness.

9) Sense of security - The sense of security of the communities is also highly impacted by the human-flood interaction in the Kosi Basin.

10) Cases of harassment of women –Women face a lack of safety and sometimes get harassed during their temporary stay on the embankment.

11) Cases of stealing – The cases of stealing also goes up, impacting the sense of safety of the communities.

12) Number of people in danger of snake and insect bites – Living in an unsafe condition, these communities face the dangers of getting bitten by insects or snakes. During floods, the snakes living in the embankment in holes come up due to flood water filling up the holes.

13) Facilities and resources to practice standards of well-being – The facilities and resources that these communities have are not substantial, which highly impact their quality of life.

14) Impact on education - Due to surface water flooding, schools do not open which impacts the quality of education.

15) Current access to emergency healthcare – The hospitals are far away in the city, which leads to not having required access to emergency healthcare, which is a necessity, especially during surface flooding.

16) Standard of care to pregnant women and personal hygiene in women and adolescent girls – The standard of care and personal hygiene is relatively low in women due to a lack of facilities and resources.

17) Number of women with increased childcare responsibility - This variable amounts to the women's responsibility to take care of the children. The childcare responsibility has severely increased to the male seasonal migration.

18) Rate of spread of infection and diseases - This variable defines the rate at which the diseases and infections spread in the community.

19) Usage of contaminated flood water for fulfilling basic needs – Due to a lack of clean water resources because most of them are flooded during surface water flooding, these communities use contaminated floodwater to fulfil basic needs.

20) Number of women going far to defecate – Due to the social implication, the women go far away in the floodwater to defecate.

21) Social implications - The patriarchal norms significantly impact the women living in the Kosi Basin. Due to this, these women feel shy and go far in the flood water to defecate.

22) Number of children following their mothers in flood water – Due to the high male migration rate, the number of children following their mother even when they go far in the flood water increases.

23) Number of drowning victims – This defines the drowning rate of the communities during surface water flooding.

24) Number of people going in flood water by foot – Due to few boats, some people go in the flood water on foot, if required.

25) Number of clean water sources getting submerged in floodwater – Due to the high volume of surface water flooding, the clean water resources, including the handpumps submerge in the floodwater.

26) Usage of boats for required purposes - This variable defines the boat usage by the community members.

27) NGO and government distributing boats - This variable defines the aid the community gets from the NGO and government in the form of boats.

28) Current maintenance of boats – This defines the current maintenance level of the community members' boats.

29) Livestock left behind in the flooded area - This variable defines the community's ability to take the livestock to the west embankment during surface water flooding to safeguard the livestock from floods.

30) Death rate of livestock – This variable defines the mortality rate of the livestock during surface floods.

31) Livestock getting sick – The livestock gets sick because of eating water hyacinth and drinking floodwater.

32) Open defecation in the flood water – People defecate in the flood water because of the submergence of the limited number of toilets they have in the area.

33) Livestock eating water hyacinth and drinking floodwater- Due to flooding of stored resources, the communities have no choice but to feed water hyacinth and give floodwater to drink to their livestock.

Kosi Basin surface water and groundwater class of variables involved

34) Volume of water released from the Kosi Barrage - This variable defines the volume of water released from the Kosi Barrage during the monsoon period of the year.

35) Discharge from Gehua, Kosi and Kamla Balan Rivers – The waterlogged communities are hugely impacted by these three rivers.

36) Surface water flooding intensity – This flood intensity depends on the Kosi River water released from the Kosi Barrage.

Interactions with other human-flood interacting sub-systems

37) Quality of life - This variable defines the quality of life of the community member, which is severely impacted by the floods.

27) Male seasonal migration rate - The young men from the villages migrate to other cities in India to find employment. With fewer agricultural opportunities in the area, the young men from these communities migrate to other cities in search of jobs to fulfil the basic needs of sustenance of their families.

38) Number of employment days lost during surface water flooding – This variable defines the number of employment days the communities lose due to floods.

39) Accessibility of toilets during surface water flooding – This variable defines the number of toilets in the area, including personal and communal.

40) Socio-economic status of communities - This variable defines the social and economic status of the community members.

41) Number of people owning personal boats – This variable defines the number of people who have their personal boats.

42) Flooding of stored resources and standing crops - The communities endure losses during surface water flooding due to the loss of stored resources and standing crops.

43) Submergence of villages and high grounds provided by the government - Due to the surface water flooding, the villages and the high grounds in the area provided by the government (which can be used to be safe from surface water flooding) get submerged in floodwater.

Appendix D

Table D - 1 Assigning vulnerability dimension to variables in the feedback-only non-monsoon embankment sub-system

S.no.	Loop label	Variables involved in the loop	Assigning vulnerability dimension to variables				
			Social	Political	Economic	Physical	Technology
Reinforcing feedback loops							
1	Security loop Social (R1)	Sense of security	1				
		Quality of life	1				
			2	0	0	0	0
2	Belongingness loop Social (R2)	Quality of life	1				
		Degree of belongingness	1				
			2	0	0	0	0

S.no.	Loop label	Variables involved in the loop	Assigning vulnerability dimension to variables				
			Social	Political	Economic	Physical	Technology
3	Livelihood impact loop Social (R3)	Number of marginalised community stakeholders living in slum huts in a small area on the embankment	1				
		Accessibility of land for agriculture and possession of livestock				1	
		Degree of financial stability			1		
		Sense of security	1				
		Quality of life	1				
		Degree of belongingness	1				
			4	0	1	1	0

S.no.	Loop label	Variables involved in the loop	Assigning vulnerability dimension to variables				
			Social	Political	Economic	Physical	Technology
4	Political power loop Political (R4)	Responsiveness of government officials to community concerns		1			
		Forced acquisition of land by dominant community stakeholders		1			
		Degree of political power of dominant community stakeholders		1			
		Number of dominant community stakeholders bribing the government		1			
			0	4	0	0	0
5	Community trust loop	Responsiveness of government officials to community concerns		1			

S.no.	Loop label	Variables involved in the loop	Assigning vulnerability dimension to variables				
			Social	Political	Economic	Physical	Technology
	Social-political (R5)	Forced acquisition of land by dominant community stakeholders		1			
		Number of marginalised community stakeholders having trust in the government	1				
		Number of marginalised community stakeholders approaching the government for community concerns	1				
			2	2	0	0	0
Total number of variable categories in reinforcing loops			**10**	**6**	**1**	**1**	**0**
Balancing feedback loops							

S.no.	Loop label	Variables involved in the loop	Assigning vulnerability dimension to variables				
			Social	Political	Economic	Physical	Technology
1	Male seasonal migration loop Socio-economic (B1)	Degree of financial stability			1		
		Male seasonal migration rate	1				
			1	0	1	0	0
2	Advance flood warning loop Social-political-technology (B2)	Responsiveness of government officials to community concerns		1			
		Resources and infrastructure for advance flood warning					1
		Amount of time people have to prepare for floods	1				

S.no.	Loop label	Variables involved in the loop	Assigning vulnerability dimension to variables				
			Social	Political	Economic	Physical	Technology
		Sense of security	1				
		Number of marginalised community stakeholders approaching the government for community concerns	1				
			3	1	0	0	1
3	Land dispute loop Social-political (B3)	Responsiveness of government officials to community concerns		1			
		Sense of security	1				
		Number of marginalised community stakeholders approaching the government for community concerns	1				

S.no.	Loop label	Variables involved in the loop	Assigning vulnerability dimension to variables				
			Social	Political	Economic	Physical	Technology
			2	1	0	0	0
Total number of variable categories in balancing loops			**6**	**2**	**1**	**0**	**1**

Table D - 2 Assigning vulnerability dimension to variables in the feedback-only monsoon embankment sub-system

S.no.	**Loop label**	**Variables involved in the loop**	**Assigning vulnerability dimension to variables**				
			Social	Political	Economic	Physical	Technology
Reinforcing feedback loops							
1	Security loop Social (R1)	Sense of security	1				
		Quality of life	1				
			2	0	0	0	0
2	Belongingness loop Social (R2)	Degree of belongingness	1				
		Quality of life	1				
			2	0	0	0	0
3	WASH (1) loop Social (R3)	Spread of infections and diseases	1				
		Human mortality	1				

S.no.	Loop label	Variables involved in the loop	Assigning vulnerability dimension to variables				
			Social	Political	Economic	Physical	Technology
		Psychological impact	1				
		Quality of life	1				
		Vulnerability to flooding	1				
		Usage of contaminated flood water for fulfilling basic needs				1	
			5	0	0	1	0
4	WASH (2) loop Social (R4)	Spread of infections and diseases	1				
		Human mortality	1				
		Psychological impact	1				
		Quality of life	1				

S.no.	Loop label	Variables involved in the loop	Assigning vulnerability dimension to variables				
			Social	Political	Economic	Physical	Technology
		Vulnerability to flooding	1				
		Standard of care to pregnant women and personal hygiene in women and adolescent girls	1				
			6	0	0	0	0
5	WASH (3) loop Social (R5)	Spread of infections and diseases	1				
		Human mortality	1				
		Psychological impact	1				
		Quality of life	1				
		Vulnerability to flooding	1				

S.no.	Loop label	Variables involved in the loop	Assigning vulnerability dimension to variables				
			Social	Political	Economic	Physical	Technology
		Number of people going in flood water by foot for required purposes	1				
			6	0	0	0	0
6	WASH (4) loop Social (R6)	Spread of infections and diseases	1				
		Human mortality	1				
		Psychological impact	1				
		Quality of life	1				
		Vulnerability to flooding	1				
		Open defecation in the flood water	1				
			6	0	0	0	0

S.no.	Loop label	Variables involved in the loop	Assigning vulnerability dimension to variables				
			Social	Political	Economic	Physical	Technology
7	Loss of livelihood loop Socio-economic (R7)	Number of employment days lost during surface water flooding			1		
		Degree of financial stability			1		
		Quality of life	1				
		Vulnerability to flooding	1				
			2	0	2	0	0
8	Impact of male seasonal migration on women loop Social (R8)	Number of employment days lost during surface water flooding			1		
		Degree of financial stability			1		
		Male seasonal migration rate	1				
		Cases of harassment of women	1				

S.no.	Loop label	Variables involved in the loop	Assigning vulnerability dimension to variables				
			Social	Political	Economic	Physical	Technology
		Psychological impact	1				
		Quality of life	1				
		Vulnerability to flooding	1				
			5		2		
9	Increased childcare responsibility on women Socio-economic (R9)	Number of employment days lost during surface water flooding			1		
		Degree of financial stability			1		
		Male seasonal migration rate	1				
		Number of women with increased childcare responsibility	1				

S.no.	Loop label	Variables involved in the loop	Assigning vulnerability dimension to variables				
			Social	Political	Economic	Physical	Technology
		Number of children following their mothers in flood water	1				
		Number of drowning victims	1				
		Human mortality	1				
		Psychological impact	1				
		Quality of life	1				
		Vulnerability to flooding	1				
			8		2		
10	Insecurity loop Social (R10)	Vulnerability to flooding	1				
		Cases of stealing from plastic or slum huts			1		

S.no.	Loop label	Variables involved in the loop	Assigning vulnerability dimension to variables				
			Social	Political	Economic	Physical	Technology
		Sense of security	1				
		Quality of life	1				
			3	0	1	0	0
11	Danger of life loop Socio-physical (R11)	Vulnerability to flooding	1				
		Number of people in danger of snake bites				1	
		Human mortality	1				
		Psychological impact	1				
		Quality of life	1				
			4	0	0	1	0

S.no.	Loop label	Variables involved in the loop	Assigning vulnerability dimension to variables				
			Social	Political	Economic	Physical	Technology
12	Drowning loop Social (R12)	Vulnerability to flooding	1				
		Number of people going in flood water by foot for required purposes	1				
		Number of drowning victims	1				
		Human mortality	1				
		Psychological impact	1				
		Quality of life	1				
			6	0	0	0	0
13	Malnourishment loop	Ability of marginalised community stakeholders to have adequate nutritious food			1		

S.no.	Loop label	Variables involved in the loop	Assigning vulnerability dimension to variables				
			Social	Political	Economic	Physical	Technology
	Socio-economic (R13)	Number of malnourished marginalised community members	1				
		Quality of life	1				
		Vulnerability to flooding	1				
			3		1		
14	Political power loop Political (R14)	Discrepancy in relief goods distribution		1			
		Political power of dominant community stakeholders		1			

S.no.	Loop label	Variables involved in the loop	Assigning vulnerability dimension to variables				
			Social	Political	Economic	Physical	Technology
		Dominant community stakeholders using political power to influence the relief distribution		1			
Total number of variable categories in reinforcing loops			**58**	**3**	**8**	**2**	**0**
Balancing feedback loops							
1	Male seasonal migration loop Socio-economic (B1)	Male seasonal migration rate	1				
		Degree of financial stability			1		
			1		1		

S.no.	**Loop label**	**Variables involved in the loop**	**Assigning vulnerability dimension to variables**				
			Social	Political	Economic	Physical	Technology
Total number of variable categories in balancing loops			**1**	**0**	**1**	**0**	**0**

Table D - 3 Assigning vulnerability dimension to variables in the feedback-only non-monsoon within embankments sub-system

S.no.	Loop label	Variables involved in the loop	Assigning vulnerability dimension to variables				
			Social	Political	Economic	Physical	Technology
1	Security loop Social (R1)	Quality of life	1				
		Sense of security	1				
			2	0	0	0	0
2	Belongingness loop Social (R2)	Quality of life	1				
		Degree of belongingness	1				
			2	0	0	0	0
3	Bribery loop Political (R3)	Responsiveness of government officials to community concerns		1			
		Number of marginalised community members able to			1		

S.no.	Loop label	Variables involved in the loop	Assigning vulnerability dimension to variables				
			Social	Political	Economic	Physical	Technology
		receive government allocated compensation money/land or land rights					
		Number of marginalised community stakeholders moving/staying to live on /near the Kosi west embankment permanently	1				
		Degree of acquisition by dominant community stakeholders of the land where these marginalised		1			

S.no.	Loop label	Variables involved in the loop	Assigning vulnerability dimension to variables				
			Social	Political	Economic	Physical	Technology
		community stakeholders used to live					
		Degree of political power of dominant community stakeholders		1			
		Number of dominant community stakeholders bribing the government		1			
			1	4	1	0	0
4	Community trust loop	Number of marginalised community stakeholders having trust in the government	1				

S.no.	Loop label	Variables involved in the loop	Assigning vulnerability dimension to variables				
			Social	Political	Economic	Physical	Technology
	Social (R4)	Number of people approaching the government for compensation/land rights	1				
		Responsiveness of government officials to community concerns		1			
		Number of marginalised community members able to receive government allocated compensation money/land or land rights			1		
		Number of marginalised community stakeholders	1				

S.no.	Loop label	Variables involved in the loop	Assigning vulnerability dimension to variables				
			Social	Political	Economic	Physical	Technology
		moving/staying to live on /near the Kosi west embankment permanently					
		Degree of acquisition by dominant community stakeholders of the land where these marginalised community stakeholders used to live		1			
			3	2	1	0	0
Total number of variable categories in reinforcing loops			**8**	**6**	**2**	**0**	**0**
1	Male seasonal migration loop	Degree of financial stability			1		
		Male seasonal migration	1				

S.no.	Loop label	Variables involved in the loop	Assigning vulnerability dimension to variables				
			Social	Political	Economic	Physical	Technology
	Socio-economic (B1)						
			1	0	1	0	0
2	Community security loop Social (B2)	Responsiveness of government officials to community concerns		1			
		Number of marginalised community members able to receive government allocated compensation money/land or land rights			1		
		Number of marginalised community stakeholders	1				

S.no.	Loop label	Variables involved in the loop	Assigning vulnerability dimension to variables				
			Social	Political	Economic	Physical	Technology
		moving/staying to live on /near the Kosi west embankment permanently					
		Degree of acquisition by dominant community stakeholders of the land where these marginalised community stakeholders used to live		1			
		Number of marginalised community stakeholders unable to go to their ancestral land	1				
		Sense of security	1				

S.no.	Loop label	Variables involved in the loop	Assigning vulnerability dimension to variables				
			Social	Political	Economic	Physical	Technology
		Number of people approaching the government for compensation/land rights	1				
			4	2	1	0	0
3	Compensation/land rights loop Social (B3)	Responsiveness of government officials to community concerns		1			
		Number of marginalised community stakeholders moving/staying to live on /near the Kosi west embankment permanently			1		
		Degree of financial stability			1		

S.no.	Loop label	Variables involved in the loop	Assigning vulnerability dimension to variables				
			Social	Political	Economic	Physical	Technology
		Quality of life	1				
		Sense of security	1				
		Number of marginalised community stakeholders approaching the government for compensation/land rights	1				
			3	1	2	0	0
Total number of variable categories in balancing loops			**6**	**3**	**4**	**0**	**0**

Table D - 4 Assigning vulnerability dimension to variables in the feedback-only monsoon within embankments sub-system

S.no.	Loop label	Variables involved in the loop	Assigning vulnerability dimension to variables				
			Social	Political	Economic	Physical	Technology
1	Security loop Social (R1)	Quality of life	1				
		Sense of security	1				
			2	0	0	0	0
2	Belongingness loop Social (R2)	Quality of life	1				
		Degree of belongingness	1				
			2	0	0	0	0

S.no.	Loop label	Variables involved in the loop	Assigning vulnerability dimension to variables				
			Social	Political	Economic	Physical	Technology
3	Boat usage loop Economic (R3)	Ability to buy boats			1		
		Number of boats available to be used for evacuation			1		
		Number of people using boats for evacuation	1				
		Ability to take personal belongings and livestock to the west embankment			1		
		Degree of financial stability			1		
			1	0	4	0	0
4		Number of boats available to be used for evacuation			1		

S.no.	Loop label	Variables involved in the loop	Assigning vulnerability dimension to variables				
			Social	Political	Economic	Physical	Technology
	Boat maintenance loop Economic (R4)	Rate of people evacuating	1				
		Ability to take personal belongings and livestock to the west embankment			1		
		Degree of financial stability			1		
		Ability to maintain working condition of boats			1		
			1	0	4	0	0
Total number of variable categories in reinforcing loops			**6**	**0**	**8**	**0**	**0**
1	Male seasonal migration loop	Degree of financial stability			1		
		Male seasonal migration rate	1				

S.no.	Loop label	Variables involved in the loop	Assigning vulnerability dimension to variables				
			Social	Political	Economic	Physical	Technology
	Socio-economic (B1)						
			1	0	1	0	0
Total number of variable categories in balancing loops			**1**	**0**	**1**	**0**	**0**

Table D - 5 Assigning vulnerability dimension to variables in the feedback-only non-monsoon waterlogged sub-system

S.no.	Loop label	Variables involved in the loop	Assigning vulnerability dimension to variables				
			Social	Political	Economic	Physical	Technological
1	Security loop Social (R1)	Quality of life	1				
		Sense of security	1				
			2	0	0	0	0
2	Belongingness loop Social (R2)	Quality of life	1				
		Degree of belongingness	1				
			2	0	0	0	0
3	Impact on drainage loop Physical (R3)	Waterlogging spread (in area)				1	
		Number of dominant community stakeholders raising their lands			1		

S.no.	Loop label	Variables involved in the loop	Assigning vulnerability dimension to variables				
			Social	Political	Economic	Physical	Technological
		Drainage density in the waterlogged area				1	
			0	0	1	2	0
4	Impact on agriculture loop Economic (R4)	Degree of financial stability			1		
		Capacity to buy agricultural implements			1		
		Yield or successful harvest of food crops				1	
		Financial losses in agriculture			1		
			0	0	3	1	0
5	Sanitation and hygiene loop	Degree of financial stability			1		
		Number of toilets in the area			1		

S.no.	Loop label	Variables involved in the loop	Assigning vulnerability dimension to variables				
			Social	Political	Economic	Physical	Technological
	Economic (R5)	Number of marginalised community stakeholders defecating openly in the waterlogged area	1				
		Water/land pollution				1	
		Number of livestock getting sick or infected with contagious diseases			1		
		Livestock health and wellbeing			1		
			1	0	4	1	0
6	Hyacinth as fodder loop	Degree of financial stability			1		
		Capacity to buy agricultural implements			1		

S.no.	Loop label	Variables involved in the loop	Assigning vulnerability dimension to variables				
			Social	Political	Economic	Physical	Technological
	Economic (R6)	Yield or successful harvest of food crops				1	
		Number of people using water hyacinth as fodder for livestock			1		
		Number of livestock getting sick or infected with contagious diseases			1		
		Livestock health and wellbeing			1		
			0	0	5	1	0
Total number of variable categories in reinforcing loops			**5**	**0**	**13**	**5**	**0**
1	Male seasonal migration loop	Degree of financial stability	1		1		
		Male seasonal migration rate	1		1		

S.no.	Loop label	Variables involved in the loop	Assigning vulnerability dimension to variables				
			Social	Political	Economic	Physical	Technological
	Socio-economic (B1)						
			1	0	1	0	0
2	Selling personal belonging loop Economic (B2)	People selling personal belongings			1		
		Capacity to buy agricultural implements			1		
		Yield or successful harvest of food crops				1	
		Financial losses in agriculture			1		
					3	1	

S.no.	Loop label	Variables involved in the loop	Assigning vulnerability dimension to variables				
			Social	Political	Economic	Physical	Technological
Total number of variable categories in balancing loops			**1**	**0**	**4**	**1**	**0**

Table D - 6 Assigning vulnerability dimension to variables in the feedback-only non-monsoon waterlogged sub-system

S.no.	Loop label	Variables involved in the loop	Assignment of dimension to variables				
			Social	Political	Economic	Physical	Technology
1	Security loop Social (R1)	Quality of life	1				
		Sense of security	1				
			2	0	0	0	0
2	Belongingness loop	Quality of life	1				
		Degree of belongingness	1				

S.no.	Loop label	Variables involved in the loop	Assignment of dimension to variables				
			Social	Political	Economic	Physical	Technology
	Social (R2)						
			2	0	0	0	0
3	Boat usage loop Economic (R3)	Number of boats available to be used for evacuation			1		
		Number of people using boats for evacuation	1				
		Ability to take personal belongings and livestock to the west embankment			1		
		Degree of financial stability			1		
		Ability to buy boats			1		
			1	0	4	0	0

S.no.	Loop label	Variables involved in the loop	Assignment of dimension to variables				
			Social	Political	Economic	Physical	Technology
4	Boat maintenance loop Economic (R4)	Number of boats available to be used for evacuation			1		
		Number of boats available to be used for evacuation	1				
		Ability to take personal belongings and livestock to the west embankment			1		
		Degree of financial stability			1		
		Ability to maintain working condition of boats			1		
			1	0	4	0	0
Total number of variable categories in reinforcing loops			**6**	**0**	**8**	**0**	**0**

S.no.	Loop label	Variables involved in the loop	Assignment of dimension to variables				
			Social	Political	Economic	Physical	Technology
2	Male seasonal migration loop Socio-economic (B1)	Degree of financial stability			1		
		Male seasonal migration rate	1		1		
			1	0	1	0	0
Total number of variable categories in balancing loops			**1**	**0**	**1**	**0**	**0**