Brick by brick:
Tracking kiln regulatory compliance and liberation across Punjab and Haryana using remote sensing methods.

By

Liam-Elio

Colabuono-McDonagh

Thesis presented for the master's in research (science) degree

School of Geography
Rights Lab
University of Nottingham

2024.

Minor corrections addressed.

Word count: 37,334

Abstract

Keywords:

Brick belt, brick kiln, modern slavery, human trafficking, earth observation, remote sensing, regulatory compliance

This thesis provides a geospatial analysis of brick kiln regulation, aiming to link this authoritative geospatial data to recent liberation reports to uncover factors and visual indicators of modern slavery and human trafficking (MSHT) practises. The brick kilns in Southern Asia have been recognised as key sources of environmental and social harm. Researchers using remote sensing methods have identified negative impacts of brick kiln production including air pollution (Arbain and Imasu, 2019; Brooks et al, 2023), crop yield decline (Adrees et al, 2016), and health risks from emissions and materials associated with brick kiln work (Khan et al, 2019; David et al, 2020; Ahmad et al, 2020; Akram et al, 2022; Hamid et al, 2022; Brooks et al, 2023).

Significantly fewer research articles have covered the nature of brick kiln work and MSHT. This lack of research into MSHT practises in the brick kilns follows a trend identified by Ekmen and Kocaman (2024) showing a lack of engagement between geospatial facilitated sustainable development research and MSHT. Their paper identifies only 1.2% (3 out of 308 research articles) focused on geospatial methods and sustainable development aimed at informing sustainable development goal (SDG) 8. SDG 8 aims to “promote sustained, inclusive, and sustainable economic growth, full and productive employment, and decent work for all” (United Nations, 2024); within this goal, target 8.7 aims to end MSHT practices by 2025 (Boyd et al, 2018).

SDG 8 requires an increased research focus on gaining geospatial intelligence on how to model the relationships between businesses, social-environmental conditions, and MSHT. Recently researchers at the University of Nottingham have mapped the entirety of the “brick belt” detecting 66,455 brick kilns across the region spanning Pakistan, Northern India, Nepal, and Bangladesh. India, the focus of this thesis, contains 69.7% of the brick kilns within the brick belt (Boyd et al, 2021). The thesis analysed two Indian states Punjab and Haryana using the established environmental regulatory documentation of brick kilns to identify links between regulatory compliance and MSHT prevalence. The hypothesis is that brick kilns that comply with environmental regulations will also be less likely to employ MSHT practices. To test this a binary classification system was designed using distance measurements from the kilns against regulation specifications. Five regulation factors were captured and output as a binary score from 1 – 10000. Using this regulation classification brick kilns were then analysed for instances of liberation. The second aim is to link this regulation compliance model to liberation data to find specific regulatory failures that suggest a higher chance of modern slavery practices occurring.

This framework aims to identify registered formal brick kilns and informal kilns as the sector is heavily underregulated and organised (Boyd et al, 2018; 2021). Due to the nature of this unorganised structure, there is no accessible register of formal brick kilns. This thesis aims to create a database of regulatory compliance for kilns using data from Boyd et al (2018:2021), Li et al, (2019), and the GeoAI database (UNDP, 2023) to explore links between regulatory compliance and MSHT. The methodology is inspired by Mondal et al (2018) and Lee et al (2021) who produced regulation compliance studies for the environmental factors of the brick kilns.

Overall, the thesis reviews 5,835 kilns identifying them with a regulation compliance code with results showing that 15.5% of brick kilns in Punjab in 2020 and 19.2% in 2024 pass all 5 regulation factors. For Haryana regulation compliance rates are higher with 22.1% of brick kilns passing all tested regulations. The method proves that regulatory compliance can be accurately assessed from remote sensing data. However, the thesis cannot provide conclusive findings for the second aim as a lack of quality and quantity of liberation data makes traditional statistical methods like regression analysis and correlation testing ineffective. The paper also finds incidences of “clean” kilns also using MSHT. The thesis concludes regulation factors may prove a stronger indication of MSHT prevalence with higher-quality data. Further research is required to identify visual and regulatory factors that can be used to predict the use of modern slavery within the Indian brick kilns.

Acknowledgements

I would like to express my gratitude to my supervisors Professor Doreen Boyd and Professor Giles Foody for their advice and support during the research and write up of this thesis. These contributions have made this project rewarding and led to a deeper engagement with the material presentenced. I would also like to thank my peers in the Rights Lab at the University of Nottingham and friends at the University across different subjects and disciplines. Discussions from the highly technical to the deeply personal have helped shape this piece of work.

Lastly, I would like to thank my family, notably my mother and father, my Nonno and Nonna and my brother Paul-Nino. Words cannot express the gratitude for your greatest encouragement, dinner table discussions and constant love and support.

Table of contents

List of figures

1.0 Introduction

This thesis provides an overview of regulatory compliance of 5,835 brick kilns distributed across the Indian states of Punjab and Haryana. The goal is to review factors of compliance and explore links with the prevalence of modern slavery practices. The method focuses on the brick industry and brick kilns, due to their associations with modern slavery (Brown et al, 2019; Boyd et al, 2018; 2021). Brick kilns are furnaces used to fire bricks for manufacturing and are associated with national urban expansion (Boyd et al, 2018: 2021) and international trade (Eli et al, 2020). Researchers from the World Bank calculate that the South Asian Region (SAR) accounts for 21% of the global brick production, second only to China. Brick kilns form a key aspect of India's economy and industry, India makes up a significant majority (81%) of the SAR brick production (Eli et al, 2020).

This high demand for bricks as cheap building materials leads to increased kiln activity which increases air pollution and environmental degradation. This demand for bricks to be inexpensive also necessitates competitive market price environments to lower the cost of production (Boyd et al, 2018) this creates an increasing risk of low wages, predatory employment practises, and in the worst-case scenarios, denial of wages entirely through modern slavery practises (Choi-Fitzpatrick, 2017). Despite the association with environmental degradation (Brown et al, 2019), health risks (Brooks et al, 2023), and declines in social well-being (Bhukuth, 2005) the brick kilns remain a sector of the Indian infrastructure and economy that is poorly regulated (UNDP, 2023) and understood (Boyd et al, 2018; 2021). To combat the challenges produced by the brick kilns timely, accurate, and precise data is required to track progress, monitor results, and inform strategies and policy (Reyers and Selig, 2020; Boyd et al, 2021). While environmental and health risks of the brick kilns have been mapped consistently, the inherent challenges of analysing MSHT have led to less geospatial research being produced (Boyd et al, 2018: 2021)

As part of the Sustainable Development Goals (SDGs) SDG 8 aims to “promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all” (United Nations, 2024). India is a signatory of these goals with target 8.7 directly tackling modern slavery and human trafficking (MSHT) practises. Furthermore, India plays an important role in the attainment of the SDGs due to being the most populous nation and SDG attainment being assessed at a global scale (Gupta et al, 2023; United Nations Development Programme, 2024). To regulate the brick kilns requires in-depth and up-to-date data on their location, operation, and use of MSHT (Boyd et al, 2018; 2021). At the time of writing many papers have covered the location and operation of brick kilns. However, few papers have engaged with geospatial research of environmental regulation (Mondal et al, 2018; Lee et al, 2021) and none have engaged with applying an MSHT analysis to current regulations.

This lack of engagement with MSHT in geospatial-facilitated human rights and sustainable development research can be assessed through two interpretations. First, historically government regulation has focused on the brick kilns as a significant environmental concern and the associations with MSHT practises were marginalised in favour of arguments concerning air pollution (Arbain and Imasu, 2019; Brooks et al, 2023), crop yields (Adrees et al, 2016) and health risks of emissions and materials from the brick kilns including asthma and cardiovascular diseases to workers and inhabitants within the proximity of the kilns (Khan et al, 2019; David et al, 2020; Ahmad et al, 2020a; Mehwish et al, 2021 Akram et al, 2022; Hamid et al, 2022; Brooks et al, 2023) These emissions are especially severe in the older fixed chimney bull trench kilns (FCBTK) technology due to incomplete combustion occurring through poor fuel feeding practices leading to insufficient oxygen levels in the kiln (Greentech Knowledge Solutions, 2014). In recent years, the High Court of Punjab and Haryana based in the city of Chandigarh have been active in encouraging the conversion from FCBTK to cleaner zigzag kiln technology showing a further focus on environmental concerns of the kilns. This focus on environmental factors of the brick kilns will have influenced data availability and the academic direction of research into the brick belt helping to explain this uneven coverage of brick kilns as largely environmental issues.

Secondly, MSHT practises are difficult to source data from, due to the illicit nature of modern slavery. This presents a contention for researchers, MSHT can be impractical and even dangerous (Jackson et al, 2018) when researching in the field as interviewees can feel intimidated or embarrassed about their situation and workers being honest about their conditions with a researcher may lead to backlash from the brick kiln owners. Remote sensing methods have been shown to provide data where field operations are not possible (Prins, 2007; Bromley, 2009; Rothe and Shim, 2018) however, these methods require a target of analysis. Modern slavery due to its hidden nature produces the challenge of finding objects that can be used as a proxy for MSHT prevalence. The difficulty in finding, mapping, and monitoring these objects also explains why little research has focused on the MSHT aspects of the brick kilns. Furthermore, this lack of available data and difficulty in producing data around MSHT in a geospatial context may explain the limited research across geospatial literature for SDG 8 (Ekmen and Kocaman, 2024).

The scale of the subject area and the dynamic nature of brick kilns means it is advantageous to use remotely sensed imagery and object detection algorithms. However, remote sensing requires an object that can be physically sensed either through visible light and observational analysis or spectral analysis. Modern Slavery cannot be sensed directly. Instead, researchers have used remote sensing to identify areas where modern slavery practises are more likely to be occurring. Brick kilns are known to use MSHT practices (Boyd et al, 2018; 2021) so with that knowledge brick kilns can be used as a proxy of modern slavery. However, there are limitations to this method. First of all, researchers need to work with actors on the ground to assess whether there is a presence of MSHT practices within a specific kiln. Second, to validate these cases requires consistent and high quality data which isn’t always possible due to restrictions on access and concerns for workers safety. Third, the limitations of the technology should also be considered. While the object detection and imagery are highly accurate (Boyd et al, 2021) mistakes can occur with false positives needing to be assessed.

For this project, the main limitations were a lack of consistent high quality data when reviewing liberation reports from our partner NGO and an inability to ground truth regulatory status against our model as no regulatory register of brick kilns was accessible if it even exists in digital form. In short there was little data to compare this model too which is a limitation of new research. Similar regulatory methods to this study has been used in an air pollution context so the model is based on best practises, but the distant nature of the study area combined with the scale of analysis does create limitations.

Despite these challenges increased surveillance of the brick kilns via remote sensing practises provides researchers with further insight to the activity within the brick kilns. This supports NGOs focused on investigating MSHT cases to identify the locations of brick kilns and their active status. Knowledge of location and activity of brick kilns can help target enforcement through regulation and law as partnerships between researchers and NGOs have shown in Boyd et al (2021, 2024). Platforms like GeoAI have visualised the pattern of brick kilns providing new data for auditors. Due to the scale of the brick belt and the illicit practise of MSHT remote sensing is the most appropriate method to tackle this challenge which requires clear resource management and the ability to adapt to changes in the brick kiln environment.

Boyd et al (2018; 2021) produced the first total brick kiln estimate across the brick belt and then later the first full-scale estimation of brick kilns within the brick belt. Other papers (Ghosh and Sarkar, 2020; Nazir et al, 2018; Li et al, 2019) used remote sensing methods to map and monitor the brick kilns before, but not at this scale. In this research by Boyd et al (2018: 2021) brick kilns are linked to SDG 8. Brick kilns are placed in an intersectional framework of SDGs where the authors argue kilns are targets of SDG connectivity. By improving the brick kilns in one sustainable goal other benefits are realised. This is referred to as the freedom dividend (Bales, 2012). Despite the acknowledgement of this intersectionality most of the literature concerning geospatial research, and the brick kilns follows an environment-first approach leaving social issues like modern slavery practises marginalised (Jackson et al, 2018; Ekmen and Kocaman, 2024). This research established brick kilns as a proxy of MSHT practises and showed that remote sensing methods could help researchers gain new insights into the brick belt. In 2021 this methodology was expanded to use deep learning methods to fully map the brick belt including data on the year brick kilns were established and their spatial context.

This thesis seeks to consolidate and move beyond mapping the brick kilns and find factors within the brick kilns that suggest a high likelihood of MSHT practice occurring. In the absence of an official record of licensed brick kilns or social well-being regulation, the uses the environmental regulation for Punjab (1998) and Haryana (1972) to classify brick kilns by regulatory compliance across five factors. This proposed model then maps these compliance scores against recent liberation data provided by a partner Non-Governmental Organisation (NGO). The thesis suggests the regulation provided by this document alongside recent liberation data of brick kilns can be utilised to build a new methodology for estimating modern slavery prevalence at scale using GIS visualisation and analysis with remote sensing methods. A spatial analysis of the brick kilns through a regulatory framework has been studied by Mondal et al, (2018) and Lee et al, (2021) before but this focused on environmental concerns of the brick kilns with little connection to MSHT.

This thesis is inspired and supported by these researchers' methods but distinguishes itself by focusing on MSHT. The goal of the regulation analysis is to identify visual indicators of slavery that can help researchers explore the key factors of a kiln that suggest a higher chance of modern slavery occurring. For this thesis, the thesis suggests that regulatory compliance could be a good indicator of modern slavery and analyses spatial data of brick kilns alongside liberation reports to suggest a pattern in identifying kilns with a high likelihood of employing modern slavery practises including forced labour, bonded labour or debt bondage and trafficking. This thesis investigates brick kilns within Punjab and Haryana for regulatory compliance by designing a set of binary classifications for brick kilns. For example, in Punjab by order of the Punjab Pollution Control Board (1998) brick kilns must be 1000 metres from each other (Mondal et al, 2018). This can be analysed in GIS by calculating the distance between each kiln relative to each other for a 1000-meter radius using a combination of near-table analysis (Esri, 2024a), spatial joins (Esri, 2024b), and buffer maps (Esri, 2023). These regulation compliance statistics are then mapped onto the liberation data to establish links between specific regulation factors and records of modern slavery.

The thesis combines state regulation with academic frameworks such as the slavery-environment nexus (Bales, 2016; Brown et al, 2019; Jackson et al, 2020) and the Bellagio- Harvard Guidelines (2012) on modern slavery to explore the potential for this method. The hypothesis for the paper is that MSHT prevalence is associated with regulation compliance as it is plausible that brick kiln owners that invest in being compliant would not risk their reputation by being associated with modern slavery. Conversely, brick kiln owners who do not comply with regulation standards will also be less likely to comply with international law and the standards set by the sustainable development goals (SDGs).

The thesis is structured in three core parts. First, the thesis reviews literature focusing on the development of geospatial applications for human rights research, sustainable development, and connections to the brick kilns. Covering spatial analysis of the brick kilns and areas of new research and technology development. Second, the methodology of this thesis is outlined and split into the considerations for the literature review and the methods used for data analysis. Third, the observations and findings of the research are discussed including a breakdown of regulation compliance data, spatial analysis of random samples of districts for each database, and key trends and patterns found in the data. The thesis concludes with insights from this research and future directions for further work.

This thesis contributes to ongoing studies by the Rights Lab at the University of Nottingham and a small but growing research field of geospatial applications for examining MSHT. Data for this project was sourced from the GeoAI database for Punjab 2020 -2023, Haryana 2020 – 2023, and a separate database for Punjab 2024

brick kilns. Liberation data from 2019 - 2024 was provided by active boots-on-the-ground investigations from a partner NGO. Using remote sensing data and GIS analysis it was possible to produce a regulation score for all the brick kilns in Punjab and all the brick kilns in Haryana. The thesis found that in Punjab the 2020 data suggests 89 of 2733 brick kilns pass all five of the regulation factors it was possible to model for this thesis. Visual and spatial analysis are provided for a random sample of kilns within these databases and while statistical models are explored, insights are partial due to limitations of resources and available data.
The spatial analysis findings of this thesis are promising with the author confident that a longer study could visualise and provide an application for analysis of all the regulation factors included in the 1988 Punjab Pollution Control Board documentation. The findings support the estimation by the Punjab Pollution Control Board that 70% of kilns may be operating without permission (CPCB, 2017; Misra et al, 2020). However, the link to MSHT prevalence is severely limited by a small pool of liberation data to draw from at present. This small pool is explained by both liberation documentation being a recent consideration and the reactionary nature of the partner NGO, the NGO can only investigate brick kilns that are reported to them, producing a bias in the data. Despite this, this method shows promise for expansion in the future with the potential to scale across more Indian states.

1.1 Research gap

Over the last decade, researchers have made significant progress in estimating (Boyd et al, 2018), mapping (Misra et al, 2020), ageing (Li et al, 2019), and monitoring (Boyd et al, 2021) the brick belt and modern slavery prevalence associated with the region. It has been recognised that the brick kilns represent a target of intersectional human rights risks and the improvement of the brick kilns' sustainability through new technology (United Nations Development Programme, 2023), better work practises and investment would have lasting implications across the SDGs in India, South Asia, and the globe. Through the freedom dividend framework brick kiln innovation leads to global impact across sustainability goals (Boyd et al, 2018). Despite this, there has been little research on the links between modern slavery prevalence and the regulatory compliance of brick kilns. By focusing this thesis on regulatory compliance, the thesis provides a fuller picture of the brick kilns in India and the potential links between regulatory compliance and the likelihood of modern slavery.
The idea is that if kiln owners are violating brick kiln building regulations, then this sign of noncompliance may spread to other regulations such as human rights and infer a higher likelihood of modern slavery. This thesis provides a novel perspective on regulation of the brick kilns which have largely been used as an environmental management tool (Mondal et al, 2018) for air pollution (Punjab Pollution Control Board, 1988). Since joining this research project a year ago, the Rights Lab at the University of Nottingham has convinced Indian states to consider the impact of the

brick kilns on social harms like modern slavery and human trafficking showing a changing of opinion and focus compared to previous years.

1.2 Aims and Objectives

This thesis aims to explore the links between regulatory compliance and ongoing liberations by partner NGOs in India to assess a link between kiln regulatory compliance and modern slavery prevalence. The best outcome is that the lack of regulatory compliance is highly associated with modern slavery. A specific set of regulations being followed or not followed is linked to kilns that have been liberated. Even if this is not the case the author hopes the database and methodology provided serve to monitor brick kilns and report those breaking regulations to official auditors who can use the GeoAI platform to verify the legitimacy of these kilns and if they use modern slavery in their workforce.

This thesis aims to address these key research questions.

- How many brick kilns in Punjab and Haryana pass the 5-stage regulation model for 2020 data?

- What trends and patterns are observed between kilns within and across these states?

- What is the spatial pattern of liberations across the brick kilns and can we use a combination of liberation data and regulation data to model modern slavery prevalence?

2.0 Literature review

A literature review was developed to gain a better understanding of the development of geospatial technology applications as a key tool in human rights research and how this development has informed contemporary research into remote sensing methods for studying brick kilns. The thesis seeks to go beyond a summary of different researchers’ findings; by following the advice of Webster and Watson (2020) a concept-based approach links the developments and the key methodological innovations and research partnerships that have shaped the subject. The aim is to show an incremental development towards a research culture of human rights monitoring through geospatial technology by drawing on the evolution of remote sensing methods, and case studies and identifying the challenges researchers had to overcome along the way.

For the first section a narrative approach considering three key themes in geospatial facilitated human rights research covering the last two decades from the early 2000s to the early 2020’s is deployed. These themes are early research and partnerships (Prins, 2007; Bromley, 2009), geospatial data as a tool for mapping and monitoring human rights abuses (Marx and Goward, 2013), and the role of geospatial data as a potential deterrent and source of legal evidence against human rights abuses (Wolfinbarger, 2012; Wolfinbarger, 2016).

The second section links sustainable development research to the brick kilns focusing on the brick kilns' connections to SDG 8 (Boyd et al, 2018; 2021) and research on modern slavery and human trafficking (MSHT) with a focus on its prevalence and research in India (Kubasiewicz et al, 2022; Anwar et al, 2023; Bhukuth, 2005; Dakua, Rahaman and Das, 2023; Mishra, 2021; Pellenq, Gunn and Lima, 2021; Shah, 2006; Singh, 2005). The thesis identifies a lack of research on modern slavery practises within the brick kilns and the Indian states of Punjab and Haryana.

An overview of previous research to spatially analyse the brick kilns is the focus of section three with three themes identified. These themes are detection and mapping (Boyd et al, 2018), temporal analysis (Li et al, 2019), and monitoring (Boyd et al, 2021). The thesis starts with the seminal work by Boyd et al, (2021) showing a full study of the brick belt including the aging of kilns using high-resolution imagery and Landsat data archives. The section then focuses on other spatial analyses of the brick kilns from both an environmental and MSHT framework.

The last section covers the ethical considerations required from researchers as geospatial technology becomes more accessible and powerful. The concerns of data protection and privacy in the context of very high spatial resolution imagery are explored (Santos and Rapp, 2019) with the thesis then exploring historic academic critiques of geospatial facilitated human rights monitoring (Walker 2020; 2021) and future research directions.

For this review, the research literature database Scopus was used and captured 282 papers that fit into the inclusion and exclusion criteria using keywords including remote sensing, earth observation, and human rights. Secondary papers cited in the captured sample were used as well as grey literature including reports, sensor and platform specifications, news articles, and NGO websites like Amnesty International. The use of inclusion and exclusion criteria is not necessary for a narrative review, but it can lead to greater transparency and help focus the review (Webster and Watson, 2020; Mengist, Soromessa, and Legese, 2020). Therefore, it has been added, and the thesis will discuss it in the methodology section of this thesis.

2.1 Earth observation for human rights monitoring 2000s – 2020s

This section will review geospatial technology and trace how applications were developed over the last two decades to facilitate fact-finding (Prins, 2007), advocacy (Bromley, 2009), and human rights monitoring (Wolfinbarger, 2016). The section contains three key themes which papers are grouped into. These are early research and partnerships, satellite imagery as a deterrent, and satellite imagery as legal evidence. At the end of this section, a short conclusion will be given to link this review back to the key research questions of the section.

This review seeks to answer the following three research questions.

- Why did geospatial technology become an influential method for human rights research in the early 2000's?
- How was geospatial technology leveraged to support human rights research?
- In what ways have research practises changed with the development of remote sensing technologies and earth observation methods?

The focus of research is on the last two decades from the early 2000's to 2023 because this marks an increasing utilisation of satellite imagery and geospatial methods for human rights monitoring as both were becoming more accessible to NGOs. Furthermore, papers written in the late 2000s describe or self-describe work within this period as early examples of geospatial applications for human rights monitoring (Prins, 2007; Bromley, 2009; Marx and Goward, 2013). This suggests that the early 2000s can be identified as the starting point of widespread development in human rights research using geospatial technology. This coincides with the first high-resolution commercial imagining satellite, Ikonos launched in late 1999, before this all-imagining satellites were owned and operated by governments reducing access.

2.1.1 Early research and partnerships

In 2003 Steinberg et al (2006) used spatial visualisation through a GIS application to display massacres that had taken place in Guatemala. The researchers argued that by displaying the abuses visually it would be easier to communicate these human rights violations to the public. Steinberg et al (2006) discuss the power of maps and spatial visualisations to communicate the scale of an event in a way that statistics and testimonials could not achieve. In the conclusions of this paper, Steinberg touches on the concept that will drive this section. In the future, Steinberg et al (2006) believed their GIS visualisations of the spatial extent and location of these massacres could be used one day as a form of documentation and potential legal evidence of crimes committed. This section reviews this development from geospatial facilitated human rights research as it progressed from documentation and mapping to monitoring and then legal evidence.

Steinberg et al (2006) did not use satellite imagery for their GIS visualisation meaning this paper is not an example of early research for earth observation and human rights monitoring but it does provide a starting point to see how these technologies and methods developed. The reasons why Steinberg et al (2006) did not use satellite imagery are not discussed within the paper but there are several reasons why this lack of satellite imagery was the case. First in 2003 – 2006 when the study was conceived and later published satellite imagery with suitable resolution to provide useful spatial data from orbit was prohibitively expensive (Marx and Goward, 2013). Second, computer power would have been a significant limitation on the scale of studies that were possible with remotely sensed data and third for the overview provided by Steinberg et al (2006) high-resolution imagery may have not been necessary. Steinberg et al (2006) is the earliest example of human rights documentation by geospatial technology that was captured by the inclusion-exclusion criteria.

The paper shows how geospatial technology was used to document and communicate human rights abuses in the early inception of geospatial-facilitated human rights monitoring.
Due to the expensive financial, resource, and time requirements of geospatially facilitated human rights research charities often teamed up with researchers and geospatial consultancy companies to produce analysis (Bromley, 2009).

One of the first examples of this collaboration between geospatial analysts, NGOs, and academic groups is Darfur in Sudan. In September 2003, a new conflict was breaking out across Darfur, Sudan. Reports of villages being systematically burned by the armed militia of the Sudanese government called the Janjaweed were impossible to verify due to a lack of access. This was because Darfur was considered unsafe and strictly off-limits to aid workers, investigative journalists, and human rights groups (Prins, 2007). Due to this response from the international community was slow and intelligence was difficult to gain and validate. Two Darfuri rebel groups the Sudan Liberation Movement (SLM) and the Justice and Equality Movement (JEM) attacked Sudanese Government military targets. The government's reaction involved arming militia called the Janjaweed who attacked villages in Darfur that were perceived to be supportive of the rebels (Holocaust Memorial Day Trust, 2024).

The Janaweed followed scorched earth tactics involving arson, displacement, murder, and rape with the US Congress declaring the event a genocide while the United Nations stopped short of that designation. Satellite imagery provided an opportunity to gain intelligence on Darfur but restrictions to financial, computational, and knowledge resources meant only a few actors could spearhead the research required to acquire this intelligence. Remote sensing methods using satellite imagery provided several advantages to researchers when gaining information about Darfur. First, Satellites due to being in orbit are not restricted by no-fly zones, territorial borders, or safety assessments. Second, monitoring Darfur remotely ensures researcher safety in dangerous areas of interest. Third, the scale of analysis and visualisation provided by geospatial technology helps communicate findings to stakeholders and explore trends and patterns. Satellite imagery can also be archived and documented providing a source of evidence of human rights abuses. This ability for maps to display and communicate violence that is hard to comprehend echoes back to Steinberg et al, (2006) where the researchers used maps to communicate a sense of scale and quantity to the violence in Guatemala that could not be communicated by statistics alone.

Prins (2007) describes in the 2004 pilot study that moderate-resolution images could be used effectively to document and analyse human rights abuses in Darfur. Prins (2007) designed a study to use Landsat Enhanced Thematic Mapper + (ETM+) sensors to record the albedo or reflectance of a surface to detect recent burnings around Darfur. This method had advantages over high-resolution visual interpretation of fires as the Landsat moderate resolution scans were much cheaper than high spatial resolution imagery. Furthermore, with the advent of Landsat, several satellite imagery sources produce archives of satellite data to investigate the past as well as the present. Another advantage was the moderate spatial resolution meant each satellite image scene covered a wider area.

This meant Prin's study was cheaper for two reasons. First, the price of moderate-resolution imagery. Second, moderate imagery covered a larger area requiring fewer images. By studying the difference in albedo, the reflectivity of a surface, between two Landsat ETM+ images Prins could detect fire and therefore infer the burning of buildings. These fire detection methods had research precedent from previous studies, Prins refers to this research concerning the Landsat band 4 sensor and its capability to detect the remains of fire through the near-infrared area (Miller and Yool, 2002; Key and Benson; 2001 Razafimpanilo, 1995).

The first image was captured on the $30^{th\ of}$ March 2003, and the second image was captured on the 4^{th} of May 2004. Prins hypothesised that burnt buildings would produce a decrease in albedo. This initial model was tested against future satellite imagery of Darfur available through the early 2000s and the Bloodhound Report (2006), a collection of testimonials from victims of Darfur. By using the Landsat ETM+ sensor to track burning buildings in Darfur, Prins could corroborate testimonials collected by Petersen and Tullin (2006) in the Bloodhound Report and provide a spatial visualisation of the destruction. This follows the work in 2003 focusing on Guatemala (Steinberg et al, 2006) where GIS software was used to spatially visualise the Guatemalan massacres.

The focus of Prins's study on albedo change based on fire scar and change detection analysis through a false colour composite rather than a visual interpretation of true colour images meant Prins (2007) could use the results of the study to identify other villages that had been burned. This shows a development from remote sensing methods as solely focused on documentation and moving towards analysis and monitoring. The Landsat ETM+ Darfur map was published by Amnesty International (2004). Prins (2007) is the focus of this section because of the innovation of the method used to track human rights violations across Darfur but their work was not the only research on Darfur at the time. At the same time as Prins's (2007) pilot study in 2004 two other groups were working on mapping the atrocities occurring in Darfur, USAID Humanitarian Information Unit (HIU) and the US Holocaust Memorial Museum. HIU published a map of Darfur using high spatial resolution imagery produced by Quick Bird 2 an earth observation sensor created by Digital Globe. Later in 2006, Google Earth produced a high spatial resolution map of Darfur used by the US Holocaust Memorial Museum for their Darfur project. Prins used the HIU high-resolution map and the Google Earth map to validate the results of the 2004 pilot study against new data. This validation was crucial as Darfur was still dangerous to visit in person for ground truthing remotely sensed imagery (Prins, 2007).

Due to the spatial resolution of the Landsat ETM+ Prins used several methods to enhance the quality of their imagery. Two Landsat ETM+ scenes were used and to facilitate comparison these were radiometrically calibrated for a semi-arid region following the approach by Hellden (1984). The spatial resolution of the Landsat ETM+ was improved from 30 metres to 15 metres using pan-sharpened imagery through the principal component method (Pohl and Van Genderen, 1998). Pan sharpening improved the ability to identify villages from the imagery while still maintaining the multispectral resolution. A previous study had shown the near-infrared area (Nir) which corresponds to band 4 on the Landsat ETM+ was the most sensitive to track evidence of fire (Pereira, 1999). As images were recorded in the dry season the study had to consider the possibility of bushfires impacting the results of the change detection.

To mitigate this source of error Prins mapped out the villages from reports that were geocoded in the Bloodhound Report and defined burned areas as requiring continuous coverage across multiple pixels. Initial research found change detection in eight villages and an albedo change threshold of 15% originating from more than 5 pixels was discovered as sufficient to infer burning. Prins tested this albedo change detection method against other fire detection methods including Miller and Yool (2002) and Key and Beson (2001). It is important to note the Bloodhound Report did not claim to be comprehensive and it is to be assumed other burnt villages were unknown to researchers at the time. While this limits Prins's study, the inability to ground truth or collect data in Darfur justifies this limitation.

A more significant limitation of Prins's study was the shorter time window of data capture due to using albedo for the change detection. This is because the surface reflectance change used to track fires normalises over time as the vegetation grows back while the high-resolution imagery studies can still clearly identify evidence of fires. This was noted in the study as several villages present in the Bloodhound Report were missing from Prin’s research including villages around Kabkabiya and Zalingei (Petersen and Tullin, 2006) as they were destroyed in 2001 so the scenes from 2003 and 2004 did not show the change in albedo as it was likely the surface reflectance had normalised (Prins, 2007). Despite these limitations, the Prins approach held a producer accuracy of 98.5%. Prins was unable to conduct ethnographic fieldwork to better understand local perspectives and provide further context to this imagery (Turner, 2003; Guyer and Lambin, 1993) so a combination of satellite imagery from multiple sensor platforms and eyewitness testimony was the most effective available set of methods.

Prins (2007) was a seminal piece of research that showed that efforts to track human rights violations could produce key analysis. It is important to note Prins (2007) was not the first study about geospatial facilitated human rights research nor was it the first study even in Darfur, but it does mark an important transition and is quoted by several papers (Marx and Goward, 2013) as a major turning point for early research. Before Prins published research in 2007, the HIU produced a map that showed the extent of destruction of villages in Darfur, Sudan. Marx and Goward (2013) discuss how this monitoring campaign by HIU required a standing request to collect all images over a certain region and time series. The method used in the HIU map to track burning in Darfur was visual interpretation looking for changes in the satellite imagery to show evidence of an attack.

This method would be seen in the work conducted by the American Association of the Advancement of Science (AAAS) and Bromley while Prins (2007) showed that visual interpretation of satellite imagery was not always necessary to monitor human rights violations. This research would then lead Bromley (2010) to use the Moderate Resolution Imaging Spectroradiometer sensor to detect fire in Darfur. In the early 2000's however medium resolution sensors were only suitable for large phenomena and limited in their application. The main advantage they had over high spatial resolution imagery was the revisit time being shorter and the cost per image often being cheaper. Prins (2007) used this to produce this study more efficiently with the low-cost approach to change detection using the Landsat sensors. At the end of the research paper, Prins states that UN agencies had been requesting geospatial applications for monitoring human rights abuses for three decades (UNITAR, 2007; Prins, 2008).

Despite these requests, Prins noted the study originally published in 2004, (De Vos et al, 2008) may be one of the first examples of remote sensing for human rights monitoring. Prins's work would go on to inform future research into Darfur including Bromley and the AAAS.

A similar manual visual interpretation change detection method was used by De Vos et al, (2008) to study conflict in Turkish Kurdistan and verify witness reports of fires and armed conflict. Land use change was detected through a manual visual interpretation of two Landsat 5 Thematic Mapper images. The first image was sourced from August 1990 and the other from October 1994 to show a pre-conflict and post-conflict environment. The study focused on large land use changes due to the medium spatial resolution (30 by 30 metres) of the Landsat sensor and the limitations of cost, data availability, and time meaning the researchers could not access higher spatial resolution images. To assign land use classes the researchers used a supervised classification method in which the training areas were identified through a mix of local knowledge and spectral response data. De Vos et al (2008) found in total more than 60,000 hectares of forest were classified as burned, more than double the official estimate of 21,000 hectares.

From the 1990s to the late 2000s satellite imagery had been used to monitor a range of human rights abuses including village destruction, mass graves (AAAS, 2009), and internally displaced people camps (Lerner and Wolfinbarger, 2013). However, De Vos et al (2008) noted a range of limitations to satellite imagery for human rights monitoring concerning the cost of data to timely acquisition of imagery and the ability of the USA to hold a monopoly on satellite imagery known in the literature as the shutter control. This last concern will be discussed more in the satellite technology developments and ethics section.

2.1.2 Satellite imagery as a deterrent and the AAAS

Two years later from Prins (2007), Bromley as project director for the Geospatial Technologies and Human Rights project at the American Association for the Advancement of Science (AAAS) published a report on emerging geospatial technologies and methods for Non-Governmental Organisations (NGOs) to monitor human rights abuses. The report detailed technological advances in geospatial technology and the work of the AAAS to provide geospatial applications and expertise to observe and analyse a range of human rights abuses. In part of the report Bromley mentions ongoing case studies the AAAS was working with partner NGOs on, these case studies would later be updated in a report by Lerner and Wolfinbarger (2013) documenting the methods used and the finding from each report with additional reports commissioned by partner NGOs and some of the work being used in international courts as legal evidence (Wolfinbarger, 2016).

The AAAS case studies within this project report (Bromley, 2009; Lerner and Wolfinbarger, 2013) ranged from cultural artefact destruction in Nakhchivan, Azerbaijan (AAAS, 2010A) to property violations in Chad and Sudan (AAAS,2018A). The document contained 31 separate case studies split into cultural artefact destruction, civilians in conflict, environmental rights, communal conflict, forced relocation, gravesites, and property rights. The AAAS partnered with a range of NGOs including Amnesty International USA (AIUSA), Human Rights Watch, Physicians for Human Rights, Crude Accountability, Turkmen Initiative for Human Rights, Bahrain Centre for Human Rights, Zimbabwe Lawyers for Human Rights, Argentine Forensic Anthropology Team (EAAF), Burma Rangers, Karen Human Rights Group and Thailand-Burma Border Consortium.

Created in 2005 this project worked with NGOs to design methods using remotely sensed data and GIS visualisation to map and monitor human rights violations. Bromley discusses the advantages of remote sensing as an accessible tool that provides large-scale data for human rights monitoring creating a potentially powerful observation system that provides crucial input into human rights work (Bromley, 2009). Another advantage identified by Bromley is the bypassing of methodological concerns for example territorial integrity or risk assessment that field researchers and humanitarian staff would have to consider (Marx and Goward, 2013) which develops on Prin's suggestion of remote sensing as a tool to bypass boundaries to accessing information from restricted or remote study areas (Prins, 2007). In this section, I focus on two key regions of interest that AAAS produced research on. First, Darfur, Sudan to show how earlier research influenced developments by AAAS, and second Aleppo, Syria where AAAS produced an initial report for AIUSA and then a follow-up report was commissioned. The differences between the two reports on Aleppo are subtle but show a changing attitude towards human rights monitoring.

The AAAS produced three pieces of research AIUSA on Sudan (AAAS, 2007; 2011; 2013). The 2007 report contributed to the AIUSA Eyes on Darfur project also discussed by Bromley (2009). Bromley (2009) adds context to early research on Darfur explaining how the area was geocoded, and villages were mapped. This mapping allowed precise information to be attained on where human rights violations were taking place which facilitated intervention. The Eyes on Darfur program created by AAAS and AIUSA was an active monitoring program that used high spatial resolution imagery from EOS-B to observe vulnerable human settlements. Bromley (2009) notes that the protected village of Malam el Hosh had at the time of writing been spared from destruction potentially suggesting that the active monitoring of the village provided a deterrent to the Sudan militia.

Bromley (2009) discusses the initial challenges of mapping individual villages, a problem Prins (2007) using a moderate spatial resolution method did not have to contend with. Location coordinates had to be accurate to 1500 metres to produce an effective observation system and considering the lack of data around the location of villages in Darfur this provided a significant challenge. The AAAS combined information from the UN-Sudanese Sudan Interagency Mapping (SIM) with the GEOnet Names Server from the US Department of Defense global database of locational data to calculate coordinates.

Despite these resources analysts at the AAAS could not according to Bromley (2009) simply cross-reference coordinates from these databases to Darfur as variations in spelling, name, and regional boundaries were present. Analysts used the Levenshtein distance algorithm to mitigate this which calculates the number of alterations in characters needed to convert one word to another. The practical use for this is producing a set of similarly spelt words. This allowed for a smoother geocoding process. Once the geocoding was complete the database allowed analysts to search for an area of interest and visually interpret differences from imagery before and after an attack, this method is known as manual change detection. Analysis from satellite imagery was documented with GIS software, allowing analysts to highlight key areas through visualisation layers. The results of this geocoding process were encouraging with 80 per cent of over one thousand event reports located (Bromley, 2009). This database provided a system for analysts to locate coordinates of key research targets and commission satellite imagery to investigate human rights violations from witness reports or other studies like Prins's (2007) moderate resolution pilot study in 2004.

The AAAS worked with Amnesty International USA (AIUSA) and Relief Web, an online humanitarian platform, identifying 819 destroyed or damaged structures, a majority of which were attacked in 2010 (AAAS, 2011). Evidence of these attacks included charred earth and hollowed-out housing structures (Bromley, 2009). AIUSA used this project to design a website that allowed members to observe the burning of buildings in Darfur and petition Sudanese President Omar al-Bashir. The same mechanisms of audience participation and Internet 2.0-facilitated monitoring are present in modern civilian science.

These mechanisms of satellite observation facilitated by internet access and the growing intuitiveness of GIS analysis tools would support a range of civilian science applications in the future. Additionally, the ability to broadcast these human rights abuses also suggested a soft political power by using satellite monitoring as a form of deterrent as Bromley considered the ability for the public to view and petition against these abuses provided increased support for charities like Amnesty International USA.

Marx and Goward (2013) provide a review of early human rights work facilitated by geospatial technology. Their paper provides more details into Darfur and the incremental spatial data built up by Prins, the HIU, and later Google Earth. In 2006 Google Earth was able to map Darfur providing easy-to-access high-resolution imagery of Darfur this alongside a further satellite study by Amnesty gave Prins the spatial data required to publish the full study inspired from the 2004 pilot (Prins, 2007). Marx and Goward (2013) draw an interesting distinction between geospatial mapping and monitoring of human rights violations.

Mapping is aligned with documentation and is the process of ordering specific satellite images to corroborate reports of human rights abuses, Prins' 2004 study can be viewed as mapping in this sense. It often leads to information being published after the event. Monitoring is conceptualised as more like a form of deterrent as far as analysts constantly record and order digital images over a large region to receive near real-time data on at-risk populations. Despite its critiques in the literature (Rothe and Shim, 2018) an early example of a geospatial human rights monitoring system is the Sat Sentinel project funded partially by George Clooney (Enough Project, 2024). SatSentinel is an example of a high spatial resolution monitoring system. Established in 2010, SatSentinel acts as a deterrent to human rights violations in southern Sudan. However, in the review, it is unclear if these high-resolution monitoring systems provide an effective deterrent. Levinger (2009) comments on the Eyes on Darfur project by the AAAS regarding this notion of high-resolution monitoring as a deterrent. They note that these projects are only as effective as their ability to motivate external actors like the US government or the United Nations (UN) to act against genocidal regimes and human rights violations.

In the Lerner and Wolfinbarger (2013) AAAS case study report and the published reports found on the AAAS website documentation of these case studies includes methodology, sensor and platforms used, and findings. This promotes transparency within the analysis which supports the more objective nature of satellite imagery compared to traditional legal evidence (Wolfinbarger, 2012). This breakdown includes the satellite imagery and the sensor specifications, software, and output results (AAS, 2018A - Z). These details are important for researchers to consider how methodologies can be improved and where research gaps are present. By presenting this breakdown for public access the data can be scrutinised and reviewed.

This thorough review of methods and findings also helps compare differences between human rights monitoring occurring in the same area across time. For example, the AAAS studied human rights violations in Aleppo, Syria. In the first study of Aleppo, the AAAS focuses on a structural damage approach while in the second study, the cultural value of Aleppo is emphasised with urban destruction being expanded beyond the destruction of the physical space. The initial research in Aleppo covered one hundred and eighty-two square kilometres of the city and its environment. Aleppo was the largest city and commercial hub of Syria. Satellite imagery was acquired using Quickbird-2 built by the European Space Agency (ESA, 2023), and IKONOS run by the Satellite Imaging Corporation (SIC, 2023).

At its time of launch in 2001, Quickbird-2 was the highest spatial resolution sensor available for commercial use (ESA, 2023) with a multispectral resolution of 2.44 metres at its original altitude of 450km and 1.63 metres at 300km as orbital altitude was lowered as the sensor was decommissioned, (ibid). IKONOS provided multi-spectral imagery at 3.2 metres with applications in urban and rural mapping including natural disasters, homeland security, and facilitating 3D Digital Terrain Models (DTMs) and Digital Elevation Models (DEMs) (SIC,2023).

The use of high spatial resolution imagery was critical to providing detailed images of armoured vehicles, shelling impacts, and fortifications (AAAS, 2023) to corroborate reports of urban conflict (Aljazeera, 2012). Since July 2012 the International Committee of the Red Cross (ICRC) has characterised Aleppo as a civil war (Red Cross, 2023) the AAAS partnered with Amnesty International USA to verify reports in 2012 of human rights concerns based around this conflict and the growing Syrian crisis (AAAS, 2018B; Bromley, 2009). The AAAS produced a set of visualisations that provides evidence of urban conflict and destruction substantiating the ICRC claims. Wolfinbarger (2016) would develop this work by the AAAS in a report on how these geospatial analyses were used in litigation and prosecution of human rights violations and international humanitarian crimes.

Satellite imagery reviewed by AAAS also shows a point location map of improvised roadblocks and fortifications. By using a point vector layer to show the location of fortifications the full report (AAAS, 2018B) shows the extent of urban destruction in Aleppo including burning buildings, evidence of shelling, and craters. The AAAS stated that due to large swathes of the city being unable to be imaged due to shadow, or other observation factors like elevation angle and robust construction materials (Lerner and Wolfinbarger, 2013) this report likely underrepresents the extent of the urban destruction (AAAS, 2018B). Despite this, the Aleppo case study by AAAS shows how geospatial technology can be leveraged to provide evidence of human rights violations that can be used in legal spaces like the International

Criminal Court (ICC) for litigation and prosecution as well as providing a global observation system to monitor these abuses in real-time (Marx and Goward, 2013).

After the Aleppo 2012 report was published by the AAAS and Amnesty International USA (Lerner and Wolfinbarger, 2013), a further study was commissioned to explore developments in Aleppo. AAAS reused the Quickbird 2 imagery from the previous research but also utilised Ikonos-2; the new sensor which replaced the original Ikonos, Pleiades, and Geoeye-1. These sensors were used to acquire seven new images to inform how the battle of Aleppo had developed since the original case study (AAAS, 2018D). These images provided a snapshot of the situation at regular time intervals between August 2012 and June 2013 covering a 9-month time window (Wolfinbarger, 2016; Lerner and Wolfinbarger, 2013).

This retrospective analysis was influenced by specific media reports of major incidents including damage to the Umayyad Mosque (AAAS, 2018D) with AAAS aiming to validate these reports. The same sampling area used in the original project was used for all imagery except for one sensor. Imagery from the Pleiades sensor on the 24th of February 2013 did not cover the full sampling area and instead focused on the northernmost one hundred and twenty-six square kilometres of the study area.

The second Aleppo case study retained a focus on the deployment of military equipment and destruction of buildings (AAAS, 2018 C - D) but also considered two new categories of observation analysis (AAAS, 2018D). Based on the results of the original research AAAS included imagery of barriers in the street as a key focus after finding many improvised roadblocks in their initial satellite imagery (AAS, 2018B). The AAAS also emphasised the value of Aleppo in this study as a UNESCO World Heritage Site. This significance of Aleppo was alluded to in the first research project, describing the city as a key cultural space and commercial hub of Syria. However, this cultural value was not a part of the original report on urban destruction analysis. This development shows a more holistic approach to urban destruction. By considering the cultural value of the city as well as the physical city this framework resonates with a deeper understanding of sustainability.

Urbicide describes the process of attacking a city for its secondary effect of demoralisation, and cultural destruction and focuses on symbolic violence to a target rather than a tactical or military objective.
The AAAS also used their first study of Aleppo to inform their analysis. Based on the results of the original research AAAS included imagery of barriers in the street as a key focus after finding many improvised roadblocks in their initial satellite imagery (AAS, 2018B).

The AAAS also emphasised the value of Aleppo in this study as a UNESCO World Heritage Site. This significance of Aleppo was alluded to in the first research project, describing the city as a key cultural space and commercial hub of Syria. However, this cultural value was not a part of the original report on urban destruction analysis. This development shows a more holistic approach to urban destruction. By considering the cultural value of the city as well as the physical city this framework resonates with concepts of urbicide. Urbicide describes the process of attacking a city for its secondary effect of demoralisation, and cultural destruction and focuses on symbolic violence to a target rather than a tactical or military objective. Urbicidal practices would also become a more significant human rights issue as SDG 11 promotes sustainable cities.

The AAAS results of this continued study showed several examples of helicopter uses and fixed-wing aircraft. Imagery showed the locations of these vehicles moving between makeshift landing zones from the athletic field of Al-Assad military academy, Artillery Academy, and Aleppo International Airport (AAAS, 2018D). These observations are consistent with reports about the use of fixed and rotary-wing aircraft by government forces to support combat operations in and around Aleppo (ibid). High-spatial resolution imagery was required to identify aircraft and helicopters accurately as spatial resolution impacts the size of each pixel in an image scan. If the pixel size is bigger than the object, then the object will not be rendered accurately. Furthermore, to get a high level of detail from an image the spatial resolution must be significantly smaller than the object of interest (AAAS, 2018B-C; Bromley, 2009). To mitigate the trade-off between spatial and temporal resolution multiple sensors were deployed. This facilitated accurate yet timely analysis of Aleppo imagining the area of interest more effectively (Lerner and Wolfinbarger, 2013).

There have been examples in the literature of satellite monitoring as described by Marx and Goward (2013) being used as a deterrent against human rights abuses. In their review, Marx and Goward (2013) discuss how high and medium spatial resolution sensors were providing documentation and evidence of human rights violations. This detection is split into direct and indirect forms. Direct detection is when a remotely sensed image can visualise the exact human rights violation, for example, high-resolution imagery of burnt buildings or evidence of military vehicles. Indirect detection involves finding a proxy to measure the prevalence of human rights abuses against, for example, abandoned agricultural fields over a long period suggesting the departure of a population which could be used to infer forced relocation. This method was used in Kosovo in the late 90’s (Terres, Biard and Darras, 1999).

Limitations of these methods are found in the inability of researchers to often access ground truthing methods due to conflict or access issues. This means it is harder to correct for other factors that cause the same impact but are not related to human rights violations. For example, in Schimmer's 2008 paper on Darfur and tracking displacement through vegetation, Schimmer acknowledged they did not control for environmental factors such as rainfall or earlier greening periods. Marx and Goward note several researchers who either did not or could not correct for these externalities.

However, Prins (2007) did account for environmental factors when producing their Darfur fire detection model. In conflict environments, it can be difficult to access the data required for these corrections to a model and ideally, when remotely sensing human rights violations associated with conflict it is useful to have imagery from before the conflict began. High-resolution imagery of before conflicts can be difficult and expensive to attain (Witmer, 2008; Marx and Goward, 2013). Marx and Goward (2013) end their paper with the conclusion that despite the promise of remote sensing methods for human rights monitoring being promising a lack of funding and political will had limited the growth of the field.

2.1.3 Satellite imagery and litigation

In 2012, Wolfinbarger, who would go on to work for the AAAS, published their doctoral thesis on the ability of remote sensing to be used as a tool for litigation. In 2016, working as part of the AAAS they showed that satellite imagery was gaining traction as a tool for litigation including several case studies of the International Criminal Court (ICC) using satellite imagery in investigations (Wolfinbarger, 2016).

The work of Wolfinbarger (2012;2013) with the AAAS and the growing development of remote sensing imagery as legal proof is a window into the role of evidentiary regimes in human rights research. Evidentiary regimes refers to the type of information that is considered authoritative evidence within government, legal or organisational processes. As social concepts change and new technology emerges the way evidence can be used has also changed. Wolfinbarger (2013) discusses the emergence of remote sensing as a tool for human rights fact-finding exploring the issues of ethics and surveillance against the need for the insight required by remote sensing for human rights documentation and litigation. Overall, the impact of the introduction of geospatial technology as part of the new evidentiary regime of data forensics and digital evidence opened new opportunities to hold to account human rights violations at scale.

Geospatial information provided new perspectives and approaches to the ICC to investigate human rights abuses. As shown in the AAAS case studies by Lerner and Wolfinbarger (2013) the documentation of human rights abuses using satellite and drone imagery provided visual evidence to courtrooms. Furthermore, geospatial technology could be used to monitor an area before a suspected human rights violation occurred. The best-case result of this monitoring would be a lasting deterrent against human rights violations providing data in near real-time. Darfur is an example where geospatial technology provided oversight and legal understanding to an inaccessible part of the world. Darfur as previously discussed was inaccessible due to a combination of safety and political factors (Prins, 2008). It was dangerous to study Darfur on the ground and even those brave enough to do so were banned due to new fly rules, the denial of journalists and aid-agencies.

The adoption of new technology into evidentiary regimes is limited by three factors. First, the rate of adoption of the technology, second the ethical concerns and third the complexity and cost of entry. Wolfinbarger (2013) explains that a range of education barriers and technological requirements meant geospatial technology was largely utilised by actors with a multinational scale of capital meaning NGOs and other charities often had to partner with organisations like AAAS. Wang et al (2013) also notes that the new evidentiary regime of geospatial technology was at first ill defined.

Consequently, the adoption of geospatial technology has been slow. As the technology has become more accessible with low code solutions, graphical interfaces and automation the power of geospatial data has been more promising and attractive. This literature shows that while geospatial evidence was valuable to international investigations the adoption of the methodology was not uniform across time or space. Location mattered in terms of education, computational power and political will to pursue geospatial methods.

Wolfinbarger (2012) notes the ability of satellite imagery to make the public aware of human rights abuses and provide detailed documentation of violations across time and space. Wolfinbarger remarks satellite image was regarded as a more scientific and objective form of legal evidence than the historical human rights evidence of witness accounts and personal photographs. These traditional forms of legal evidence fell under the category of deniable information and easily dismissed by perpetrators while satellite imagery was viewed with more authority. In the thesis, Wolfinbarger (2012) aimed to do two things, analyse the opportunity of satellite imagery for litigation against ethical and methodological concerns from researchers and explore how moderate and low spatial resolution imagery could also be used in litigation alongside high spatial resolution imagery which was becoming more mainstream. Wolfinbarger explores this new objectivity that satellite imagery was granted by society through a feminist analysis of the acquisition and processing of these images.

Wolfinbarger (2012) advises that the design choices and subjectivities researchers make when producing this imagery should not be seen as a black box but examined and made accessible. This open approach to satellite imagery is a key aspect of remote sensing research and as discussed previously is still an active discussion in remote sensing methods and ethics concerning the positionality of research. By making the sensors, methods, and theories used to remotely sense a human rights event easily accessible researchers can compare methods and replicate studies leading to a more objective study.

This accessibility of information removes the black box of processing satellite imagery. This design philosophy is heavily present in modern practise and seen earlier in how the AAAS provides data on their projects, satellite imagery details, and analysis.
In 2016 Wolfinbarger showed that to some extent human rights monitoring of violations was influencing human rights, particularly in facilitating documentation, advocacy, and litigation. This influence went as far as the AAAS in their report being asked to provide some of their case studies as evidence for criminal litigation in the International Criminal Court (Macauley, 2013).

These requests included a conference and workshop on the potential of geospatial technology for litigation by AAAS open to members of the ICC (University of California, Berkley, 2012) and evidence provided and used in cases with the International Court of Justice (ICJ), the Permanent Court of Arbitration (PCA) in the Hague and the International Criminal Tribunal for the former Yugoslavia (ICTY) (Wolfinbarger, 2016).

While Wolfinbarger (2016) notes that satellite imagery spatial resolution and access improved significantly between the beginning of the AAAS case studies in 2013 and 2016 geospatial techniques were still a significant financial, resource, and time investment. Marx and Loboda (2013) discuss the details of these investments, including high-power computer systems, expensive analysis software and most crucially if researchers need to use resolution imagery these scenes can cost thousands of dollars. However, resolution imagery while being cheaper was often harder to interpret requiring more experienced expert analysis (Wolfinbarger, 2016). Due to these limitations as seen with the AAAS, charities often relied on partner organisations to source this data. Wolfinbarger (2016) provides a detailed account of these partnerships between AAAS and charities which include global groups and small organisations. Furthermore, as Wolfinbarger (2016) reports the ICC began warming to the possibility of using satellite imagery as one of its scientific evidence techniques for documenting and producing evidence to be used in trials.

The Beyond Reasonable Doubt report summarises these cases (Berkley Law, 2012). The report echoes the views of Prins (2007) and Bromley (2009) regarding the strength of satellite imagery to circumvent administrative and national boundaries, and security impediments and minimise risk to researchers and investigators due to the remote nature of the methodology. Additionally, data archives of satellite imagery like Landsat provide the ability to investigate historical human rights abuses with a reconstruction of events or to monitor events across time. As satellite imagery developed in 2010 localised and near real-time data became more publicly available expanding the utility of space-borne satellite imagery. However, there were still significant barriers to the adoption of geospatial analysis by human rights organisations (HROs) and NGOs.

Expertise required to interpret satellite imagery and remotely sensed data becomes more significant when working with moderate and low-resolution imagery as it was more difficult to obtain, analyse and interpret. Consequently, even in 2016, Wolfinbarger reported there had been few organisations able to use remote sensing methods in their human rights framework.

Wolfinbarger (2016) concludes with two significant concerns for remote sensing facilitated human rights research to context with. First, like many technological tools concerns over peer review and reliability of data are raised. Returning to the concept of opening the black box (Wolfinbarger, 2012) quoting Ioannidis discusses how replication of published academic results is difficult due to a lack of quality methodological data provided by researchers. This challenges the notion of satellite imagery as a more objective and scientific form of legal evidence as replicability is the quality that gives scientific data its perceived objectivity.

Wolfinbarger (2016) urges a system of review is needed to validate not only academic research but all published research to maintain quality of authority and assure the consumer of information on their confidence of the results. Second, despite progress, the quality of human rights documentation is targeted with calls to further make transparent methods and data used by stakeholders and the need for mechanisms of verification either by a third-party organisation or within the litigation process. These concerns over variability are more significant in the present as deepfake geography spurned on by artificial intelligence image generators becomes part of the research environment and public consciousness.

This section has reviewed the development of geospatial technology and methods to devise applications to facilitate human rights mapping and monitoring (Marx and Goward, 2013; Boyd et al, 2018; Wolfinbarger, 2016). this section helps illuminate our three research questions. First, geospatial technology became an influential method for human rights research in the early 2000s due to increasing accessibility to satellite imagery and education on how to spatially analyse data. It was considered by many researchers (De Vos et al, 2008; Prins, 2008; Wolfinbarger, 2012) to be more objective than witness testimonials and other methods used previously in both attempts to spread awareness and legally punish those who violate human rights of others.

The early 2000s was also when the data-rich Landsat archive was made public allowing researchers access to moderate spatial resolution imagery and its archive for free. Prins (2008) showed Landsat moderate spatial resolution methods were cheaper than high-resolution imagery for purposes like fire detection in Darfur Landsat products like the Landsat ETM+ scan used In Prins study cost hundreds for a single scene which despite being 100 times less expensive than high spatial resolution methods (Prins, 2007) could still be prohibitively expensive (Marx and Goward, 2013). These expenses quickly add up when reviewing larger areas or monitoring a human rights situation across multiple time points.

Due to these expenses remote sensing methods for human rights are often highly constrained either across geographical focus or temporal scope. Second, geospatial technology was leveraged to document or identify human rights abuses either to corroborate witness testimonials or give researchers and NGOs a better understanding of the extent of destruction in critical areas. Later geospatial technology would be considered for its ability to provide a deterrent due to providing more eyes on offenders and political pressure to act (Bromley, 2009; Levinger, 2009) and evidence for litigation (Wolfinbarger, 2012; 2016). Wolfinbarger (2016) shows that geospatial imagery can be used for litigation and noted several ICC case studies where it has been used effectively. Levinger (2009) argued that these methods would only provide effective deterrents if they could pressure regional and national actors to sanction offenders and support those whose human rights were violated.

2.2 Sustainable development and the brick kilns

This section reviews literature exploring the research on the connection between brick kilns and sustainable development. First, the progress from the United Nations (UN) Millenium Development Goals (MDGs) is considered from 2000 - 2015 to the Sustainable Development Goals (SDGs) from 2015 - 2030 exploring their differences and scale. Second, the thesis reviews research on the brick kilns specifically including the geospatial methods that researchers have used to map and monitor their development. Finally, the brick kilns are connected to sustainable development by examining modern slavery and human trafficking within the brick manufacturing industry. This section includes research papers with a rights-based approach, geospatial focus, or those discussing modern slavery and human trafficking. The focus on modern slavery and human trafficking informs this thesis' primary focus on the brick kilns and SDG 8.

The SDG framework was chosen due to three reasons. First, the SDG framework has been used in research that inspires the methodology and research design of this work so there is an argument for compatibility. Second, the SDG framework is a well-recognised legal and human rights-based approach that has been signed and ratified by the country of interest in this paper. Third. as the SDGs are meant to be achieved by 2030 this research provides a review of progress on MSHT which is liked to goal 8 of the SDG. Furthermore, I draw on Boyd et al (2018) argument of SDG intersectionality and find the approach is fruitful in this analysis as a significant portion of the brick kiln research is focused on air quality and environmental factors it is useful to link sustainable development goals together to show how a vulnerability in one area can compromise the whole system.

In absence of discussing other frameworks and approaches to economic development and the environment this work instead reviews modern critiques of human rights and SDG based research engaging with the literature to inform best practise in this study.

This section focuses on three main research questions.

- How did the SDGs develop from the MDGs?
- How do frameworks like the slavery-environment nexus help researchers understand the intersectionality between environmental degradation, forced labour, and social harm?
- What methods have been used to remotely sense the prevalence of modern slavery through the proxy of the brick kiln?

2.2.1 Geospatial data for Sustainable Development Goals

The Sustainable Development Goals (SDGs) are a collection of seventeen goals set by the United Nations in 2015 (Jackson et al, 2018). The SDGs replace the

Millennium Development Goals (MDGs), which were established in the year 2000. The SDGs provide a more interlinked system of goals and call for a unified effort from signatories. The scope of the goals is also expanded in the SDGs compared to the MDGs. This is a progression from the MDGs in which the goals were targeted at developing nations.

(Woodbridge, 2015) and had a much smaller scope. In the MDGs, 8 goals were established while the SDGs focus on 17 goals. The SDGs also aim to address the structural inequalities that lead to sustainable development challenges. This produces a deeper analysis of inequality in development compared to the MDGs. For example, while the earlier MDGs aimed to remove people from situations like poverty (MDG 1) the SDGs take a more structural approach and aim to provide an environment that will keep people out of poverty for good. As such they cover not only the provision of aid in a range of areas but also how to create self-sustaining development by alleviating the root causes of poverty.

For critics of the MDGS, this shows a development within the SDGs to not only fix the symptoms of inequality but to challenge inequality itself (Winkler and Williams, 2017). Furthermore, as the SDGs cover more goals as it takes a wider view on what sustainable development looks like going beyond the aim of eliminating poverty. The efficacy of the MDGs is a deeply debated topic, the MDGs promoted an international movement against extreme poverty reducing poverty by 50% globally. However, the spatial distribution of these targets and variability between the successful implementation of each target limits the impact of the MDGs. This variation is intensified by the fact the MDGs only focused on developing nations mostly in the global south. This leads some critics to consider the problematic notion of the developed countries pushing this agenda of development onto the developing countries. Winkler and Willaims (2017) explain the reason for this problematic relationship. Human-rights activists were not consulted on the design of the MDGs. Rather, the MDGs were a technocratic solution prioritising methods to achieve overall global development rather than address local, regional, and national inequality directly.

This line of argument is also seen in Laliberte (2015) who critiques the notion of human rights and geospatial facilitated human rights monitoring as limited by its connection to the legal structure. This connection to the legal structure promotes spatialised justice which is uneven and Westernised in its assumptions of what development and protection from justice should look like leading to a technocratic and legalistic approach to development. Other arguments and academic concerns of international human rights and the role of geospatial technology will be discussed later in section 2.4.

The adoption of geospatial technology for human rights has been gaining traction in a range of sectors aimed at providing data insights for achieving the SDGs (Anderson et al, 2017). However, Jackson et al, (2018) discusses how these efforts have been largely separated from geospatial technology research into SDG 8 and specifically modern slavery and human trafficking (MSHT) practises. Since Jackson et al, (2018) identified this gap in geospatial research on ending modern slavery and human trafficking ((MSHT) Part of SDG 8 as target 8.7) research interest in using geospatial technology for MSHT research is growing but it is limited by the hidden nature of MSHT and political will. Notably, Anderson et al, (2017) focus sustainable development largely on environmental sustainability issues.

Jackson et al, (2018) notes that while developments like the AAAS and NGO researcher partnerships had popularised the use of geospatial technology in human rights research, modern slavery had never been examined. Kevin Bales recognised the utility of satellite imagery, at their visit to the UN's Office for Outer Space Affairs (UNOOSA) and mooted the idea of tracking modern slavery through satellite imagery and GIS (Bales, 2007). The same aspects of satellite imagery that make it so advantageous for conflict and human rights monitoring can also be found in modern slavery research facilitated by geospatial technology. However, while satellites are unrestricted by national and regional borders, with the ability to capture large areas of interest and provide a data archive to monitor events through time the inherent difficulty of remote sensing modern slavery comes from the hidden nature of the practise.

As discussed by Marx and Goward (2013) remote sensing requires an object that can either be directly linked to the phenomena of interest or used as a proxy measurement for the phenomena. The difficulty of modern slavery is finding an object that can act as a proxy. For example, an analyst can use satellite technology to monitor areas where slavery is known to take place, these places are usually difficult or dangerous for researchers to visit in person which makes remote sensing so effective, however, the object used to provide a proxy measurement of modern slavery will shape the analysis that can be conducted.

Brick kilns for example are an object that act as a proxy for modern slavery, but it is inaccurate to suggest the presence of a brick kiln alone signifies the occurrence of modern slavery, rather the brick kiln due to its associations with poor labour practises, modern slavery and environmental harm can be used as a proxy for modern slavery prevalence. The object of the brick kiln shapes what analysis can be conducted. Analysts can scan the brick kilns across time, geography, and seasons but without contextual information from the local area, it is hard for analysts to convert remote sensing data and satellite imagery into valuable insights.

Consequently, combining satellite imagery with input from survivors, experts, and ground truthing provides a powerful tool to better understand the dynamics of modern slavery. These methods have been used in several pieces of research in sectors including brick kilns in South Asia (Boyd et al, 2018; Boyd et al, 2021; Boyd et al, 2022), mining (Brown et al, 2021), and fishing (Jackson et al, 2020). Many of these sectors that are associated with modern slavery also are associated with environmental degradation. This has been termed the slavery-environment nexus (Bales, 2016; Brown et al, 2021; Jackson et al, 2018). The interplay between SDGs provides the opportunity for policymakers and researchers to realise freedom dividends, the idea that by alleviating one social harm others naturally follow. For example, working on alleviating modern slavery (part of SDG 8) also contributes to a culture of good employment which alleviates poverty (SDG 1). These connections can also run deeper, and researchers have identified specific connections between the built environment, natural climate, and social landscape (Brown et al, 2021). Despite these connections few geospatial papers focused on SDG attainment link their focus on environmental factors, urban design or health conditions to MSHT.

2.2.2 Brick kilns and SDG 8

This lack of attention from the geospatial community; especially those focused on SDG attainment, to MSHT and SDG 8 more widely was recently acknowledged by Ekmen and Kocaman (2024) in their paper that reviewed 308 geospatial for SDG attainment research projects. They found only 3 papers (1.2% of the sample) had a direct focus on SDG 8.

A lack of engagement from the research community cannot be explained by a lack of importance within MSHT. The number of people experiencing modern slavery is rising and a key issue related to environmental degradation, severe health conditions and gender violence (Boyd et al, 2021).   According to the latest Walk Free Global Estimates of Modern Slavery report (ILO, 2022) 49.6 million people live in modern slavery including forced labour and forced marriage. This figure has increased since the Jackson et al, (2018) study which cited the modern slavery population at 40.3 million. Many of these people work in the mining, brick manufacturing, fishing, and forestry sectors (Paul, Bandyopadhyay, and Raj, 2022; Brown et al, 2021). The Bellagio-Harvard guidelines on the legal parameters of slavery were established to address a lack of clarity in the interpretation of slavery in international law (Harvard Guidelines, 2012). The guidelines describe slavery as the exploitation of a person(s) through coercion, threat, or realised violence (Harvard, Guidelines, 2012; Jackson et al, 2020).

As discussed above, despite the adoption of geospatial technology for human rights monitoring across the biggest charities including Amnesty International (Prins, 2007; Bromley, 2009) little academic work outside of the Rights Lab at the University of Nottingham has used geospatial technology to detect, map, and monitor modern slavery as part of SDG 8. The interconnectivity between the SDGs means that other papers can be used to study the academic research between sustainability and the brick kilns but this lack of research into SDG 8 shows a significant gap in the literature. The top 5 SDG research areas according to Ekmen and Kocaman (2024) being: SDG 15, (Life on land) SDG 11 (Sustainable cities and communities), SDG 6 (clean water and sanitation), SDG 13 (climate action) and SDG 9 (industry innovation and infrastructure).

Furthermore, the application keywords were focused on climate change, urbanisation, ecosystem services, and food security. This further supports the claim by Jackson et al, (2018) regarding Anderson et al, (2017) that despite the growth of remote sensing for humanitarian and human rights research methods to track SDG 8, the goal is not underrepresented. This finding is significant as the Ekmen and Kocaman (2024) paper shows Anderson et al, 2017 is the most cited piece of research focusing on remote sensing applications for SDG research with 172 citations.

These results also reflect the findings of the literature review using Scopus which had the following results. Six papers on modern slavery and eight papers on human trafficking. Less than half of these papers were focused on brick kilns, leading to a small sample of papers to review relating directly to SDG 8 and the brick kilns. Furthermore, search strings for India and its related states that are focused on in this thesis (Punjab and Haryana) combined with modern slavery returned zero results.

GIS has been used to track sustainable development within India with Gupta et al (2023) spatially analysing SDG attainment by reviewing the Mahatma Gandhi National Rural Employment Generation Act (MGNREGA). This is a public welfare scheme linked to progress in SDG 5 Gender Equality (Kelkar, 2011), SDG 8 Decent Work and Economic Growth (Ghose, 2015), and SDG 10 Reduced Inequality (Muzafar and Janangir, 2017). Overall, the act created over 2-billion-person days of employment during the financial year 2018 – 2019 (Gupta et al, 2023). The scheme aims to strengthen the quality of life and resource base of India's poor with a guarantee of 100 days of wage employment per annum to rural households. Gupta et al, 2023) note this act has had a significant impact on India for SDG 1 which aims to eliminate poverty (United Nations, 2023). This work echoes the intentions of this thesis where GIS analysis is used to record regulation indicators that could suggest a higher risk of slavery prevalence. No mention of SDG 8 is made in the results of Gupta's et al, (2023) findings despite SDG 8 being mentioned briefly there is no mention of child labour, modern slavery, or human trafficking (Gupta et al, 2023). It seems that it is easier to derive SDG indicators from SDGs focused on climate change and environmental factors.

Until recently this focus on environmental harm has been the case for research into the brick kilns with land degradation and climate change being studied over social issues like SDG 8. The brick kilns are a key space of modern slavery and have been a focus for geospatial research despite their relatively smaller size of interest in the global academic community. Using the knowledge that the brick manufacturing sector is associated with modern slavery practises including child labour, human trafficking, and debt bondage researchers could devise methods to link the brick kilns' remote sensing data to prevalence studies for modern slavery (Boyd et al, 2018). The brick kilns were used as the object of interest for inferring modern slavery for three main reasons.

First, brick kilns have a specific visual shape and spectral signature making it possible to track brick kilns across varying levels of spatial resolution. Second, brick kilns unless shut down or demolished are static objects, once discovered and located they are relatively easy to track and analyse across time. Third, brick kilns are associated with social issues and environmental issues like air pollution, heat stress and land degradation associated with modern slavery make them important targets for a range of sustainable development initiatives.

2.2.3 India MSHT and regulation

SDG 8 includes target 8.7 which aims to eliminate modern slavery, human trafficking, and other exploitative labour practices (Boyd et al, 2018). Modern slavery and human trafficking are often connected by the term MSHT, 40 million people are estimated to be in some form of modern slavery (Lavelle-Hill et al, 2021). MSHT covers many forms of exploitation that are difficult to monitor since MSHT impacts people who are hidden from view by design. Despite this researchers have managed to devise a range of methods that draws attention to the structures, politics, and process of MSHT. Brick kilns are the object of SDG intersectionality (Boyd et al, 2021) MSHT is the process that links these SDGs. For example, target 8.7 directly links to Target 16.2 which aims to end abuse and exploitation, especially focusing on children while Target 5 looks at promoting gender equality. MSHT is a significantly gendered process (Lavelle Hill et al, 2021; Boyd et al, 2018) with sex work especially being aimed at trafficking women (Xia et al, 2020; Biemann, 2005;).

Modern slavery is a complex group of practices consisting of the enforcement of one person's will over another through economic, violent, or coercive means. While most of the practises of slavery in terms of ownership and slaves as property have been eradicated, this new form of slavery makes no claims to ownership but instead denies and oppresses agency which leads to a similar outcome for those experiencing modern slavery (ibid). The challenge of combating modern slavery is twofold, first, a lack of quality and quantity of data means the extent of modern slavery in specific locations is largely unknown. Second, attempting to model modern slavery using traditional statistical methods causes a large source of inaccuracies. These inaccuracies are due to overfitting in models which is caused by a large source of predictive variables without a metric of how efficient these variable are.

This lack of knowledge around variable efficacy is due to a lack of prevalence estimates for modern slavery meaning there are few reliable data sets to perform regression analysis against. Johnstone and Titterington (2009) describe this as being small *n* large *p* where *n* is observational units or data sets, and *p* is the potential driving factor. This is a problem that impacts many issues described as wicked problems (Head and Alford, 2015). Furthermore, these statistical approaches often underestimate other predictive variables for example the relationship between women’s vulnerability to MSHT and access to economic resources (Lavelle-Hill et al, 2021).

Through the mapping of the brick, kilns researchers can track spaces of modern slavery by inferring its presence linked to the brick manufacturing industry and labour practises at the kilns (Scoles, 2019).   Brick kilns are heat-insulated structures used to flame bricks using soil and dry clay (Boyd et al, 2018). Different types of brick kilns have different shapes but due to their colour, shape, and size at high spatial resolution, they are identifiable. Due to being man-made at medium spatial resolution brick kilns can still be tracked through their spectral response (Paul, Bandyopadhyay, and Raj, 2022)). Bricks kilns are a key target of human rights research that benefits from the freedom dividend because their operation promotes environment degradation, health hazards, bonded labour, and other forms of modern slavery and human trafficking (Brown et al, 2018; Boyd et al, 2018 Jackson et al, 2018).

Investigators in South Asia are especially interested in the location of bull trench brick kilns (Paul, Bandyopadhyay, and Raj, 2022) and modified fixed chimney kilns

(Maithel et al, 2014) as these kilns are out of date, associated with modern slavery practises of bonded labour and do not comply with environmental standards. Despite the bricks produced from these kilns being highly polluting they are economically favoured by owners as they can be produced at 60% of the economic cost of cleaner kiln technology (Luby et al, 2015). Due to these costs and the work required to modernise India and Pakistan especially have continued to use the century old, fixed chimney bull trench kilns.

Abbas et al (2022) discusses the complications with adoption to more energy efficient and environmentally friendly brick kilns, while their study is conducted in Punjab Pakistan, the insight from this research still may help the thesis understand the slow adoption of more environmentally friendly brick kilns in Punjab India, Haryana and Jammu and Kashmir. Abbas et al, (2022) surveyed 63 brick kiln owners who owned either cleaner zig-zag kilns, fixed chimney bull trench kilns or clamp type kilns. The questions were used in a Likert scale with 35 factors examined consisting of 20 drivers of innovation and 15 barriers. Factors included regulatory, financial, technological, social and environmental issues, which could influence the decision of owners. Abbas et al, (2022) used the Rogers model of innovation framework to study owners' attitudes towards upgrading their kiln along competitive advantage, compatibility, complexity, trialability and observability as key factors in if innovation is a good choice. Abbas argues it is important to understand hesitancy towards brick kiln innovation to inform better conversion strategies. Cleaner zigzag technology kilns would improve environmental and health standards within the kilns.

Based off these advantages along with better energy and production efficiency the argument to transition is clear. However, to get the most cost efficiency out of these new zig-zag brick kilns Nasim and Sharif (2020) show it is better to retrofit bull trench kilns into zig-zag kilns rather than making new zig-zag kilns. The reasons for this are retrofitting means avoiding a lot of the heavy start-up costs associated opening a brick kiln including land leasing and construction of the kiln.

MSHT research in India is only featured in a small number of publications with researchers rarely using the term modern slavery when discussing brick kilns. The search term child labour returns more results with five results fully accessible from sixteen papers. These studies come from across the entire brick belt and include Larmar et al, 2017; Baul et al, 2023; Pellenq et al, 2021; Bhukuth, 2005. Bhukut (2005) studied child labour and debt bondage making it the most explicitly focused MSHT paper out of the sample of five. The study took place in Tamil, Nadu, and Southeast India their findings show a technicality between the debt bondage of parents in the brick kilns and child labour. Bhukuth (2005) explains that kiln workers often do not directly employ children but rather the debt owed by the kiln workers is so great that to increase productivity the parents deploy the labour of their children.

Therefore, this increased productivity from child labour facilitates bargaining power for the parents. This finding is also represented in Kubasiewicz et al (2022) who studied the role of equid ownership on increased brick kiln work productivity and therefore bargaining power. In 2005 before the 2015 SDGs, child labour was classified as work done by children that was harmful to the child. This definition was distinct from child work which was work done by children that was not harmful to the child. The reason for the distinction was the lack of capacity for the International Programme for Eliminating Child Labour (IPEC) to focus on the entirety of child employment due to the multi-faceted nature of the issue, a theme that would be raised again in the SDGs (Schlemmer, 1997; Bhukuth, 2005). Child labour is understood in two approaches which differ based on cultural and geographical context.

First, child labour can be determined by overall poverty. In this system child labour is used when the lack of labour would reduce family income to below survival levels (Basu and Van, 1998), and therefore poverty can be seen as the main determinant of child labour (Ray, 2000). This system applies to Pakistan but not Peru (Bhukuth, 2005) with the difference being cultural values towards educational access. The second system analyses the investment in education from the parents as child labour and education are usually conflicting practises even if they are not mutually exclusive (Grootaert and Kanbur). Within the literature on MSHT, knowledge asymmetry is the explanation for why parents send children to child labour firms. The parents are not aware of the differences between an exploitative child labour firm and a non-exploitative child work firm (Rogers and Swinnerton, 2002). This lack of information is a theme across research and understanding of the brick kilns' relationship to modern slavery practices like child labour.

Since the 1990's an increasing number of state and non-state actors and stakeholders have recognised the extent of this new form of slavery. This is most notable in the recognition of modern slavery in SDG 8 and especially target 8.7. Lavelle-Hill (2021) recognises that modern slavery is an especially difficult term to describe referring to the Bellagio-Harvard guidelines which describe the legal parameters of slavery. Defined in this guideline as "any situation of exploitation that a person cannot refuse or leave because of threats, violence, coercion, deception, and/or an abuse of power" (WFF, 2018a). Practises of modern slavery can include debt bondage, forced labour, work camps, forced marriage, bonded labour, sexual exploitation, and human trafficking. This is not an exhaustive list, and this group of practices can be broken down into more specific practices.

This paper also identifies that there is a misapprehension that modern slavery is a problem in low to middle-income countries (LMIC), but it is more accurate to depict MSHT as a network with nodes in every country. Through their research on sex work Biemann (2005) provides an insightful analysis into the global network of MSHT. This study critiques the depiction of sex work as a binary between choice and victim illuminating the grey areas created by systematic pressures and supported by the human trafficking industry. Many of these insights can be used to understand other situations of MSHT.

Due to this issue of many potential driving factors Levelle-Hill et al (2021) find in their review that most research around MSHT has come from theoretical approaches and social sciences. This work focuses on groups most likely to be vulnerable to MSHT including economic migrants, political asylum seekers, illiterate people (Fitzgibbon, 2003), orphaned children (Rau, 2002), homeless people (ILO, 2001), and those long-term unemployed (Rosell and Larsen, 2018). Studies like Boyd et al, 2018 which design methods based on proxy measurements of MSHT are mentioned in this review, but Levelle-Hill differentiates this work from social science research on slavery prevalence due to its focus on types of groups and sectors most vulnerable to exploitation (Lavelle-Hill et al, 2021; Fitzgibbon, 2003; Rau, 2002; ILO, 2001; Diego-Rosell and Joudo Larsen, 2018). One advantage of remote research when studying MSHT is that researchers are less likely to put vulnerable individuals into greater harm or further risk of harm due to not having to interview brick kiln workers and other people suffering modern slavery directly. However, Jackson et al, (2018; 2020) discuss how researchers need to exercise caution regarding satellite imagery and research design even when viewing modern slavery remotely.

High spatial resolution is favourable to gain increased visual data, and sensor technology has progressed to the extent that researchers risk identifying individuals which can be dangerous for those in situations of MSHT (Jackson et al, 2018; Notley and Gannon, 2016). This tension between privacy and the production of high-quality spatial satellite imagery has been pushed by technological innovation in imagery and politics over data for example, GDPR and other privacy-based laws and regulations (Coffer, 2020). In their paper, Santos and Rapp (2019) summarise a list of identifiable information possible to discern through high-resolution satellite imagery. This paper also discusses the issue of spatial resolution of 10cm being pushed for by industry satellite imagery data providers. Currently, the best spatial resolution publicly available from commercial sensors is 26cm (Coffer, 2020).

This section has shown how brick kilns are a key area of sustainable development research with impacts in environmental and social dimensions. With the SDGs promoting an interconnected approach to development, multi-disciplinary solutions and frameworks are required (Boyd et al, 2021). Boyd et al, 2021 argue brick kilns are objects of SDG intersectionality, and research has shown that making the brick kilns more sustainable in any dimension would have significant benefits across the SDG national and global attainment (Jackson et al, 2018; Boyd et al, 2021;). Conversion to zigzag kilns is a key priority here both for the government of India and the local populations living near the brick belt. Researchers and policymakers need to understand the reservations of brick kiln owners in making this relatively cheap transition from bull trench kiln to zig-zag (Abbas et al, 2022) for Indian states like Punjab to understand how to speed up conversion.

This review has also shown a gap in the literature between modern slavery and the states of India with Punjab and Haryana resulting in no papers scoped for search terms regarding modern slavery. This follows a lack of remote sensing research focused on SDG 8 and modern slavery specifically. The thesis has also covered the contentions between the relative safety of remote sensing methods compared to physical fieldwork concerning at-risk populations (Jackson et al, 2018; Boyd et al, 2018) and the need for research analysts to think critically about the type of resolution required for their project considering the risk of high-resolution imagery in identifying individuals which can result in backlash from aggressors (Jackson et al, 2018).

2.3 Geospatial research and the brick kilns

The third literature review section focuses on the development of research combining remote sensing methods and brick kilns in northern India. This covers the detection and mapping of the brick kilns starting with the estimation of the total number of kilns in the brick belt by Boyd et al, (2018) and then following the brick kiln detection literature across environmental and social factors for example Nazir, Ather and Taj (2023) research on detection of illegal kiln activity in Punjab Pakistan. Due to the relatively small amount of research on the brick kilns literature is taken from other regions than India and Pakistan. This includes DeWitt's et al, (2021) remote sensing inventory and analysis of kilns in Kabul, Afghanistan, and Lee's et al, (2021) study of brick kilns in Bangladesh. The thesis then moves to the literature on how the brick kilns have been analysed including research on the establishment and age of kilns (Li et al, 2019), investigations into regulatory capacity (Mondal et al, 2018; Lee et al, 2021) and research to monitor the brick kilns consistently (Boyd et al, 2021).The findings support previous research that suggests while the brick kilns have been a target of research for decades (Boyd et al, 2018) research connecting remote sensing and the brick kilns is limited largely to environmental studies and management (Jackson et al, 2018).

This section focuses on three questions.

- What methods were used to detect brick kilns across the brick belt?
- How has geospatial human rights literature covered modern slavery within the brick belt?
- What future directions of research are possible to better explore the brick belts connected to modern slavery practises?

2.3.1 Detection and mapping

The scale of the brick belt and the hidden nature means traditional methods for tracking modern slavery within the brick belts are impractical. To regulate the brick kilns requires data on their location and operational status. Bales (2012) had argued that remote sensing methods could provide sufficient data across wide areal extents for human rights research. Remote sensing analysis promises several advantages to traditional methods for modern slavery estimation and research. First, satellite imagery does not require the same permissions of aircraft, boots on the ground research and drones allowing researchers to bypass safety and territorial concerns. Second, satellite imagery provides a data archive back to the 1970’s allowing researchers to compare imagery across time, finding changes in the land cover images. Third, when working with at risk-populations in-person interviews and ethnographic research can be limited in efficacy by distrustful workers and fears of backlash from their employers (Jackson et al, 2018).

Geospatial research within a human rights and sustainable development context has historically focused on environmental issues (Jackson et al, 2018) or large-scale issues arising from conflict, for example, the research into Darfur, Sudan (Marx and Loboda, 2013; AAAS, 2018B) or Northern Uganda (AAAS, 2018E). These new approaches also needed to consider efficiency, regarding time but also computational and financial resources (Marx and Goward, 2013). Satellite imagery provides a relatively cheap and effective method to track the brick kilns at scale across the brick belt which covers multiple territories. To track slavery from space in South Asia required a phenomenon that could be remotely sensed that was either directly representative of modern slavery or could be inferred from it (Boyd et al, 2018). This links back to Marx and Goward's (2013) understanding of designing remote sensing methodologies based on what the researcher is trying to measure and finding an object, land cover, or spectral reading that is representative of that element being measured. Boyd et al (2018) showed that brick kilns could be tracked from high resolution imagery and deep learning methods. This paper provided the first full estimation of modern slavery within the brick kiln industry by using the brick kilns as a proxy for the prevalence of modern slavery practises. Brick kilns are well-established spaces associated with modern slavery.

The distinctive visual shape of the brick kilns alongside their spectral signature meant bricks kilns could be located in high resolution imagery and used as training data for lower spatial resolution classification models. Suggesting lower spatial resolution imagery could be used to find other brick kilns. Boyd et al, 2018 was the first research paper to estimate the extent of modern slavery within the brick manufacturing sector of Southern Asia focusing research on the brick belt with an aerial extent of 1,5551,997km2 which runs through Bangladesh, Nepal, India, and Pakistan (Li et al, 2019). The ability for remote sensing to cross borders freely was a significant benefit to using remote sensing over other research methods, which is a theme identified repeatedly since Prins (2007) allusion to the possibility of remote sensing to remove these restrictions on information access and research. The brick-making industry is a large part of the economy and developing infrastructure of Southern Asia (Hawksley and Pradesh, 2014), and at the time of writing (Boyd et al, 2018) production was growing with the demand for building materials (Baum, 2010). Using a sample area of the research region of interest (ROI), Boyd et al (2018) acquired high-resolution satellite imagery.

Another advantage of this imagery was it was free. This increasing accessibility to more detailed data shows a development in technology within remote sensing. This development is significant both in terms of financial cost required to utilise high resolution imagery but also the computational cost as computers become more powerful remote sensing becomes a more sophisticated method for research for large scale projects. This high-resolution imagery was captured by WoldView-2 and Pleiads-1A/1B satellites (Boyd et al, 2018). The sample area for the project was decided via random sampling. A grid of 100km^2 square cells was overlaid on the Brick belt using GIS from which cells could be randomly selected and analysed. A random number generator was used to pick 30 cells of the grid from the sample study. Analysts then visually interpreted each of these cells to identify brick kilns.

Visual interpretation was used for these original 30 cells. This analysis showed a standard deviation of 4.6 kilns per cell. This data was used to produce a target amount to secure a random sample with a 95% confidence level (Neter et al, 1993; Cochran, 2007). 320 cells were determined as the necessary sample size.

This resulted in an average of 0.0357 kilns per Km2. For the 320 cells 1142 kilns were found in total with 43% of cells featured one or more brick kilns. When the authors scaled this average across the brick belt an estimate of 55,387 brick kilns was produced. The lower estimate was 44,542 and the upper estimate was 66,270. As this was the first effort to estimate kiln quantity across the brick belt there was no direct estimate to compare against. In the Boyd et al (2021) study 66,455 brick kilns were mapped suggesting the 2018 estimate was accurate.

To evaluate the accuracy of the estimation method crowdsourcing was employed by the authors. A 250km^2 region of Rajasthan was reviewed for kilns with 15 volunteer interactions per image. Foody (2014) had discussed the weaknesses of crowed sourcing previously including spammers and inaccuracies. These discussion points influenced the methodology of Boyd et al (2018). 15 volunteers were chosen to mitigate malicious actors and to cover the entire study area. Once 15 observations were made the image was removed from the sample of available images with a final review from the expert visual interpreter who was the main author of the study (Boyd et al, 2018). The mechanics of citizen science research echo the dissemination of human rights data discussed by Bromley (2009) and Wolfinbarger (2012; 2016). A near neighbour clustering algorithm (available at https://github.com/zooniverse/aggregation-for-caesar/releases/tag/0.1) was used to mitigate false negative results. That could be caused by volunteers picking slightly different areas when analysing kilns. The algorithm grouped cells together resulting in a five-pixel radius in which results were collated.

For Boyd et al (2018) expert visual interpretation, crowdsourcing visual interpretation, and a final analysis by the independent adjudicator (the lead author Doreen Boyd) were all combined to produce an accuracy rating of 99.6% for the initial data set. When interpretations conflicted the interpretation of the independent adjudicator was weighted most significantly and taken to be the “ground truth” (Boyd et al, 2018). This approach also reduced the risk of poor data quality through malicious actors like spammers (Foody 2014; Foody et al, 2013) 262 kilns for the 320 cells of imagery were all agreed to be kilns by the volunteers, expert interpreters, and the independent adjudicator. Both the independent adjudicator and volunteers detected one additional brick kiln which was classified as a true positive result. Another 16 brick kiln results were identified by volunteers, but all of these were classified as false positives and commission errors.

This dataset was first used as an estimate of the location and quantity of kilns (Boyd et al, 2018) and then used as training data for a machine learning program that was designed to identify and classify where brick kilns were located across the study area (Boyd et al, 2021). Estimated across the 1,551,997 km^2 study area, 55,387 kilns were present (Boyd et al, 2018). Through these estimations of brick kilns which are known spaces of modern slavery, slavery becomes an indirect phenomenon that can be sensed by tracking the location of brick kilns and their age (Li et al, 2019; Scoles, 2019). Later research expanded this estimation of brick kilns in the South Asian brick belt to depict the spatiotemporal patterns of these kilns including linking them more explicitly to the other sustainable development goals (Boyd et al, 2022).

In 2018 Nazir et al (2018) also produced a brick kiln detection method for South Asia. Their method used a gated neural network rather than the initial Boyd et al (2018) study which used crowd sourcing and visual interpretation. Both Nazir et al, (2018) and Boyd et al (2021) used deep learning approaches to analyse the entire brick belt aiming to detect and locate all brick kilns within the area. This work would go on to influence Nazir et al (2019) and will be discussed later in section 2.3.4.

Nazir et al (2019) used a different brick kiln detection method using low spatial resolution imagery and heat signature analysis in the smog period. Their study identified illegal brick kilns by comparing air pollution data across Pakistan. This study used Landsat 8 Thermal Infrared 1 band and the Sentinel 5 TROPOMI (TROPOsheric Monitoring Instrument) to detect heat signatures from the brick kilns to estimate their operational status.

The researchers noted that technology limitations meant it was not possible to track the emissions of individual kilns due to the propagation of gaseous emissions and heat measures. Instead, the spatial analysis was conducted at the Tehsil scale. A Tehsil is a subdivision of a sub-district area. Nazir et al (2019) used the Punjab Brick Kiln Census and Kiln-Net paper (Nazir et al, 2018) to retrieve 9348 brick kiln locations.

Results showed 27 out of 128 areas researched were responsible for an increase in smog and air pollution. The burning of fossil fuels in brick kilns was linked to SO2 and particulate matter emissions which contribute to poor air quality and health problems. Nazir et al (2019) also briefly discuss their research in the context of working with the ILO (International Labour Organsiation) and NIH (National Institute of Health) to regulate brick kilns to promote better human rights conditions and shut down illegal kilns.

2.3.2 Geospatial facilitated human rights research and the brick kilns

As discussed above the trend of geospatial facilitated human rights research having a limited engagement with SDG 8 impacts the academic focus around modern slavery in the context of the brick kilns. Ekmen and Kocaman (2024) have shown this lack of coverage of SDG 8 exists across geospatial research with only 3 of 308 (1.2% of papers in the Web of Science sample) relating to SDG 8. This section explores how geospatial methods are used to analyse human rights and sustainable development challenges within the brick kilns of India. Most of this work takes an environmental or health risks approach without explicit links to modern slavery despite the concepts of the freedom dividend and environment-slavery nexus suggesting the fruitful interaction between sustainable development goals (SDGs).

Anderson (2017) notes a growing trend in geospatial methods for human rights and sustainable development research linking various goals to different research papers within geospatial technology studies. As Jackson et al (2018) described, the

Anderson (2017) paper shows little attention to SDG 8 and modern slavery. This is significant as the literature review by Ekmen and Kocaman described Anderson (2017) as the most cited piece of research on the Web of Science sample (2024). Earth observation methods are argued as a key tool for sustainable development attainment and policy strategy, providing the ability to facilitate data driven decision making at scale.

The brick kilns have been the targets of a range of geospatial research across India and within other nations such as Pakistan (Khan et al, 2019) and Afghanistan (DeWitt et al, 2021) The papers captured in the literature review can be categorised in the following research areas; Urban development (Majumder et al, 2023), air pollution (Guttkunda and Calori, 2012 ; Guttikunda, Goel and Pant, 2014; Arbain and Imasu, 2019; Misra, Imasu and Takeuchi, 2019; Misra et al, 2020), land degradation (Saini et al, 1999), health concerns (Khan et al, 2019), land use change (Singh and Asgher, 2005; Misra, Rai and Rai, 2019; Ghosh and Sarkar, 2021), village poverty (Marcinko et al, 2022).

Air pollution studies of the brick kilns include GIS produced emission inventories (Guttikunda and Calori, 2013), air pollution management (Guttikunda, Goel and Pant, 2014; Misra, Imasu and Takeuchi, 2019) and particulate matter emissions (Arbain and Imasu, 2019). Guttikunda and Calori (2013) designed a GIS emissions inventory for spatially analysing air pollution in Delhi, India.

The brick kilns have also been linked to air pollution management and the health impacts of emissions (Misra, Imasu and Takeuchi, 2019; Misra et al, 2020). Brick kilns are associated with the worst anthropogenic air pollution globally (Misra et al, 2020). By mapping the brick kilns in Delhi using Sentinel 2 imagery researchers aimed to correct for the underrepresentation of brick kilns as a source of air pollution. Brick kilns in Southern Asia are characterised by a lack of data. Even within the environmental realm brick kiln reports concerning emissions and environmental impacts are limited due to no official record of brick kilns being publicly available (Misra et al, 2020). The researchers used object detection methods and pixel classification to locate 1564 brick kilns. The method calculated a 28% average underestimation on the amount of brick kilns and applying this to the original kiln count produced a higher kiln count of 2172 kilns for Delhi.

Misra et al (2020) note a lower F score; calculated by the following equation F = 2 x (Recall x Precision) / (Recall + Precision) than Nazir et al (2019) and Foody et al (2019). Misra et al (2020) produced an F score of 0.83 while Nazir et al (2019) scored one and Foody et al (2019) scored 0.94). this suggests Nazir and Foody produced a more accurate classification model, due to the difference between spatial resolution used. This result shows the importance of high-resolution spatial data when tracking brick kilns. The spectral resolution methods used in Misra et al (2020) led to omitted features. One reason for this was the similarity between the spectral response of the arid soil and the brick kiln surface reflectance leading to the classification model outputting some brick kilns as false negative results. False negative results were also produced by dormant or non-operational kilns being overgrown, causing vegetation to influence the spectral response output and lead the classification model to tag the image as land cover rather than brick kiln.

In our research the rights lab have been aware of these methodological challenges when using spectral response classification to detect brick kilns. Using high resolution data from Google Earth helps eliminate these concerns by performing visual analysis of false negative results. However, high resolution data is limited in its temporal resolution meaning it is possible a kiln may have changed in operational status or been moved entirely, leading to a lag in time between research data and the real-world conditions. Like Boyd et al (2018;2021) Misra et al (2020) links the brick kilns location to the periphery of urban centres, with kilns often forming in clusters. Clustering of kilns is an interesting finding as it suggests a contention between kiln proximity for short supply lines and regulatory compliance. Misra et al (2020) state that most brick kilns are less than 10km away from urban boundaries suggesting many kilns do follow the 1000 metre kiln to city proximity rule set out by various Indian states (Punjab pollution control board, 1989).

Misra et al (2020) calls for a comprehensive regional database of brick kilns to study kiln location and their operational status and characteristics. Characteristics could include demographic statistics of brick kiln workers, history of kiln operational status, observations of structural changes and regulation compliance metrics. The researchers note that while air pollution and environmental factors of the brick kilns have been covered and known, the spatial characteristics of the brick kilns remain uncertain both in terms of the location of the brick kilns but more significantly the drivers of their presence relative to cities and urban-rural spaces.

2.3.3 Aging and analysis of the brick kilns

Li et al, (2019) provided a historical development of the brick kilns over 35 years using a combination of high-resolution Google Earth World View 2 imagery with a spatial resolution of 0.46m from Google Earth Engine and Landsat breakpoint detection methods. Landsat sensors were used alongside Worldview 2 imagery due to the Landsat data archive being able to age kilns that were constructed before the year 2000 as World View 2 was launched in 2009 (ESA, 2024). The Landsat sensors used were Landsat 5 Thematic Mapper (TM), Landsat 7 Enhanced Thematic Mapper (ETM+), and Landsat 8 Operational Land Imager (OLI). This capability of remote sensing to investigate the past through data archives echoes the arguments of Marx and Loboda (2013) and Wolfinbarger (2016) who saw the ability of remote sensing to investigate and prove previous events to be a significant benefit to NGOs' fact-finding operations.

Another advantage of Landsat sensors beyond their ability to provide long-term imagery records is their moderate spatial resolution means a higher revisit period than the high-resolution World View 2. This means more satellite imagery of the same location is available from Landsat data than World View 2 as the temporal resolution is denser for Landsat allowing for more accurate aging due to shorter time intervals between imagery. This temporal density is made more significant by the factors of cloud cover which can make individual satellite imagery scenes unusable.

A higher quantity of satellite imagery scenes due to a lower return rate helps alleviate this issue.

Ageing the brick kilns was an important development in understanding the brick kiln landscape. This is because regulatory compliance changes based on the age of brick kilns which means without understanding the age of the kilns it is difficult to accurately map compliance (Punjab Pollution Control order, 1998). Furthermore, brick kilns can change in their operation status and kiln type as time goes on which means only by monitoring the kilns continually can accurate data be assured.

This pilot study assessed a random sample of brick kilns against this breakpoint change method before producing “wall-to-wall maps” (Li et al, 2019 pp 133) of kilns and their age to give to anti-slavery organisations interested in a particular region. Results were promising, the time series from 1984 – 2018 held a correct prediction percentage of 83.04% and root-mean-square-error (RMSE) of 3.6 years (rounded to 1 decimal place). Li et al (2019) focused on 831 kilns from the kiln sample discovered and presented by Boyd et al (2018). By monitoring changes in the spectral response of land cover over time using the Landsat short-wave infrared bands which are sensitive to land cover change. This instance of change in spectral response is called a breakpoint and can be used to assign a time of brick kiln construction as the spectral response of the land changes. Breakpoint detection methods use satellite imagery and machine learning to detect when land cover has changed providing a more resource-efficient way to track the building of brick kilns.

A breakpoint is representative of any land cover change so to verify that the breaking point was the construction of a brick kiln and not another land cover change Li et al (2019) used a random forest (RF) classifier algorithm. Random forest algorithms combine sets of decision trees using a process called ensemble learning to process numerous permutations of a solution. This was essential to this study as the data was too expansive to be manually interpreted. Results showed that using this method accurate aging of the brick kilns was possible with a correct prediction percentage of 83.4%. Higher spatial resolution imagery from Google Earth had a lower temporal resolution due to both revisit time differences between high-resolution sensors and the duration of these data capture programs and so had a time window per image of 4.35 years on average. Compared to Landsat imagery which had a potential revisiting period of 16 days when not accounting for images being unusable due to cloud cover and other observation factors. This gave Landsat a time window per image of 3.57 years. Results showed that 41% of brick kilns were 10 years old or younger since construction, and 39% were 10 – 20 years old. Rajshahi, Jharkhand, and Uttar Pradesh were all areas with a significant number of new kilns.

Concluding this study Li et al (2019) suggest devising mapping all kilns and their age of construction in specific areas of interest to human rights groups and researchers. This visibility of brick kilns can support work on the ground to investigate brick kilns and track their development. This research builds on Boyd et al (2018) and Foody et al (2018) to address further gaps in knowledge around brick kilns to provide better resources for policymakers and stakeholders.

2.3.4 Monitoring and regulation

In 2021 the research was combined from detecting, mapping, and aging the kilns to produce GeoAI, a platform that could monitor the development of brick kilns across India. Developing their ideas from Boyd et al, (2018) researchers including Li (Li et al, 2019), Jackson (Jackson et al, 2018), Foody (Foody et al, 2019; Foody et al, 2015) and Bales (Bales, 2012) who have been discussed previously would integrate machine learning into their brick kiln quantification and mapping research to visualise spatiotemporal patterns of brick kilns. Previous studies have used machine learning (Paul, Bandyopadhyay, and Raj, 2022; Lavelle-Hill et al, 2021; Nazir et al, 2020; Foody et al, 2019), crowdsourcing methods (Foody et al, 2015) or a combination (Herfort et al., 2019) to provide crucial information on the brick belt.

In 2020 the Kiln-net architecture proved promising for mapping the brick kilns using a two-process machine learning method (Nazir et al, 2020) but Boyd et al (2021) were the first research project to provide a complete map of the brick belt. This work also explicitly linked several SDG goals together that could all be addressed through a focus on brick kilns. These included a significant focus on SDG 8.7 based on the effort to end modern slavery, urbanisation (SDG 11, 12) environmental degradation and pollution (SDG 3, 14, 15), and climate change (SDG 13). While other studies have discussed links between SDGs (Jackson et al, 2018; Misra et al, 2020; Foody et al, 2019) Boyd et al (2021) pushed these connections further by explicitly linking them to their exact SDG goal and the focus of the brick kiln. By understanding brick kilns as these objects of SDG intersectionality (ibid) researchers can provide a powerful economic as well as social justice argument for the investment to modernise brick kilns. Arguing tackling modern slavery creates benefits on multiple goals and therefore bestows a freedom dividend (Foody et al, 2019).

Using very high resolution (VHR) satellite imagery from Airbus Pleiades with a 50cm spatial resolution. Pleiades was a constellation of 2 satellites 1A and 1B (Airbus, 2023). With a daily revisit capacity and designed for precision mapping. Boyd et al (2021) used these satellites to image the entire brick belt before using a convolutional neural network (CNN) to identify and visualise all brick kilns. Key features to identify a brick kiln where size, shape, the presence of a central chimney, and the long shadow this chimney casts. The presence of a central chimney and shadow along with a higher surface reflectance helps separate functional from abandoned kilns and other similar land features (ibid). The YOLOv3 CNN architecture was used for this study as at the time it was highly regarded as fast and efficient for object detection with an acceptable trade-off with detection accuracy (Yunong et al, 2019; Nazir et al, 2020 ;). Another benefit of the architecture was that it was efficient enough to handle the significantly large amounts of data produced by VHR imagery and the process could be repeated for new kilns that were discovered.

An iterative three-step approach to train the architecture was devised. First, the CNN was trained on a dataset from Boyd et al (2018). Second, the output of this kiln classification from Boyd et al (2018) was manually reviewed by an expert visual interpreter in a similar approach to the former study (ibid; Boyd et al, 2021). Once omission and commission error rates were calculated the third stage was using this refined training set to retrain the CNN on a larger network size of 608 x 608. After this three-stage process had been successfully iterated through, with the third step of retraining taking 20,000 iterations, known as epochs, and 24 hours in duration it was possible to map the whole brick belt. Results mapped 66,455 brick kilns which is in line with the estimation of 55,387 (Boyd et al, 2018) the approach also held a 92.83% overall accuracy. This accuracy rating was calculated by an interpretation expert using visual comparison in a similar method to Boyd et al (2018) and Foody et al (2019).

Alongside this VHR mapping of the brick kilns Boyd et al, (2021) incorporated the research from Li et al (2019) to develop a spatiotemporal review of brick kilns. This process was supported by visual interpretation of VHR data from WorldView, Pleiades, GeoEye-1, and Quickbird imagery from 2000 to the time of research downloaded from the Google Earth engine (Boyd et al, 2021). This VHR imagery comparison was used as there was not reliable enough ground data to train the classifier. The same Landsat to VHR time series analysis used in Li et al (2019) was used again to get a higher precision time signature for the construction of a brick kiln. With a time, window of 1988 to 2018 (Boyd et al, 2021) every single brick kiln was mapped with 69.7% or 46,319 being in India, 17.3% or 11,497 in Pakistan, 11.3% or 7509 in Bangladesh and 1.7% or 1130 in Nepal. This study provides a proxy measure of modern slavery prevalence and vulnerability across the brick manufacturing industry in South Asia.

As brick manufacturing becomes more economically attractive due to urban sprawl driving up demand combined with downward pressure on wages. When there is no intervention, this pressure extends to a complete denial of wages (Choi-Fitzpatrick, 2017). The geographical distribution of brick kilns being uneven and highly concentrated around urban settlement centres supported this hypothesis (Boyd et al, 2021). Furthermore, with the population of India, the largest host of brick kilns, and other South Asian countries rising and predicted to continue to rise in population this combination of urban sprawl, economic demand, and absence of political will or countervailing social norms creates a growing vulnerability for modern slavery, climate risk, environmental degradation, and health issues (ibid).

This section has synthesised research on the brick kilns tracing the development from mapping to analysis and then monitoring. The interconnected nature of the SDGs and the extensive negative social and environmental impacts of the brick kilns make the research on environmental management useful for understanding the conditions that brick kiln workers operate within. Searching for modern slavery in connection to the brick kilns and remote sensing provided few results outside of the work by the Rights Lab when the thesis did the same search for brick kilns and child labour a few more publications were returned, and these papers have also been considered in the above section. A distinct lack of modern slavery research is found when compared to environmental management and health and social wellbeing research. This is the trend for both research using remote sensing methods and research that does not.

2.4 Ethical considerations of geospatial research and future directions

The final section of this literature review considers the state of high spatial resolution imagery and its concerns with data protection and privacy. Privacy is a key ethical issue in the methodological design of geospatial-facilitated human rights research especially when the target of this research could potentially put people in danger of repercussions (Jackson et al, 2018). The thesis explores a range of critiques and concerns directed at remote sensing methods designed to support international human rights research. Privacy is considered as a main concern both for those that analysts research and the broader public. Papers by Walker (2020;2021) are used to explore counterarguments to concerns for geospatial facilitated human rights methods and give guidance on how this thesis negotiates these academic challenges. The last section covers future research in remote sensing and human rights research the ethical and methodological practise considerations for geospatial facilitated human rights research and the considerations of studying modern slavery.

This section focuses on three questions.

- What risks are associated with high-resolution imagery regarding data protection and privacy?
- What critiques are found in the research literature concerning geospatial facilitated human rights monitoring?
- How can researchers employ best practises and ethical considerations to mitigate these two sets of concerns?

2.4.1 Privacy and high-resolution imagery

With the continual improvement of sensor spatial and temporal resolution researchers have become increasingly concerned with the contention between geospatial technology for human rights monitoring as an important function and concerns over privacy, retaliation, and the complex relationships between observer and observed. Coffer (2020), Santos and Rapp (2019) and Maniadaki et al, (2021) provide insight into this contention and contemporary research issues related to this development in spatial resolution. A range of national and international frameworks have been developed to negotiate these contentions, but researchers are concerned emerging technologies offer a network of data protection and privacy concerns.

In the European context, GDPR compliance is a significant source of contention between privacy and high spatial resolution sensors. As the spatial resolution of imaging systems increases the risk to privacy is two-fold. First, the increased quality in spatial resolution means smaller objects can be identified by sensors. Second, as high-resolution sensors get better, they become more accessible as previous high-resolution sensors become more mainstream and cheaper (Coffer, 2020). Ethical questions of sensor resolution are especially important in the context of human rights monitoring and modern slavery research (Jackson, 2018). The best practice is for researchers to carefully consider the resolution required for their project. For example, a remote sensing project studying areas of tree loss does not require the type of high-resolution imagery that can capture personally identifiable information. Santos and Rapp (2019) discuss the push for 10cm spatial resolution sensors, currently 31cm is considered the highest spatial resolution but moves towards 10cm super high-resolution imagery are developing (ESA, 2024). The growth in satellite-based imagery has also led to both developments in small satellite constellations and technological advances in bigger satellite sensor systems with massive constellations of microsatellites being launched into low earth orbit (Crisp et al, 2020).

While some of these privacy fears are for now unfounded for example it is not possible even with 10cm spatial resolution to identify individuals, the growing development between satellite spatial resolution, image recognition algorithms, and accessibility to near real-time imagery has led experts in EO and law to urge caution. Space imagery is already subject to a set of legal principles as part of the Outer Space Treaty (OST) of 1967. However, Santos and Rapp (2019) show that none of the OST or interconnected international or national laws regarding space imagery consider privacy leaving GDPR to fill the gap. GDPR focuses on protecting individuals, not groups, and as researchers in the field have noted including Floridi (2014) often it is groups of people who are targeted and identified by satellite imagery, not individuals. It is also groups that are likely to be the subject of study by government agencies and intelligence teams.

This invisible and ubiquitous satellite imagery leads to three major privacy concerns. First, the inherent invisibility and omnipresence of satellites serve as a panopticon not only for human rights abusers as discussed in (Wolfinbarger, 2012; 2016) but for normal citizens too who may feel uneasy not knowing the purpose or the actor that has control of the sensor remotely observing them. Second, as satellite sensors and the earth observation ecosystem develop there is a fear of function creep, defined as the growing list of exceptions, operations, and activities beyond the original selected operation. Santos and Rapp (2019) argue this risk grows with the ability for satellite imagery to be disseminated on the internet and reappropriated for other purposes than its original intent.

Third, while it is not possible to identify individuals yet in terms of facial recognition the associated data between privacy of location and space combined with being able to identify and remotely sense human bodies risks making people uneasy about going to public or semi-public spaces without being remotely sensed. This leads to a decline in use of public space as a combination of CCTV, remote sensing and facial recognition promote an imagined or realised surveillant society.

Finally, linking to the risk of privacy of location there are privacy concerns over associations between individuals. The concern is that by remotely sensing the number of cars outside a house the social dynamics of the household could be inferred. When combined with other data the line between big data and personally

identifiable information becomes blurred.
The risk of discrimination due to the combination of profiling and machine learning algorithms which can be biased in their operation is a serious ethical issue for remote sensing.

The concerns are emboldened by the nature of the companies that are using satellite imagery. Conceptions of the shutter control and absence of transparency arguments are difficult to dismiss when intelligence agencies and private thinktanks can access high resolution satellite imagery with ease. Chandra and Bhatia (2020) tackle this contention from a legal perspective stating the combination of artificial intelligence with satellite imagery risks groups being discriminated against or targeted by satellite imagery programs.

<u>2.4.2 Walker papers</u>

These concerns of satellite imagery are also aimed more specifically at geospatial facilitated international human rights research. Walker (2020;2021) engaged with these academic critiques suggesting the academic community had misjudged the role of remote sensing in international human rights research.

Walker notes there was a gap in understanding between the academic theory of remote sensing and the practical applications of the tools and methods used in human rights situations and disaster management. Their paper responded to three main concerns. First, researchers criticised remote sensing for being used as an objective or uncontested form of knowledge that led to the removal of the human element of human rights. Second, another line of critique suggested an overreliance on satellite imagery could marginalise first-hand experience and boots on the ground operations. Thid, some researchers were cautious or unreservedly against the adoption of a military intelligence technology into the field of academia and human rights.

To gain firsthand experience themself before engaging with these critiques Walker conducted 40 hours of semi structured in person interviews with analysts, researchers and other members working within and part of the international human rights sector. Walker (2020) also undertook direct participant observation to gain a deep experience of day-to-day operations and the practical uses of remote sensing.

Their paper covers critiques of cautious approval (Wang et al, 2013; Livingston, 2015; Witmer, 2015; Raman and Livingston, 2018), explicit critiques (Witjes and Olbrich, 2017; Rothe and Shim, 2018; Olbrich, 2019), and direct reservations (Parks, 2005; Herscher, 2010, 2014; Hasian, 2016). As satellite imagery is largely owned by governments or corporations with histories in military and intelligence sectors academic critiques of remote sensing and human rights monitoring are concerned with the links to statecraft and epistemological power dynamics. This is seen explicitly in the connection between the US government and its ability to impose restrictions on satellite companies concerning the distribution of remote sensing imagery known in the literature as shutter control (Heidner, 2014).

These controls are justified by the US government and others due to national security claims or the projection of Western policy. These critiques link to the work by

Laliberte (2015) on human rights and their association with Western power structures. These concerns have been discussed in the restrictions concerning the resolution of imagery over Israel and the occupied territories (Parks, 2005; Herscher, 2014; Hasian, 2016; Rothe and Shim, 2018). Walker sees value in these critiques but notes that they fail to consider how IHR analysts and investigations perceive these issues. Walker notes that shutter control has never been truly invoked by the US or another national body. Walker concludes that even a textbook example of shutter control; which they believe was less about censorship and more about national security, did not prevent human rights investigators and journalists from reporting on Afghanistan (Walker, 2020; HRW, 2001; 2002). In this argument Walker draws apart distinctions between academic theory and practical application.

In the field, Walker stated how in practise remote sensing imagery did not drive investigations or shape the type of human rights abuses that were investigated as critiques (Herscher, 2014) had suggested. Analysts did not perceive remotely sensed imagery as unmediated truth and instead used it alongside witness testimony, ground truthing, and other research methods as a tool that complemented other research methods and resources deployed. In the conclusions to the paper, Walker claims these academic critiques require more first-hand experience of the iterative and evolving process of remote sensing work for human rights monitoring. Walker (2021) would investigate this gap in understanding further during their PhD thesis.

Walker (2021) posits that remote sensing had enhanced the abilities of human rights actors to position themselves as significant geo-political actors by providing a platform from which actors could challenge traditional state monopoly over international news and political narrative creation. This can be seen back in Bromley (2009) where the dissemination of satellite imagery could show human rights violations to the international community that were not being covered consistently by traditional news media.

Overall, Walker (2020;2021) suggested that an overreliance on the output of international human rights groups work ie the maps and reports was biasing academics to be against geospatial facilitated human rights research. This was remedied they suggested by gaining hands-on first-hand experience with analysts and human rights research groups. They also stated researchers underestimated the development and evolution of remote sensing methodologies within human rights research groups.

2.4.3 Future research and best practise

As geospatial research becomes more data heavy with big data, artificial intelligence and deep learning methodologies becoming more ubiquitous it is important for researchers to push for further transparency in their research design and methods. Wolfinbarger (2016) noted that alongside the concern that the methods within remote sensing had not developed beyond breakpoint analysis of before and after interpretation, another concern was that many remote sensing research projects were not recorded in enough detail within the methodology to be replicable, Wolfinbarger (2016) may have been focused on replication due to the legal stance of their work, but it is an important factor of best practticse to consider. It links back to concepts of transparency and the black box of analysis that Wolfinbarger (2012) touched on in their thesis. Wolfinbarger (2016) notes satellite reports often omit a range of factors of analysis including location coordinates, imagery meta data and sensor specifications. Without this data or access to the original data through a portal or platform the validity of the data cannot be verified.

Wolfinbarger also deepens the concerns of privacy with the notion that near real-time high-resolution satellite imagery presents the risk of exposing the location of vulnerable groups who can then be targeted by malicious actors. This is compounded by the lack of regulation of access to high resolution imagery and little restriction on the use and modification of satellite imagery.

Another concern for future research is the adoption of satellite constellations and small sats. Sousa (2023) explores the expansion of small sats since the 1980s tracing the role of small sats in the first space missions to attempt to commodify space data using small sats including cube sats (Denis et al, 2017). The continuous development of small sat capabilities for earth observation methods meant that applications devised in 2010 but considered impractical or infeasible in the early part of the decade were possible by the decade's end (Sousa, 2023). Constellations of small sats also helped reduce costs and run more efficiently. Sousa refers to this in the faster, cheaper, better era of NASA which despite being considered flawed due to this streamlined approach leading to many NASA space mission failures in the 1990s to early 2000s suggested a new development in small sat technology These developments will require increased transparency and ethical compliance from researchers.

This section has reviewed the literature on high spatial resolution and risks of data protection and privacy, Walker's (2020) responses to current critiques from the academic community, and future developments in the technology of remote sensing and methods. First, despite high spatial resolution imagery not being detailed enough to identify individuals directly the links between facial identification technology, the growing accessibility of satellite platforms and imagery, and low earth orbit small satellite development make it possible for individuals to be identified by association and location. The examples Santos and Rapp (2019) give of license plate recognition, thermal sensors, and systems that read IP addresses and track RFID devices to intercept electronic communications like calls and SMS messaging paint a dystopian picture of constant but unknown surveillance. Researchers link these concerns to GDPR and other data protection regulations.

Following on from the data privacy concerns academic critique around the use of remote sensing in human rights monitoring and research has followed concerns over the history between satellite imagery and the military-industrial complex, the Western focus on human rights, and the ability for nations like the USA to influence the spatial resolution limits and accessibility to certain regions known as shutter control. Walker (2020) argued these criticisms stemmed from a lack of understanding between academic theory, the development of satellite technology, and how international human rights analysts use remote sensing on a day-by-day basis. By ground-truthing remotely sensed data either through local knowledge, witness testimonials, or published reports, with these methods depending on practicality and feasibility, analysts can use satellite imagery as a complementary tool to other research methods. When considering high-resolution imagery analysts should think critically about the needs of the research project.

3.0 Methodology

3.1 Literature review

The thesis used a narrative literature review structure to highlight connections between geospatial facilitated human rights monitoring and contemporary efforts to use geospatial analysis to track modern slavery. A clear understanding of previous research over the last two decades informed the study's processes and methods to track modern slavery from brick kiln regulation factors. As seen previously, certain sections of the literature review produce little research within the boundaries of the inclusion-exclusion criteria. This includes research on the link between modern slavery and brick kilns, geospatial technology and modern slavery, and past examples of modern slavery research methods using geospatial technology. This will be discussed in the conclusions of this section.

The literature database Scopus was used with the following keywords split into two search models. The keyword search was configured to capture papers with the following terms in the title, abstract, and keywords section. This allowed the thesis to define a large area of capture for analysing papers included with the search terms.

Figure 1 – A table showing key words for literature review.

Model 1 – Development of geospatial technology and human rights monitoring	Model 2 – MSHT in India and the brick kilns
Remote sensing	Punjab
Earth observation	Haryana
Human rights	Brick kilns
GIS	Regulation
Mapping	Child labour
Modern Slavery	Modern slavery
Sustainable development goals	Human trafficking
Citi*en science	

Scopus captured 1955 papers included in the inclusion and exclusion criteria. An inclusion-exclusion criterion is often used in systemic literature reviews to produce a more reliable study as the objective method used Is a higher level of evidence than other review structures. However, Webster and Watson (2020) suggest that a literature review can employ multi-method structures drawing on different elements to enhance the paper's methods. An inclusion-exclusion criterion helps mitigate thesis bias by setting rules that papers must be screened against. The thesis screens papers against the date published, keywords, subject of study, and document type.

Figure 2 -A table showing inclusion exclusion criteria factors.

Inclusion exclusion criteria factor	conditions
Date published	Must range from 2000 – 2023
Keywords	Refer to the figure above
Subject of study	Social Sciences Earth and Planetary Sciences Environmental Science Computer Science Engineering Arts and Humanities
Document Type	Article

This produced the following sets of paper results for each search string. Note some search strings.

Search string	Papers captured	Papers reviewed
“Remote sensing” AND “human rights”	33	23
“Earth observation” AND “human rights”	4	3
“GIS” AND “human rights”	44	6
“Mapping” AND “human rights”	314	27
“Remote sensing” AND “modern slavery”	3	3
“Mapping” AND “modern slavery”	6	0
“Remote sensing” AND “Sustainable Development Goal*”	391	30
“Earth observation” AND “Sustainable Development Goal*”	136	24
“High-resolution imagery” AND “Sustainable Development Goal*”	2	1
“GIS” AND “Sustainable Development Goal*”	238	6
“Mapping” AND “Sustainable Development Goal*”	655	6
“GIS” AND “human trafficking”	4	1
“Mapping” AND “human trafficking”	17	2
“Remote sensing” AND “brick kiln*”	15	7
“Earth observation” AND “brick kiln*”	2	1
“GIS” AND “brick kiln*”	7	1
“Mapping and brick kiln*”	9	2
“Citi*en science” AND “brick kiln*”	14	2
“Regulation” AND “brick kiln*”	25	15
“India “AND “human trafficking	47	10
“Punjab” AND “brick kiln*”	31	19
“Haryana” AND “brick kiln*”	11	6
“Brick kiln*” AND “child labour”	16	5

Total (including 5 search strings outputting < 2 results)	2029	204

Figure 3 -A table showing search strings and returned paper results.

Note some search strings have been removed from the final write-up due to a lack of papers being output. All search strings displayed produced a paper capture count higher than 1.

The large number of papers excluded from the literature review after the inclusion-exclusion criteria is due to the thesis screening them out after reading the abstract and introduction. This practise is used to screen papers as a paper can pass the inclusion-exclusion criteria and still not be appropriate or relevant to the author's intended study. In this context, many of the large paper subtractions are due to an imbalance between geospatial technology research into the different sustainable development goals (Ekmen and Kocaman, 2024). Within their 308 papers reviewed for geospatial technology focused on research the SDGs only 1.2% were related to SDG 8.

Alongside these primary papers, the thesis reviewed papers from citation searches and grey literature including websites, NGO pages, reports, news articles, and technical specifications of sensor and platform technology. These were used as appropriate to support the researcher's understanding of the literature. The thesis notes an ongoing lack of geospatial research concerning SDG 8 echoing findings from Jackson et al (2018) and Ekmen and Kocaman (2024). This uneven distribution of SDG research in geospatial technology for sustainable development and human rights monitoring produces a small number of papers that are suitable for primary study.

This imbalance in modern slavery and human trafficking research is also evident in India and specifically the Indian states of Punjab and Haryana, the focus of this study. Results for search strings “Punjab AND human trafficking” and “Haryana AND human trafficking” show less than 1 result per search query. Furthermore, none of the human trafficking work captured in the “India and human trafficking” query is explicitly linked to the brick kilns. Interestingly despite modern slavery and human trafficking returning few results relevant to the brick kilns changing the search term to child labour outputs 16 results with 5 relevant papers.

A concept-based approach drove the review of these papers as the thesis aimed to put into practise the advice from Webster and Watson (2002; 2020). A concept-based approach goes beyond a synthesis of what other authors have reported and discussed, instead seeking to draw ideas together showing a development between researchers This concept-based approach seeks to link papers between technological developments like very high spatial resolution imagery, theoretical frameworks including the slavery-environment nexus and Bellagio-Harvard guidelines to ground the study of MSHT in the historical context of wider geospatial facilitated human rights monitoring efforts.

3.2 Data analysis

3.2.1 Study area

The study area for this thesis consists of two Indian states, Punjab and Haryana. Punjab is the focus of this analysis due to more liberation data and brick kiln data being available for the area. Punjab is in the northwest of India and bordered by the Indian states of Himachal Pradesh to the north and northeast, Haryana to the south and southeast, and Rajasthan to the southwest. Two Indian union territories also border Punjab; these are Chandigarh to the east and Jammu and Kashmir to the north. An international border between Punjab India and Punjab Pakistan is situated in the west of Punjab. It is the 16th largest state by population with 27 million inhabitants within 23 districts. Punjab is a wealthy state in India suggesting both a greater ability to convert bull trench kilns to zigzag and greater resources for auditors and investigations into non-compliant brick kilns. Punjab covers 50,362 km2 with 2733 brick kilns in 2020 and 2417 brick kilns in 2024.

Haryana was split from Punjab state in 1966 becoming its state. It is in the northern part of India. Due to originally being split from Punjab, the two states share a capital in Chandigarh. The state covers 44,212 km2 and ranks as the 18th most populated state in India with 25,351,462 inhabitants. The joint court between Punjab and Haryana has actively encouraged brick kiln conversion to cleaner methods and designed regulations to update the brick kilns (Punjab Pollution Control Board, 1988).

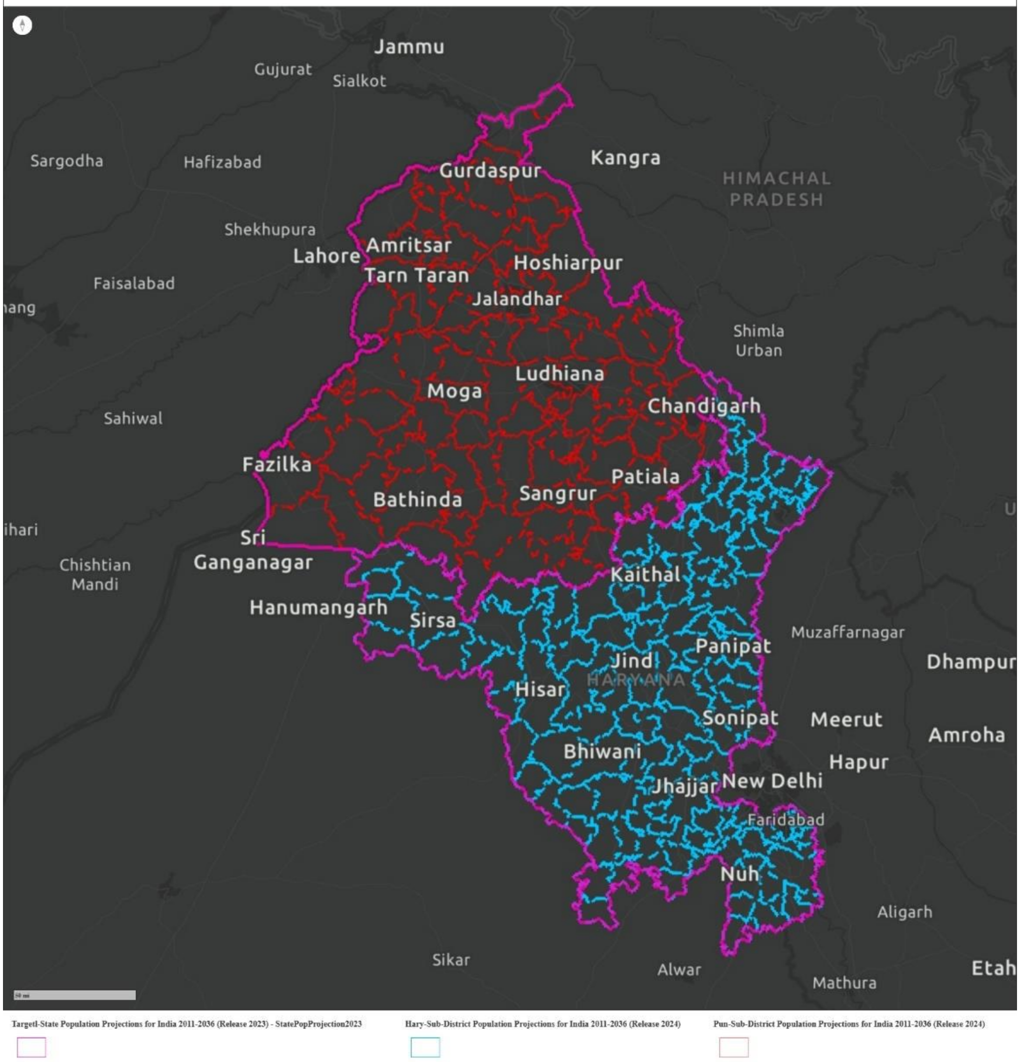
Figure 4: Punjab and Haryana polygon from State Population Projection 2023

3.2.2 Data collection and spatial analysis

The thesis used a GIS program to visualise data from a partner NGO, the GeoAI platform and Esri layers available on ArcGIS living atlas. In this section the thesis

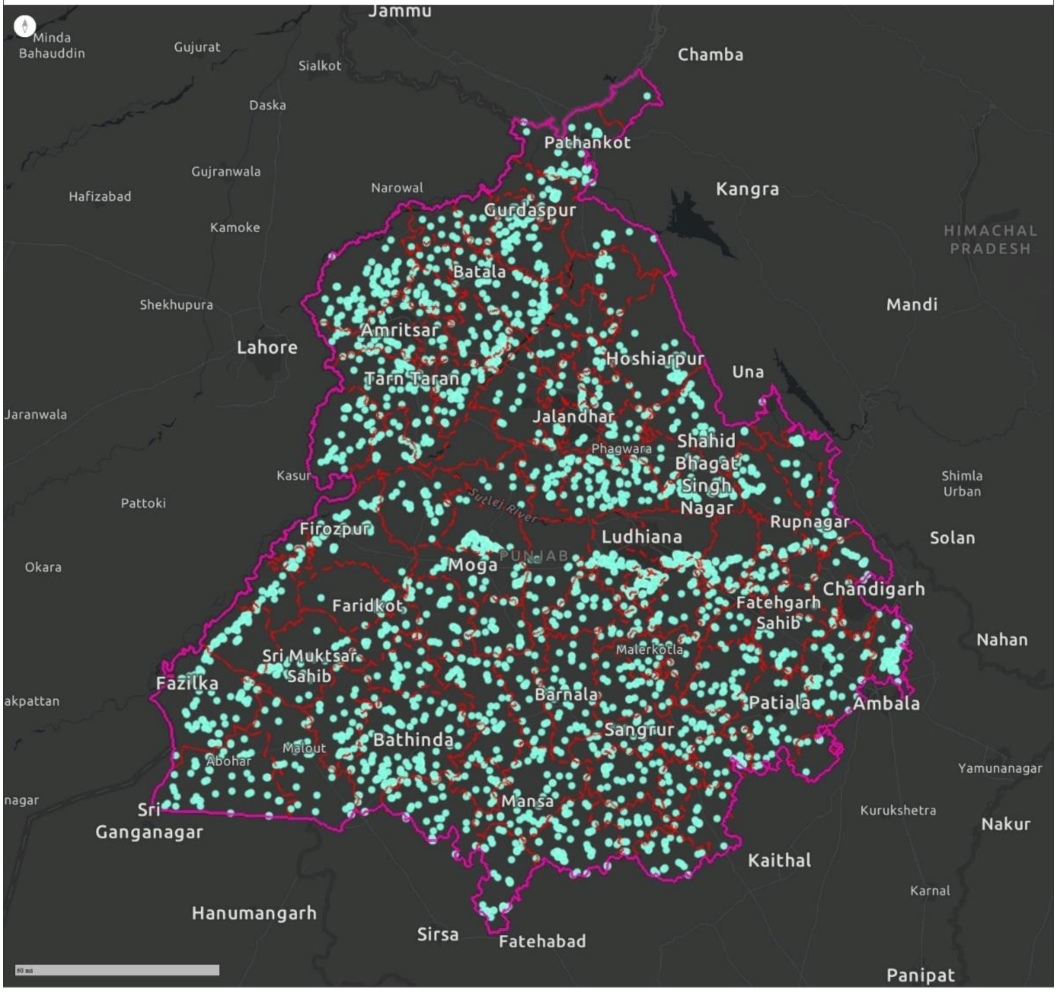
discusses how data was collected from these sources and adapted to visual layers for analysis in the GIS program.
The thesis covers location point layers extracted and the initial analysis of the kilns. Next the thesis discusses the inclusion of layers from the Esri living atlas to provide further geographical context and how the GIS program was tailored to produce summaries of district and sub-district kiln and liberation data. In figure 4.1 subdistrict regions are overlapped onto the state polygons of Punjab and Haryana.

Figure 4.1: Punjab and Haryana subdistricts polygon from State Population Projection 2023



As stated previously the thesis worked alongside researchers from the Rights Lab at the University of Nottingham. This gave the thesis access to the source data for the GeoAI platform and adapt this to the GIS program. A CSV of the brick kiln data for Punjab 2020 – 2023 and Haryana 2020 – 2023 were uploaded to the GIS program and geocoded to create point layers of kilns across the two states. In figure 4.2 below this is visualised with Punjab in blue and Haryana in green in figure 4.3.

Figure 4.2: Punjab brick kilns visualised 2020-23

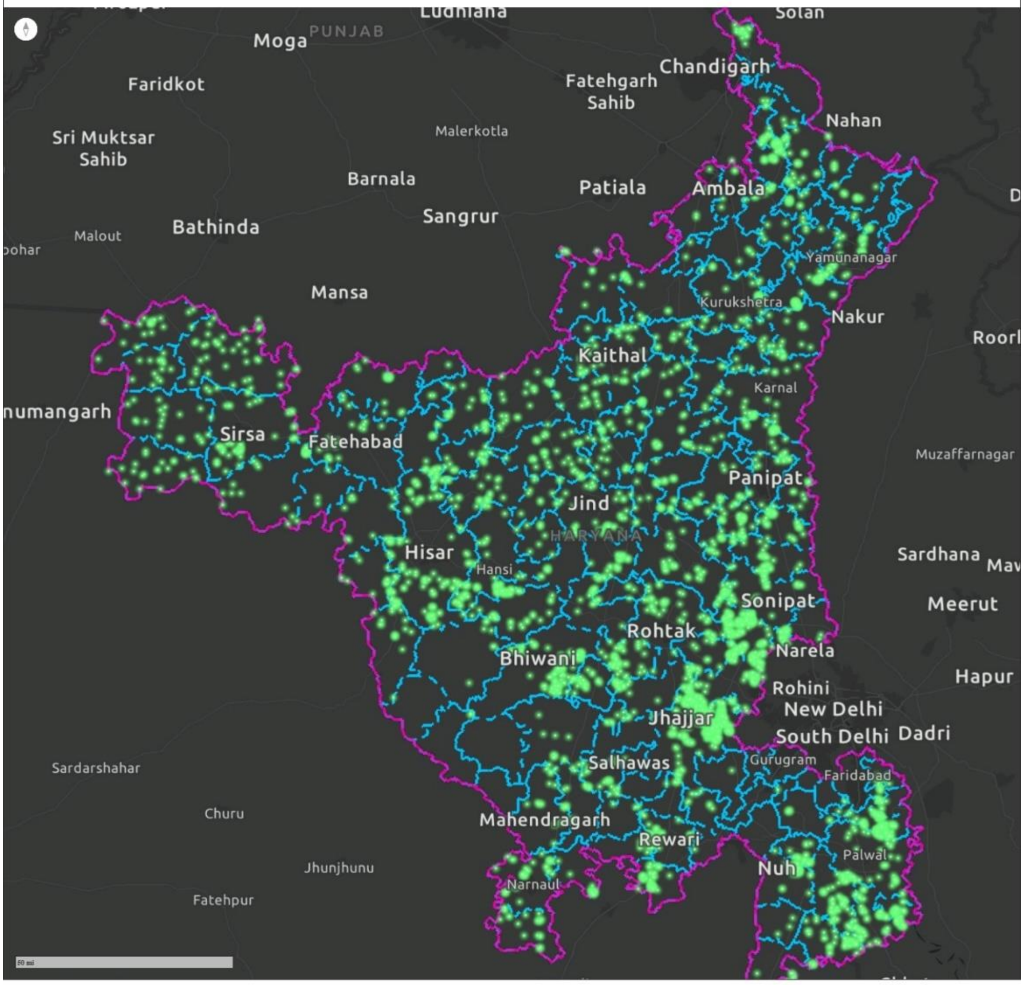


Targetl-State Population Projections for India 2011-2036 (Release 2023) - StatePopProjection2023

Pun-Sub-District Population Projections for India 2011-2036 (Release 2024)

Punjab Kilns Visualised 2020-23

Figure 4.3: Haryana brick kilns visualised 2020-23



Haryana kilns 2020-23

Targetl-State Population Projections for India 2011-2036 (Release 2023) - StatePopProjection2023

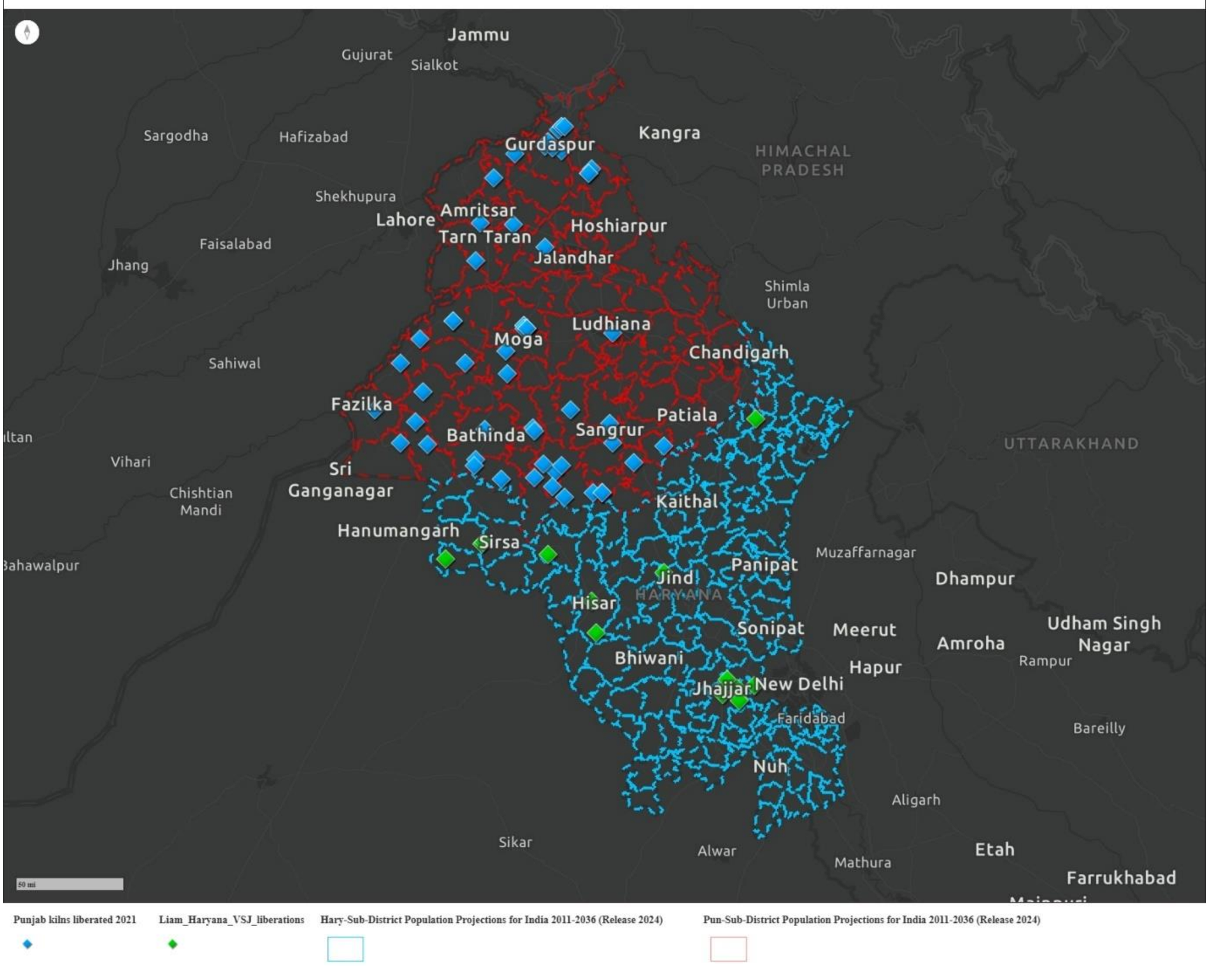
Hary-Sub-District Population Projections for India 2011-2036 (Release 2024)

The author has contributed to the design and maintenance of the GeoAI database since joining the rights lab in 2023 for this research thesis. Alongside the GeoAI data which consists of brick kiln data for Punjab 2020 -2023 and 2024 and Haryana 2020 and the thesis has collected demographic data for the two Indian regions of interest from the Esri living atlas GIS catalogue available at (https://livingatlas.esri.in/server/rest/services/State_Population_Projections2023/MapServer/0).

Documentation for brick kiln regulations was downloaded from the official government websites for Haryana, Punjab This data also included distance measurements from water sources, educational facilities, and roads. The thesis used these measurements to design a model that could track kiln regulation compliance from geospatial analysis of proximity between kilns and certain objects. These regulation scores could then be mapped to liberations and exploratory data analysis methods including descriptive statistics, inferential statistics and regression could be applied to the spatial data between the kiln locations and regulation score and the liberation data provided by VSJ. To the right is a visualisation of liberated kilns across the two Indian states

However, the output of these results would only show kilns characterised by state or district as the GeoAI database had only coded kilns into these spatial areas. Therefore, to provide further geospatial context and segment the areas of analysis into sub-district scale, spatial data was merged with the sub-district map of Indian states provided by Esri India from the ArcGIS Esri living atlas.

Figure 5.0: A map showing liberation points from the partner NGO for Punjab and Haryana



Land cover and land use data was also collected from Esri in the Living Atlas data collection. Land cover and land use help determine if kilns are within proximity of a town or city as this cannot be calculated with other methods like near table analysis and near analysis as producing a near analysis for a city or town would require multiple calculations between location points for towns and cities against the one location point for the brick kiln.
It was also possible to model polygons for each city and town in Haryana and Punjab but this approach seemed less efficient than manually checking proximity using buffer analysis and location points from the kilns.
The land cover land use map used was imaged at 10 metre spatial resolution by the sensor Sentinel 2. This imagery was produced by Impact Observatory and Esri. The Sentinel 2 imagery also includes a time series showing how land use and land cover have changed from 2017 – 2024. The thesis uses the most recent time series data to produce maps of kilns.

3.2.3 Spatial analysis

Using the GeoAI 2020 brick kiln database results the thesis reviewed and updated brick kiln locations and activity status. Once this was done and the activity status of each brick kiln was known a final set of 2733 brick kilns for Punjab were mapped onto a GIS program. This result is in line with the estimates from the Punjab pollution control board 2019 documentation. The researchers working on the GeoAI database had collected data on proximity measurements for roads and water bodies alongside information on the home district of the brick kiln and the type of brick kiln (Bull trench kiln or zigzag). This data helped to create a set of binary classifications for brick kilns to classify them as compliant or non-compliant on a range of regulatory factors. In the Punjab pollution control board documentation these factors are listed (Punjab pollution control board, 1998; 2019; 2023). 8 factors were originally identified for this study for Punjab however with the resources available the thesis was unable to model all 8 factors. A further dataset of 2024 Punjab kilns helps to compare the comparison between expected kiln closures based off regulatory compliance capture and the kilns that were shut down between 2020 – 2024.

Factor	Method for modelling	Comments	Utilisation status
Brick kiln to kiln proximity	The brick kilns in Punjab are required to be 1000 metres in proximity. This was possible to model using a mix of near table analysis (ArcGIS Pro, 2024) and buffer zones to manually check a sample of brick kilns. Using a random number generator, I selected 20% of the kilns to manually	Due to using a point layer for the coordinate of each brick kiln it is possible more kilns are failing this proximity regulation. However, the near table analysis is a strong generalisation of the proximity rule. The point layer also means an exact location for the kiln-to-	Factor 1 (0 – 1)

	assess to make sure the near table analysis had been performed properly.	kiln proximity is not stated and is instead a generalisation.	
Brick kiln to road proximity	From the GeoAI database I worked with another researcher to implement all major roads into the GIS map. After testing some different methods a generated near analysis for 100 metres was used with the same checking method as above.	The Punjab pollution control order and following documentation define main roads (Punjab pollution control board, 1998). This definition was used to decide what did and did not count towards this regulation. The regulation states kilns must be more than 100 meters away from a road.	Factor 2 (0 – 10)
Kiln type	GeoAI initially captured bull trench and zigzag kilns. These were reviewed by using the coordinate latitude and longitude data in Google Earth Engine (GEE).	The Punjab pollution control order and other stake holders have been pushing the adoption of zigzag setting brick kilns. New kilns must be zigzag, and old kilns need to adapt to this technology. The date however for this transition deadline keeps getting pushed back. Kiln type was captured initially by the GeoAI platform and then updated through GEE manual image interpretation	Factor 3 (0 – 100)
Kiln to city proximity	Using the location points from the GeoAI data and updated Punjab 2023 shapefiles created by a researcher at the Rights Lab the thesis mapped kiln coordinates against a land cover land use record by Esri which was remote sensed using the Sentinel 2 sensor. The 1000 metre	While India has plenty of cities and towns India also has other urban classifications that did not fit into this model. For the sake of accuracy this model only accepts areas which the GIS or google recognised as cities for the proximity analysis. Consequently it is possible a wider number of kilns break	Factor 4 (0 – 1000)

	proximity regulation was then manually interpreted for all 2733 kilns as automated methods were not possible due to permission settings on the layer. A 1000 metre buffer was combined with the navigation basemap and sentinel 2 imagery to help identify built up cities.	this regulation than the thesis model suggests.	
Kiln to town proximity	A similar method to kiln to city proximity was deployed here with manual interpretation between buffer distances and the Sentinel 2 imagery. Towns were harder to identify than cities.	Like kiln to city proximity India uses other urban classifications. These were not included in the analysis.	Factor 5 (0 – 10000)
Kiln to Garden	NA	According to the Punjab Pollution Control order documentation brick kilns must be 100 metres from garden nurseries. However, with the resources available for this research and the time constraints this factor was not considered in the regulation model.	Not used
Kiln to mango	An initial method for mapping mango areas was considered using open-source data but the data was not compatible with the GIS application.	No comments	Not used

The five-factor liberation model In Punjab used kiln to kiln overlap, kiln to road overlap, kiln type, kiln to city and kiln to town proximity to provide 5 regulatory factors on which kilns could be classified against. Results of this analysis were then grouped by regulatory codes and districts in Punjab. The codes worked in a binary sequence from 0 (designated for a kiln that follows all 5 regulations) to 11111 (designated for a kiln that breaks all regulations). These kilns were then colour coded to differentiate them in the spatial visualisation and data labelled for ease of understanding.
The Haryana model used the same 5 factors, but the regulation includes different

measurements (Haryana Government Food and Supplies Department, 1972). The Haryana model captures 3102 kilns. Kiln overlap with cities is calculated at 1500 meters rather than 1000 and town overlap is 800 metres rather than 500 as in Punjab. The 1500 meters was decided due to Haryana splitting cities between class A – C because the thesis method cannot identify the class of city for each city within the scope of this project the measurement of 1500 meters is taken from the max distance of 3000 meters and the minimum distance of 800 meters.

Near and near table analysis

Regulation factors 1,2 and 3 could be modelled by combing the data for the GeoAI database and near analysis. Near analysis provides a calculation of distance between two points. The location point data from each kiln was uploaded into a near table which provides data on feature points within a specified distance of the target location point. For regulation factor 1 which tracks kiln overlap the thesis used near analysis to calculate distances between kilns and then checked a sample of 10% of the results by checking buffer layers against kiln locations. The measurement for the buffer and the near analysis were 1000 metres as specified in the Punjab regulation (Punjab Pollution Control Board, 1989) and Haryana regulation (Haryana Government Food and Supplies Department, 1972).
The 10% sample provided an expected 100% accuracy but checking the results of the model is a useful step to ensure the model is fit for purpose. By checking a sample of results manually the thesis draws a balance between ensuring accurate data and time efficiency.

Buffer analysis

Buffer analysis was used both to check the near table analysis and to infer town and city regulation compliance. The land use land cover Sentinel 2 map by Impact Observatory and Esri provides a visualisation of built-up areas, but these are not classified between villages, towns, and cities. Instead, the thesis calculated buffer layers to manually assess the proximity between kilns and towns and cities. The basemaps in ArcGIS provide context on towns and cities and if the location was uncertain the local place name was searched on google to check for town and city classification.
Town and city proximity were determined by the Pubjab and Haryana regulation documentation with slight changes between the states. In the Punjab documentation city to kiln proximity must be more than 1000 metres and town to kiln proximity must be 500 metres. This 500-metre regulation was adjusted from the original 750 metres in a 1999 amendment (Punjab Pollution Control Board, 1989). For Haryana regulation proximity is dependent on the type of city, this was not within scope of the project to account for. The thesis already knew the manual interpretation of buffer layers to Sentinel 2 imagery would be a significant time cost and the thesis did not have access to data showing the different classifications of cities.
Instead, the thesis generalised all city proximities at 1500 metres which is half of the 3000-metre proximity for the class A cities, 500 metres less than class B cities and 200 metres more than class C cities suggesting a fair generalisation between the three classes.
Town regulation in Haryana is a consistent 800 metres.

Aging analysis

The database from Li et al (2019) study provided the thesis with contextual information on when kilns were established. This is important as the date kilns were established determines how likely it is the kiln needs to follow regulations. This is because the regulation documents state that for certain proximity regulations kilns established before regulations were published can receive no objection status. Similarly to kiln license the thesis had not found a

data source showing kilns that have a no objection status. As such the assumption is kilns established before 1998 can be considered void from regulation rules. This assumption will likely have a small impact on the regulation analysis as one of the main findings in Li et al (2019) is that brick kiln production before 1998 was severely limited and many of the brick kilns were established from 2009 and later.
The aging analysis can also be used to determine how kilns grew within certain districts and sub-districts. Analysis of districts will be provided by the thesis using a random number generator to randomly sample brick kilns.

Liberation mapping

The liberation data was mapped to a location point layer allowing for a visualisation of where liberations have occurred. The liberation data was then added to the zone look up application which allowed the user to click sub-district polygons and receive a summary of layer outputs. The practical value of this is it allows researchers to quickly review different data about the brick kilns that has been collected across the last few years.
Liberation was then charted against different regulation outputs of brick kilns to find patterns and trends within the data. The liberation data also contained the year a liberation took place, and this was used by the thesis to track the development of liberations across time for different Indian districts of Punjab and Haryana.

Clean kilns mapping

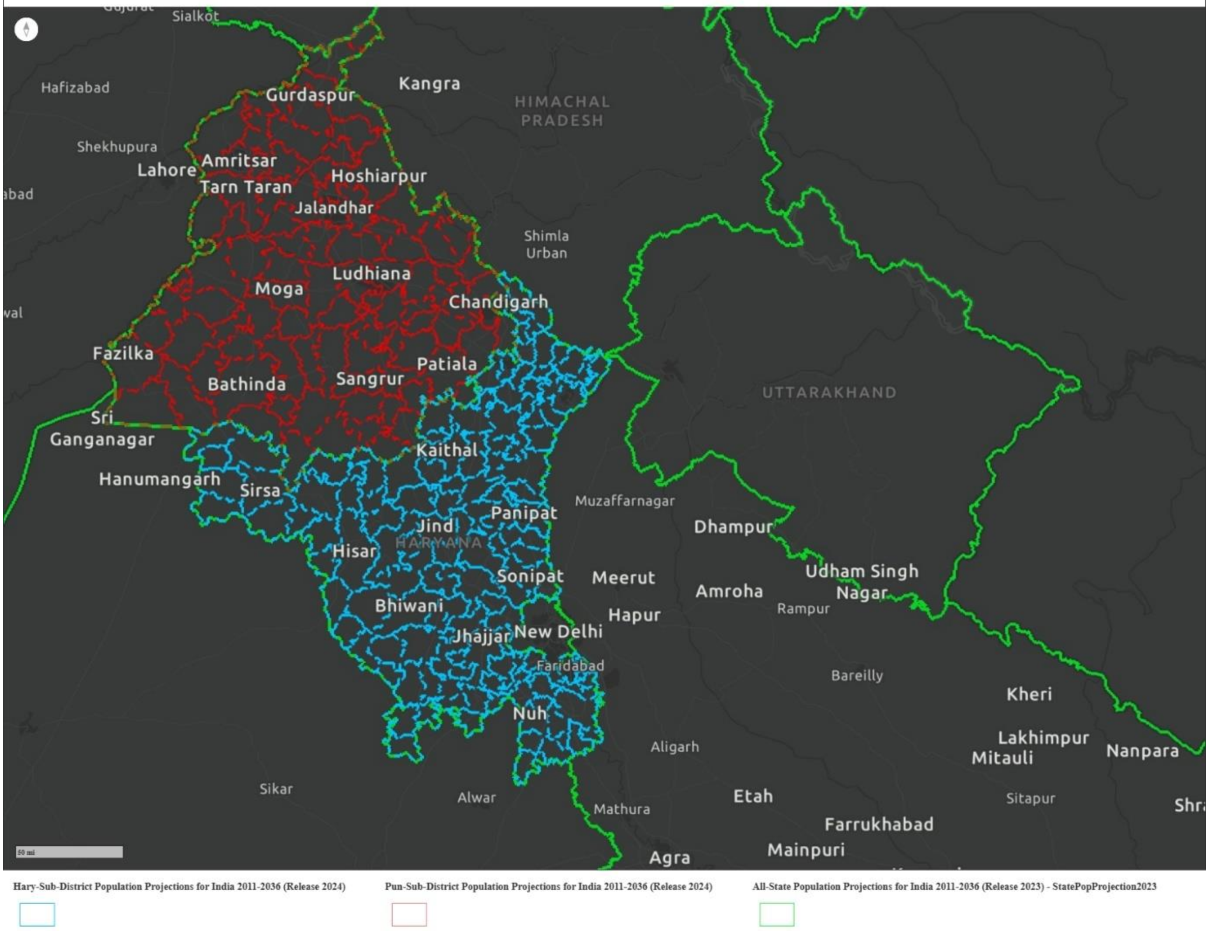
Filtering the regulation score value on the brick kilns for Punjab and Haryana states to 0 provided a visualisation of all the kilns that have passed all 5 regulation tests within the model. This produced an output of 424 brick kilns for Punjab 2020-23, 399 clean brick kilns for Punjab 2024 and 687 for Haryana 2020. Clean kilns were spatially correlated to liberation hot spots suggesting these kilns have not been liberated because there are no rumours of MSHT. However, due to a lack of true negative value this cannot be confirmed. Furthermore, it is also plausible our partner NGO are only gaining access to kilns that are non-regulatory compliant suggesting this significant lack of clean kilns in liberation reports.

Visualising geographical context layers

Alongside the brick kiln regulation model, the visualisation was designed to clearly communicate the geographical context of India and the different states. To achieve this the thesis used land cover and land use maps with district, sub-district polygon layers and true colour satellite imagery basemaps. The thesis method also used a vector polygon map from Esri India (last updated 7/19/2023) which included population statistics and projects from 2011 – 2035. This layer was then duplicated and filtered to show the Indian states of interest to this research project. For further geographical context district and sub-district layers were created to provide a spatial visualisation of the different areas of the Indian states. These 2 layers were colour coded to make them distinctive from each other and the total set of Indian states.

When the Punjab and Haryana brick kiln regulation data was visualised on top of this background geospatial data the author formatted the GIS online map into a zone look up application. This allowed the author to explore the data in more depth by clicking each sub-district of Punjab and seeing a summary of geospatial data. This data could then be explored and analysed.
The zone look up application used sub-district polygons as panels to group information facilitating analysis. Due to the zone look up layer requiring one layer for the polygon of focus zone look up applications were developed separately for Punjab and Haryana.

Figure 7.0: A map showing Indian state boundaries with district polygons for Punjab and Haryana



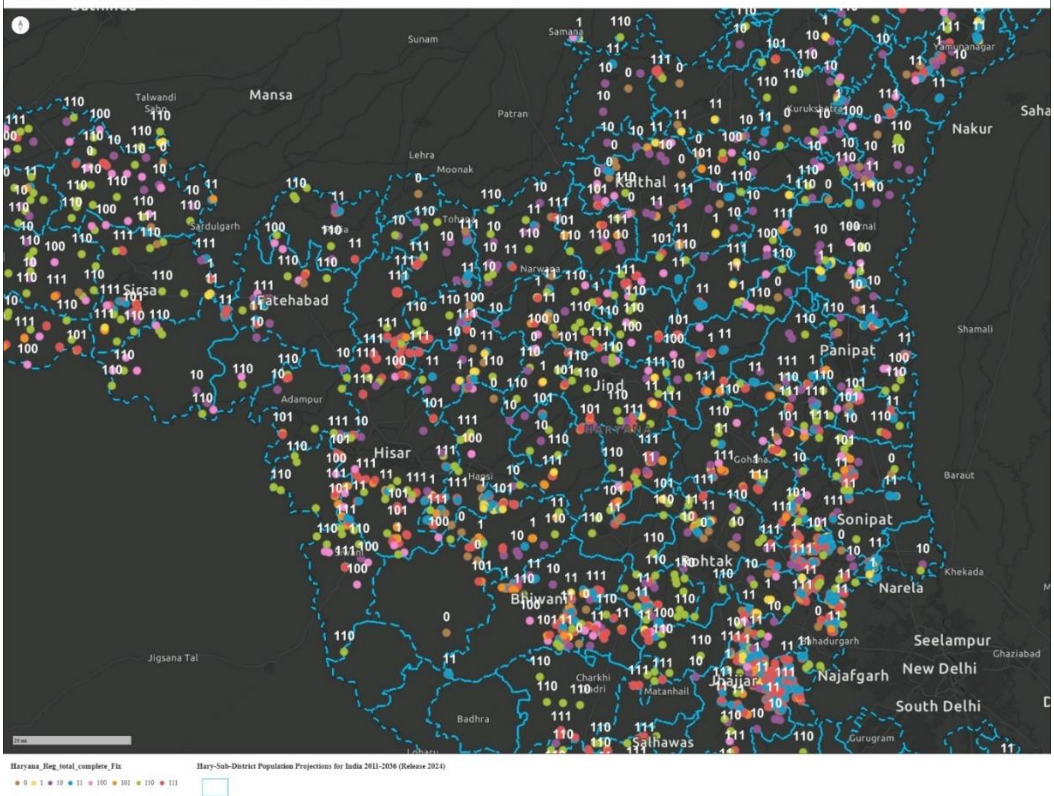
The NGO working with the University of Nottingham described the ability to consistently monitor the brick kilns as a new form of enforcement. An enforcement asset that can successfully monitor and provide more authoritative data to combat the illicit activities occurring within the brick belt. Therefore, from a cost benefit analysis remote sensing provides an effective tool for this research. Researchers must be careful when producing knowledge to take mitigations against the knowledge being weaponised. To improve surveillance for the global south could be interpreted from a neo-colonial or securitisation approach and mitigations must be put in place against this.

The concerns over ethical considerations of remote sensing are addressed by Walker (2020;2021;2022) these concerns need to be balanced against the value of

this resource and grounded in the day-to-day operations of remote sensing for human rights research as well as ethical theory.
the brick kilns exist in spaces that are still not consistently well documented, many of the features that influence brick kilns and can be used to extract useful knowledge are not contained within the authoritative data of these countries. This gap in knowledge can be addressed by satellite technology via remote sensing. Furthermore, while issues of surveillance are crucial the proposed study intentionally limits the spatial resolution of the platform to make individual identification significantly difficult.

Figure 7.1: A map showing Punjab kilns visualised by regulation score

Figure 7.2: A map showing Haryana kilns visualised by regulation score



3.2.4 Exploratory data analysis

Initially the thesis method intended to use these spatial analysis layers to produce statistical tests between liberation data and regulation compliance. The Liberation data takes a location of a kiln, demographics of liberated persons and date of liberation. The regulation compliance elements track for 5 regulation factors for both Punjab and Haryana. However, a lack of liberation quantity and quality of data made it difficult for the author to produce any reliable correlation or linear regression analysis. The author suggests this lack of strong correlation is likely due to no data for kilns that do not use modern slavery. Therefore, this lack of true negative result skews the data and makes correlation impractical.

The thesis is adapted therefore to produce exploratory data analysis for liberation and regulation scores. Exploratory data analysis has been used previously in spatial analysis of human trafficking (Gupta and Sharma, 2023). This method uses descriptive statistics, visualisation, and comparative statistics to gain intelligence on MSHT practises in the brick kilns.

The thesis uses the visualisations of liberation data, regulation scores and dates of when the kilns were established to produce an analysis of development of brick kilns across recent years. While the lack of correlation to liberation results makes regression impractical the difference in the number of persons reported as liberated from the kilns across time and regulation scores

Figure 8.0: A map showing Punjab kilns with regulation score = 0 suggesting a kiln is clean

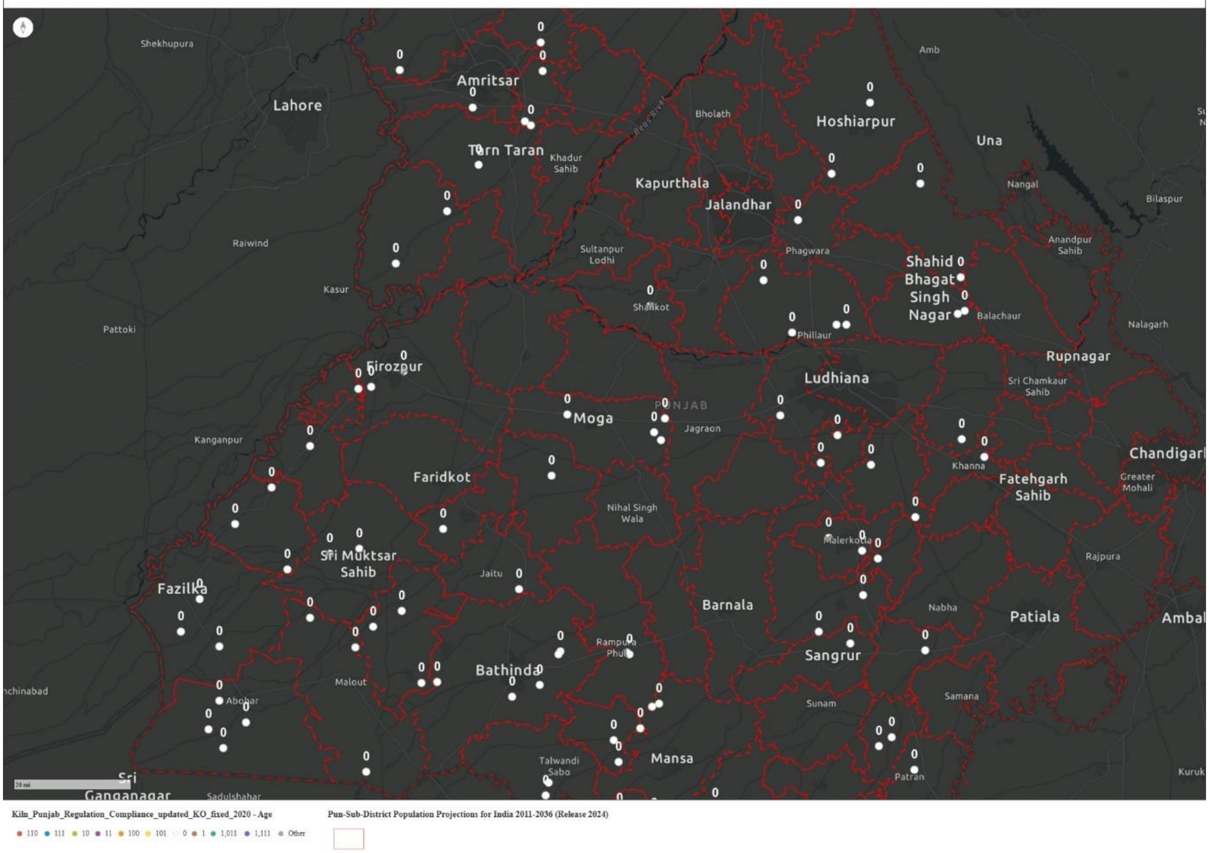
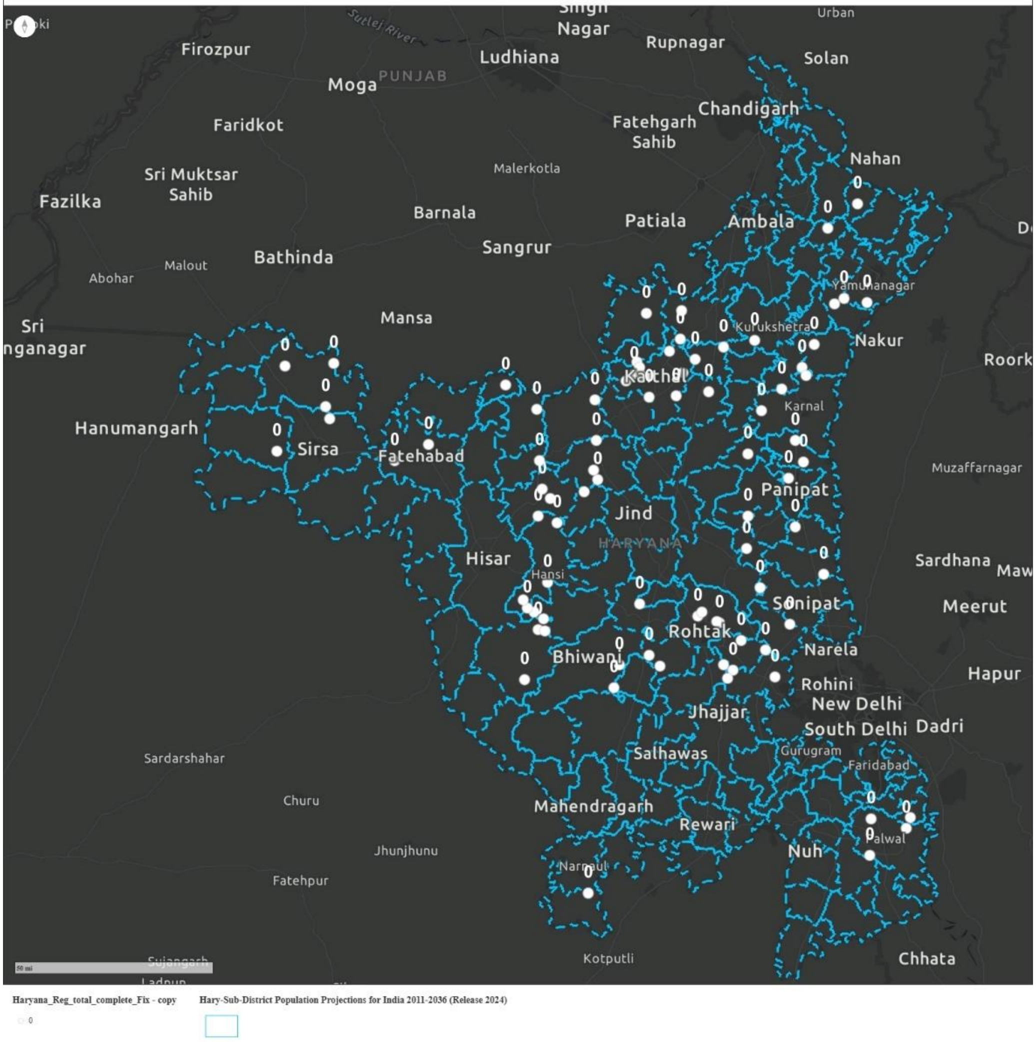


Figure 8.1: A map showing Haryana kilns with a regulation score = 0 suggesting a kiln is clean



3.3 Findings and statistical tests

Figures 8.0 and 8.1 show kilns that have passed all five of the regulation factors. 424 kilns in the Punjab 2020 – 23 and 399 in the 2024 data are classified as clean with an additional 688 kilns classified as clean in the Haryana 2020 – 23 data. The first finding from this model is for the data sets from 2020 – 23 few kilns pass all 5 regulation factors. The author has not been able to map all regulation factors suggesting that regulatory compliance may be even lower than estimated in this thesis. The data from this model suggests 15.5% of Punjab kilns in 2020 – 2023 are regulatory clean with this improving to 19.2% In 2024. Haryana returns a result of 22% of kilns as clean for a three-regulation factor analysis. Analysis was limited due to lack of efficient classification of city and town areas.

The spatial pattern between clean kilns and liberation records could suggest a lack of access to certain districts within Punjab as we see certain districts are entirely untouched by liberation efforts. It is also possible that the spatial correlation between liberation and clean kilns within the west of the maps shows that clean kilns are not being audited either due to a lack of access by the NGO or because they are not associated with allegations of MSHT practise. The figures below show liberation hot spots again but compared against Punjab brick kilns that are non-compliant.

Below is the summarise layer for non-compliant kilns in the Punjab 2020-23 dataset. Here darker colours indicate more non-compliant kilns for that area and lighter areas

indicate less non-compliant kilns. It is plausible with more liberation data and the introduction of a clear true negative result this choropleth map could show trends between liberations and regulation compliance of kilns.
The author notes that there does seem to be a spatial correlation between number of clean kilns and total liberations reported within a sub-district.

The visualisations below start to show a trend. When accounting for the highest population of clean kilns with sub-district polygons there is a link between low numbers of liberation and high numbers of clean kilns. The author does not accept that this spatial correlation can be explained by lack of access to a district as figure 9A and 9B show many liberations occur within neighbouring sub-districts of the same district. It should be noted that polygons in Mansa and Sangrur present challenges to this trend as they are visualised on the clean kiln population map but also have been subject to high ratings for total liberations and mean average liberations. Gurdaspur also provides a potential challenge to this explanation of the data as it shares a high number of clean kilns and liberations. These sub-districts are analysed below with liberation reports and regulation score factors included. This sample will be expanded in the findings chapter later in the thesis.

Figure 9.0: A spatial analysis showing a summary of non-complaint Punjab kils for layer “Punjab kilns 2020-23

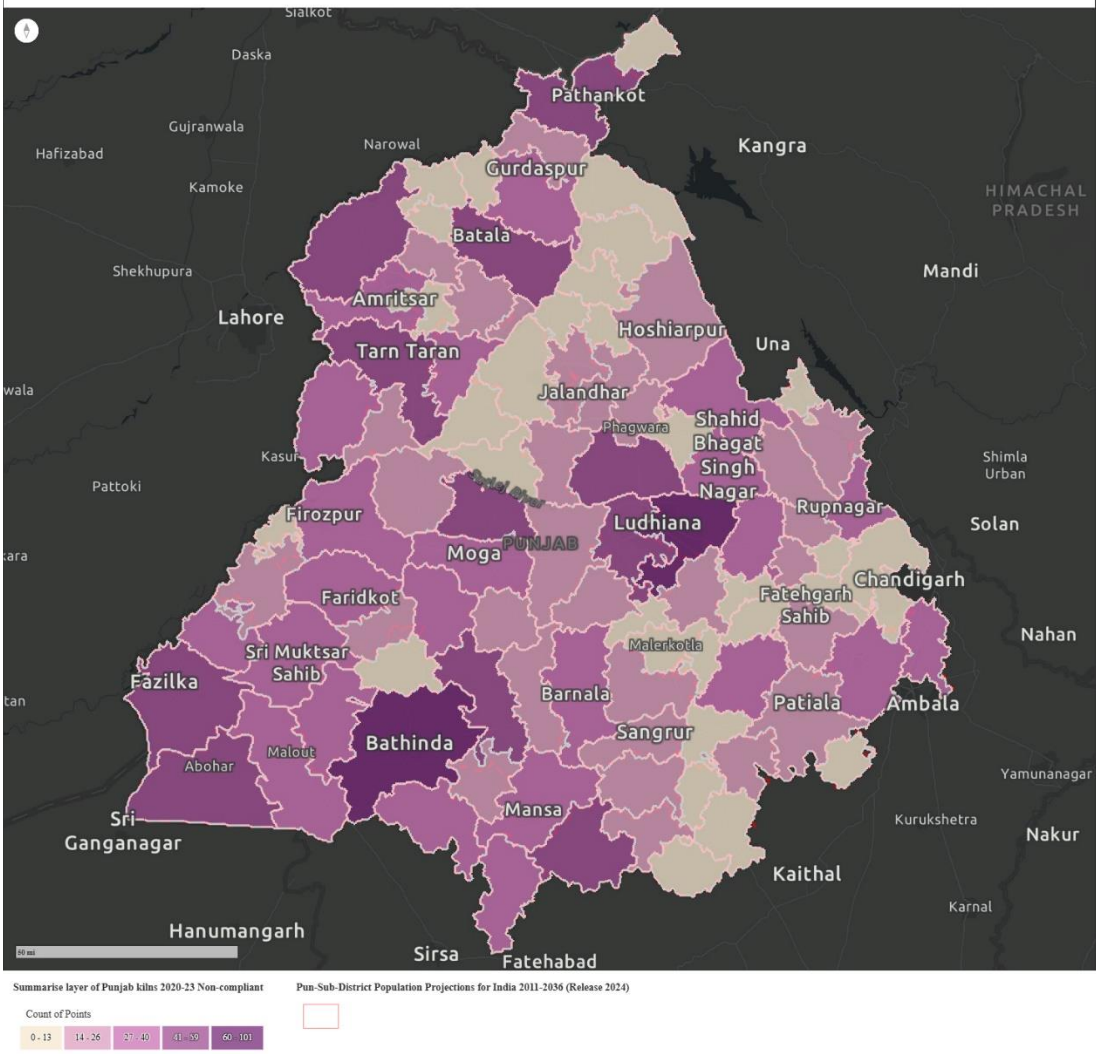


Figure 9.1: A spatial analysis showing mean average number of total liberations for Punjab kilns aggregated by sub-district

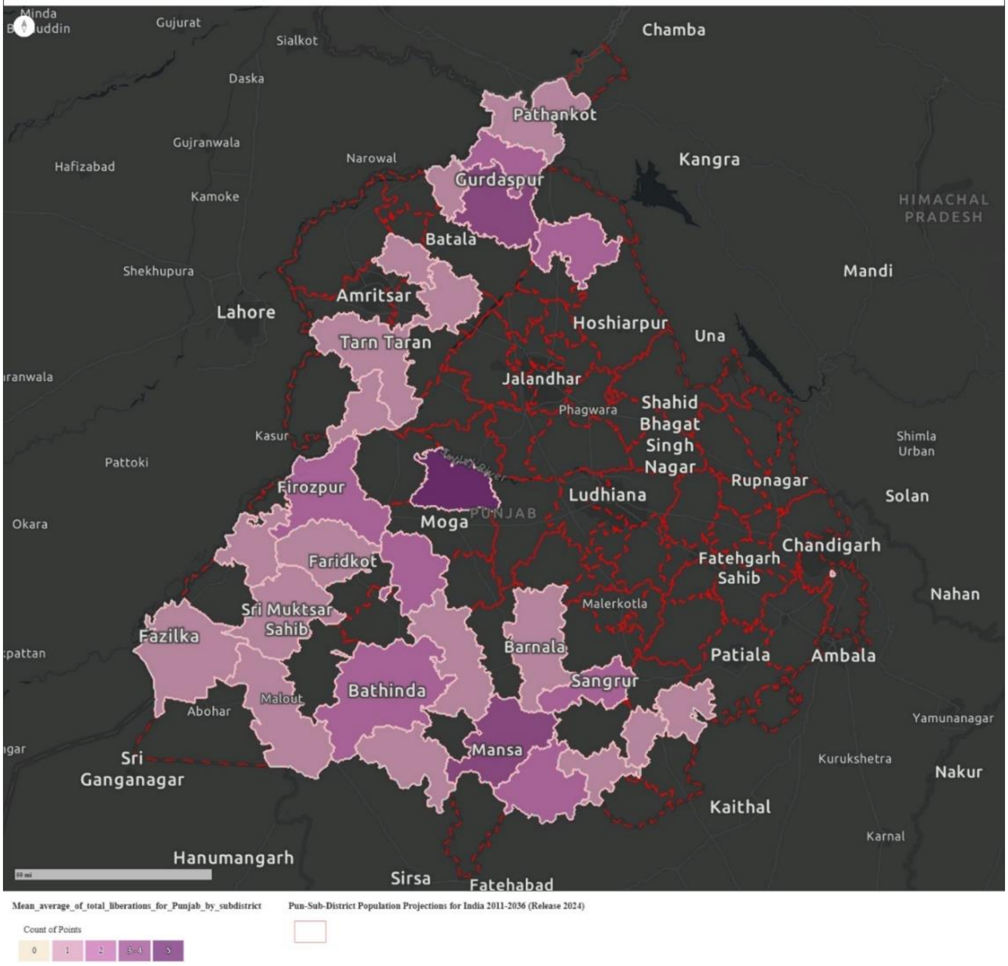
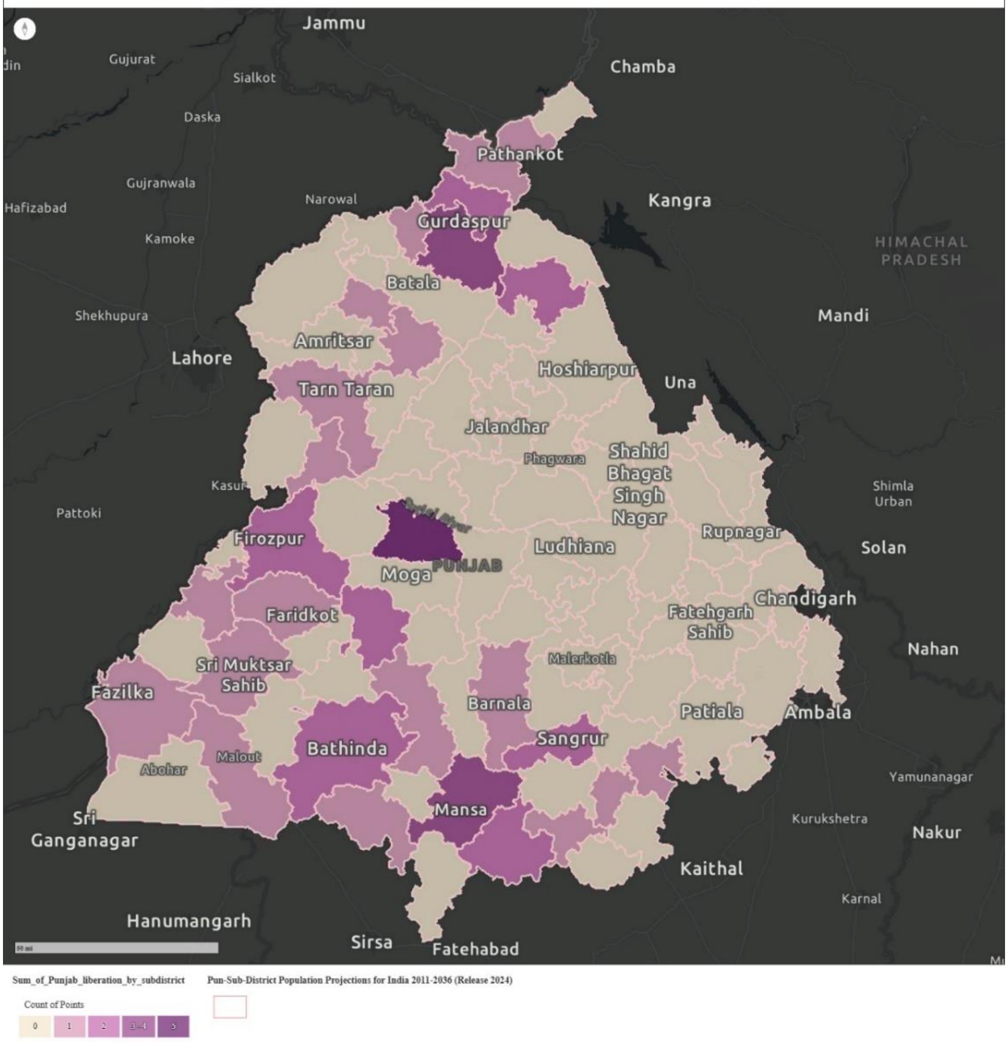


Figure 9.2: A spatial analysis showing the sum of total liberations in Punjab by subdistrict



However, this connection between liberation and kiln regulation compliance is limited by the data on liberations is not sufficient both in quantity of reports with only 44 for Punjab and 15 for Haryana and quality of documentation to draw insights into modern slavery prevalence. Kilns are only liberated once the NGO receives word from a bonded labourer or resident of modern slavery practises within the brick kilns. Therefore, with the current practises the author cannot know if a kiln that has not been liberated uses or does not use modern slavery. Furthermore, the liberation data does not indicate if a kiln has been visited without modern slavery practises being observed. All liberation reports show modern slavery practises within the kilns.
This means this method must balance the view from the partner NGOs that all kilns contain some form of bonded labour and the Punjab and Haryana state perspective of few kilns using modern slavery. Despite this difference in perspective, it is still possible to assess the difference in regulation score and the number of bonded labourers found in each kiln.

Figure 9.3: A spatial analysis showing Punjab subdistricts with more than 9 clean kilns

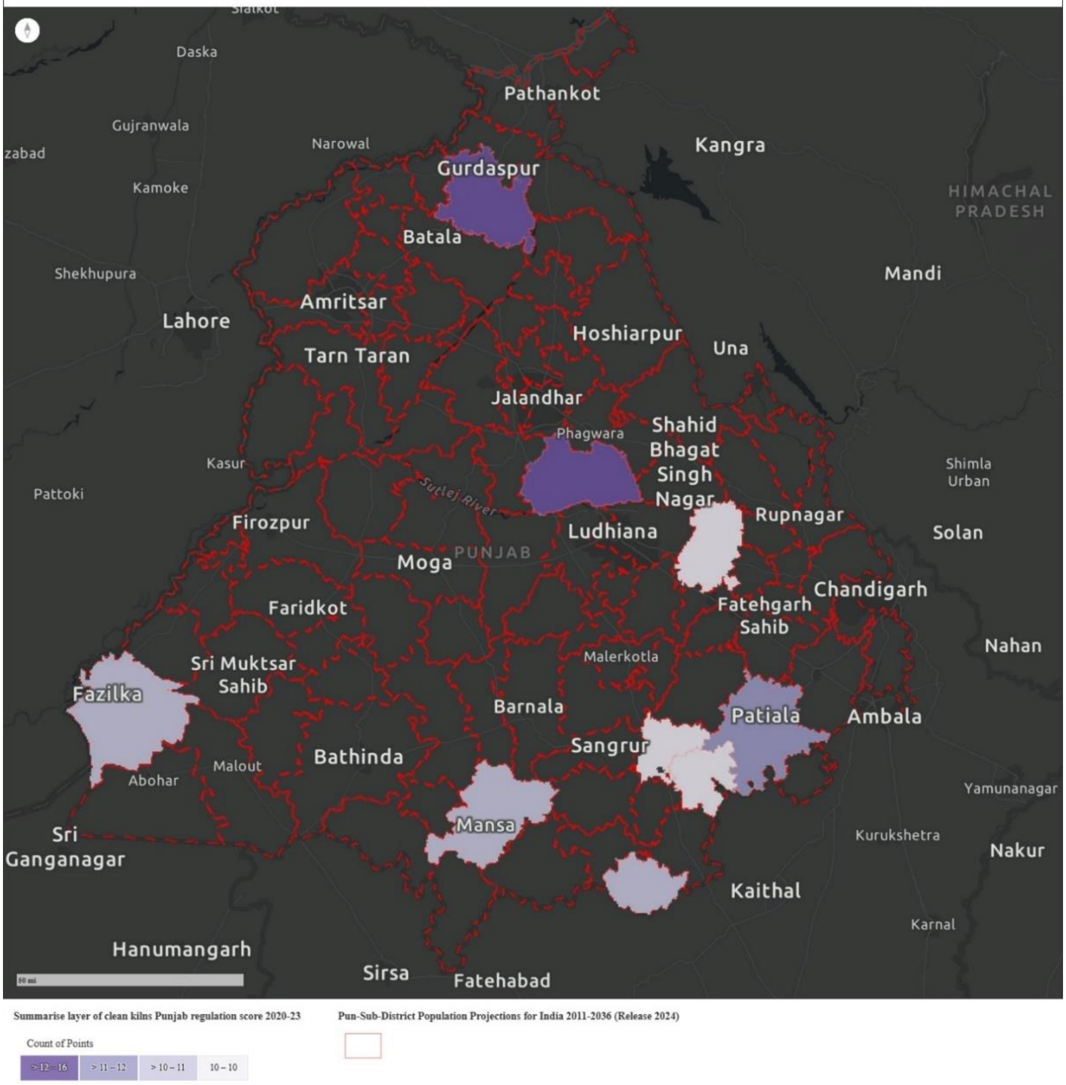


Figure 9.4: A spatial analysis showing Haryana subdistricts by sum total liberation

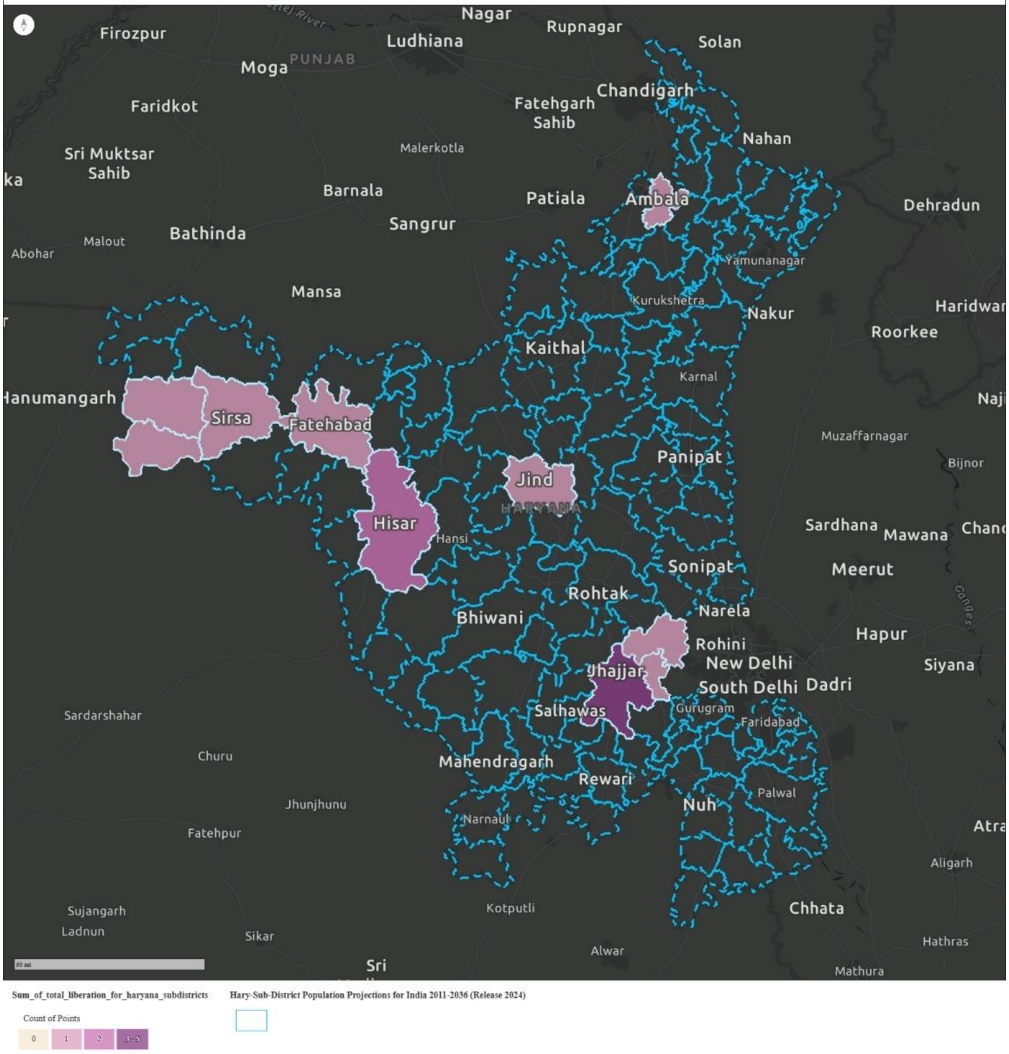
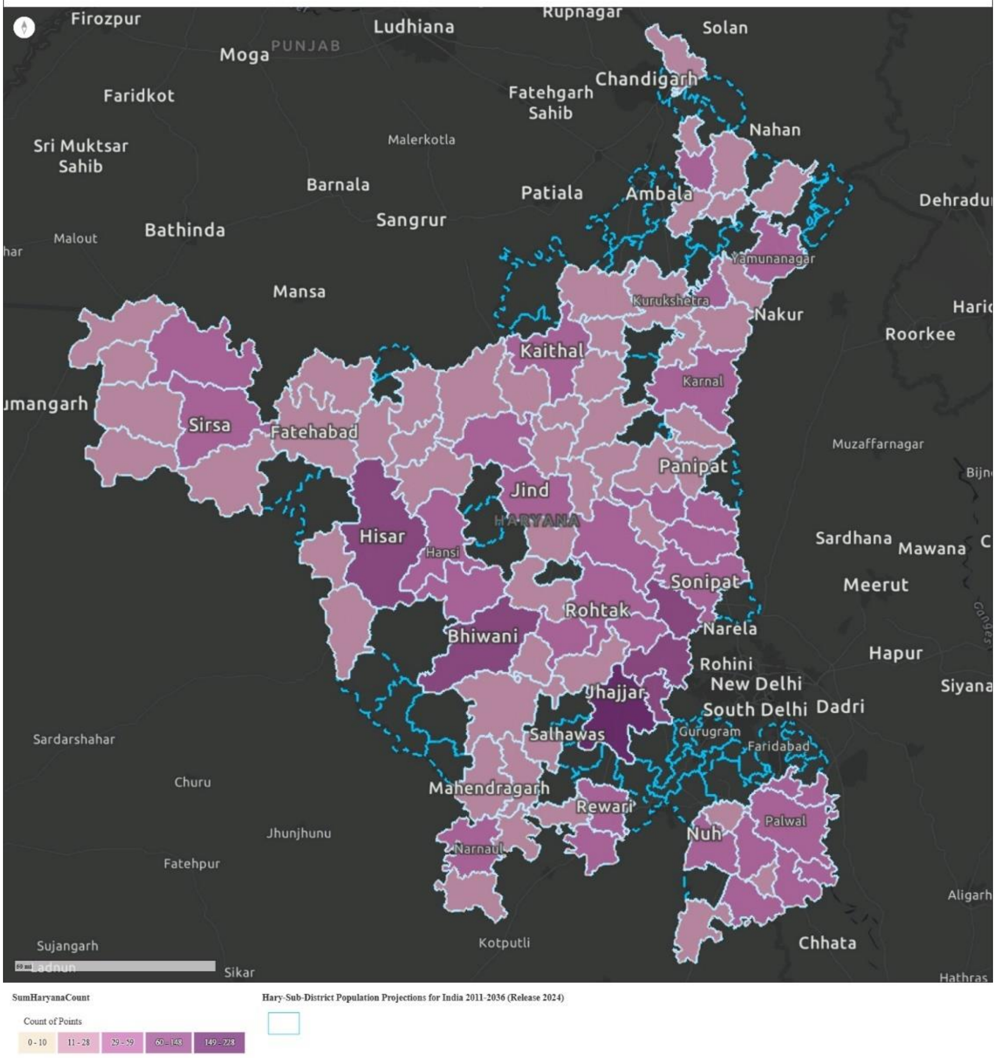


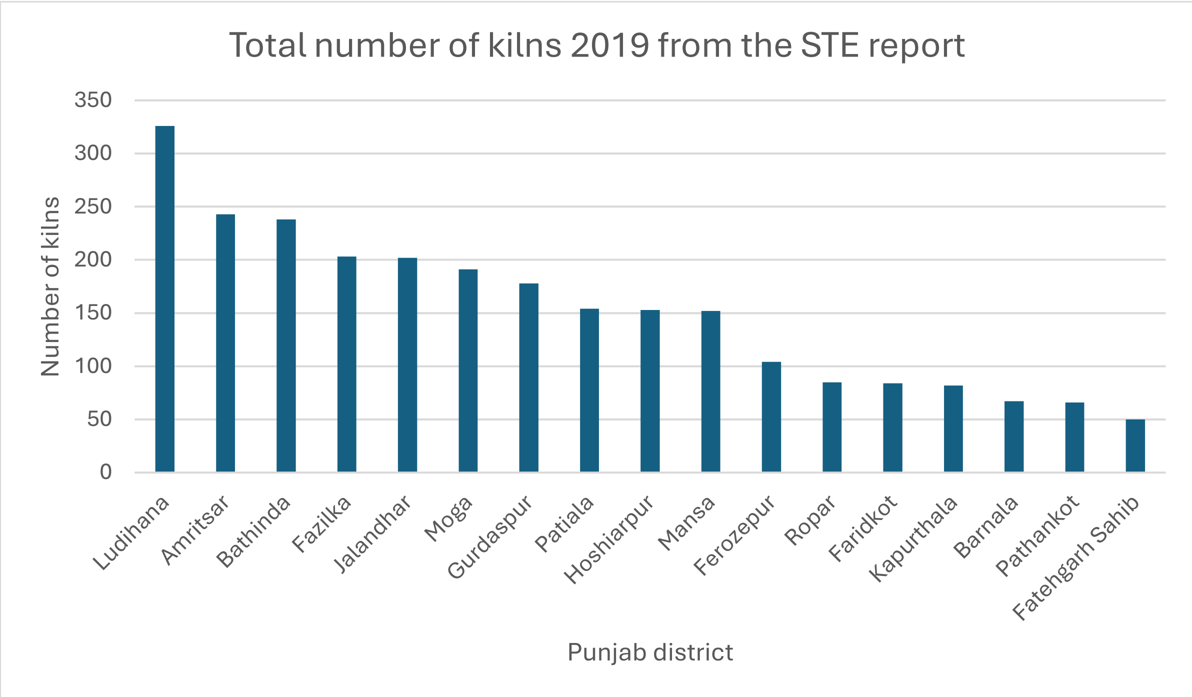
Figure 9.5: A spatial analysis showing Haryana subdistricts with more than 9 clean kilns



4.0 Punjab

4.1.1 Punjab 2020-23 and STE 2019 data

India is the second largest producer of bricks globally, the STE estimates more than 100,000 brick kilns are in India producing about 250 billion bricks annually (STE,2019). The GeoAI platform detected 66,455 brick kiln structures across the brick belt with 69.7% (46,319 kilns) in India (Boyd et al, 2018;2021). The state of Punjab is among the leading brick producers in India producing 8% of the national brick supply at 15-20 billion bricks per annum (STE, 2019). Key clusters of brick kilns are found in the districts of Ludhiana, Moga, Ferozpur and Jalandhar. In 2019 the Government of Punjab's Department of Science Technology and the Environment (STE) published a tentative estimate of brick kilns by district in Punjab. This report estimated 2,800 brick kilns were operating in Punjab with the following kiln by district breakdown in figure 10. The STE segments Punjab into 17 districts covering 0.5 – 0.6 million workers.



As seen in figure 10 the STE brick kiln statistics closely match other data sources with Ludihana ranking 1st, Moga ranking 6th and Jalander ranking 5th by number of kilns in the 2019 report. There is a difference between the rank of Ferozepur in the STE report and the other two data sources and GeoAI data (GeoAI, 2020). After analysing the GeoAI data the author noted that in the STE Ferozepur is split into Fazilka and Ferozepur while in the GeoAI data and other sources these two areas are combined into Ferozepur. The GeoAI database uses the official district regions from the 2011. Using this database the author shows how Fazilka and Ferozepur are displayed in the GIS application, to make this data comparable where possible the author combines Indian states to reflect the districts used in the GeoAI database.

Figures 11.0 and 11.1 show the difference between the STE boundary of Fazilka and Ferozepur and the GeoAI boundary. This choice between how to define this area has significant impact on the data as in the STE report Fazilka contains 203 brick kilns and Ferozepur contains 104 brick kilns compared to Ferozepur in the GeoAI 2020 data before modification contains 238 kilns. Ferozpur (Firozpur)

Figure 11.0: A map showing the STE boundaries between Fazilka and Ferozepur

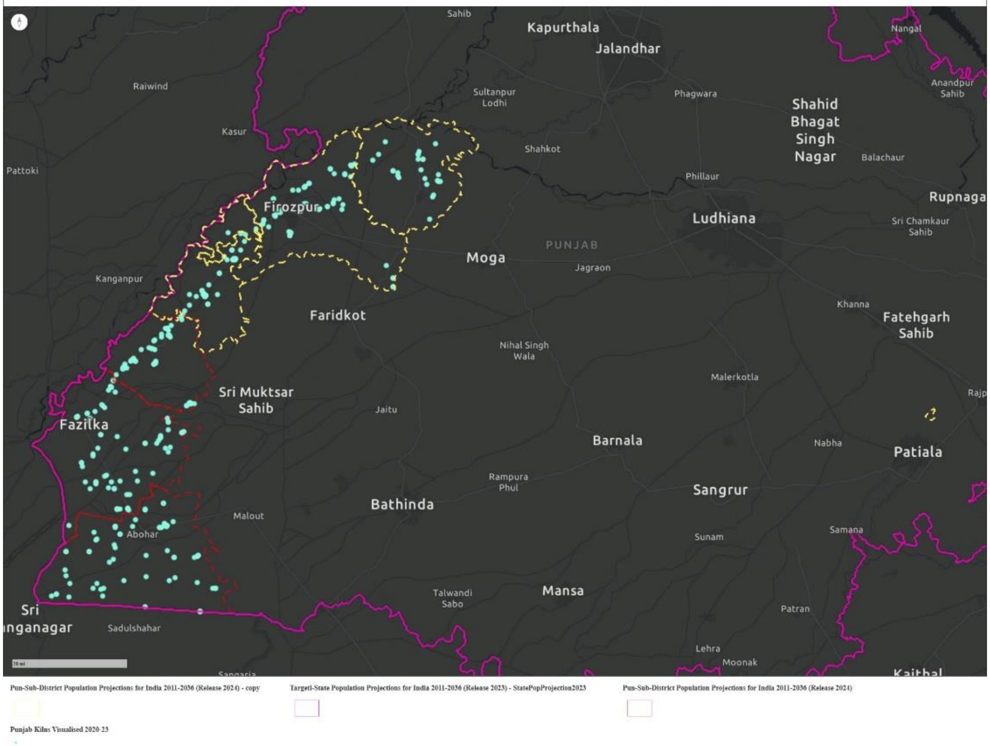
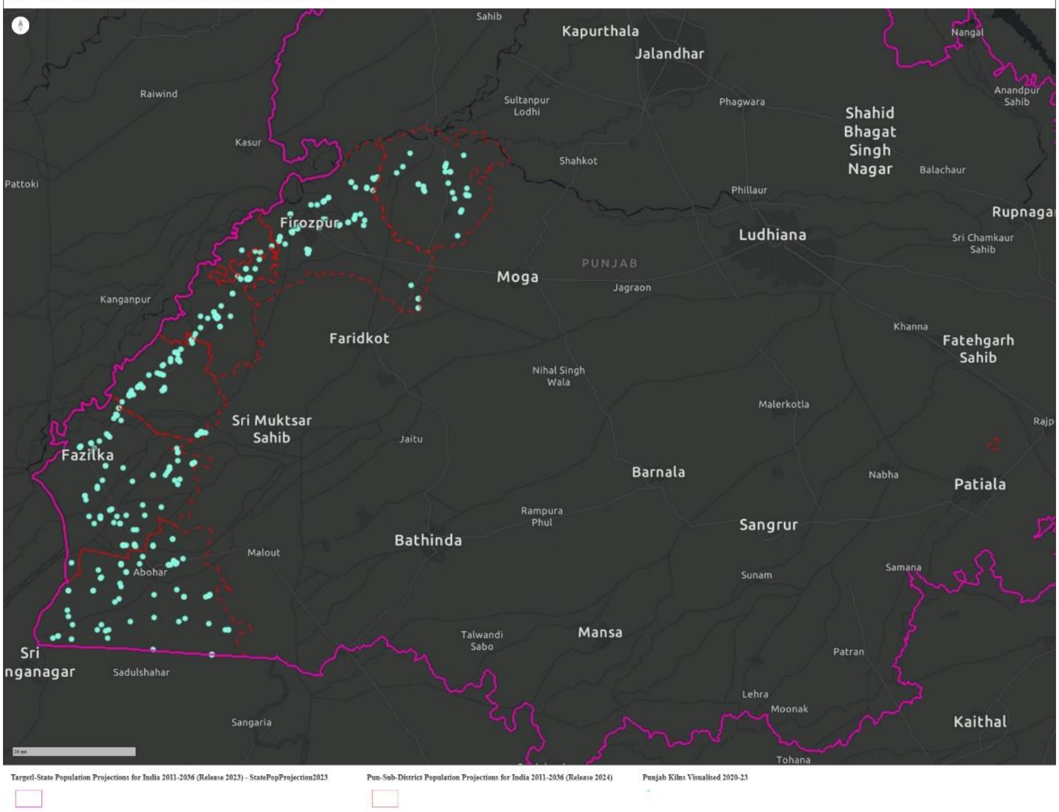
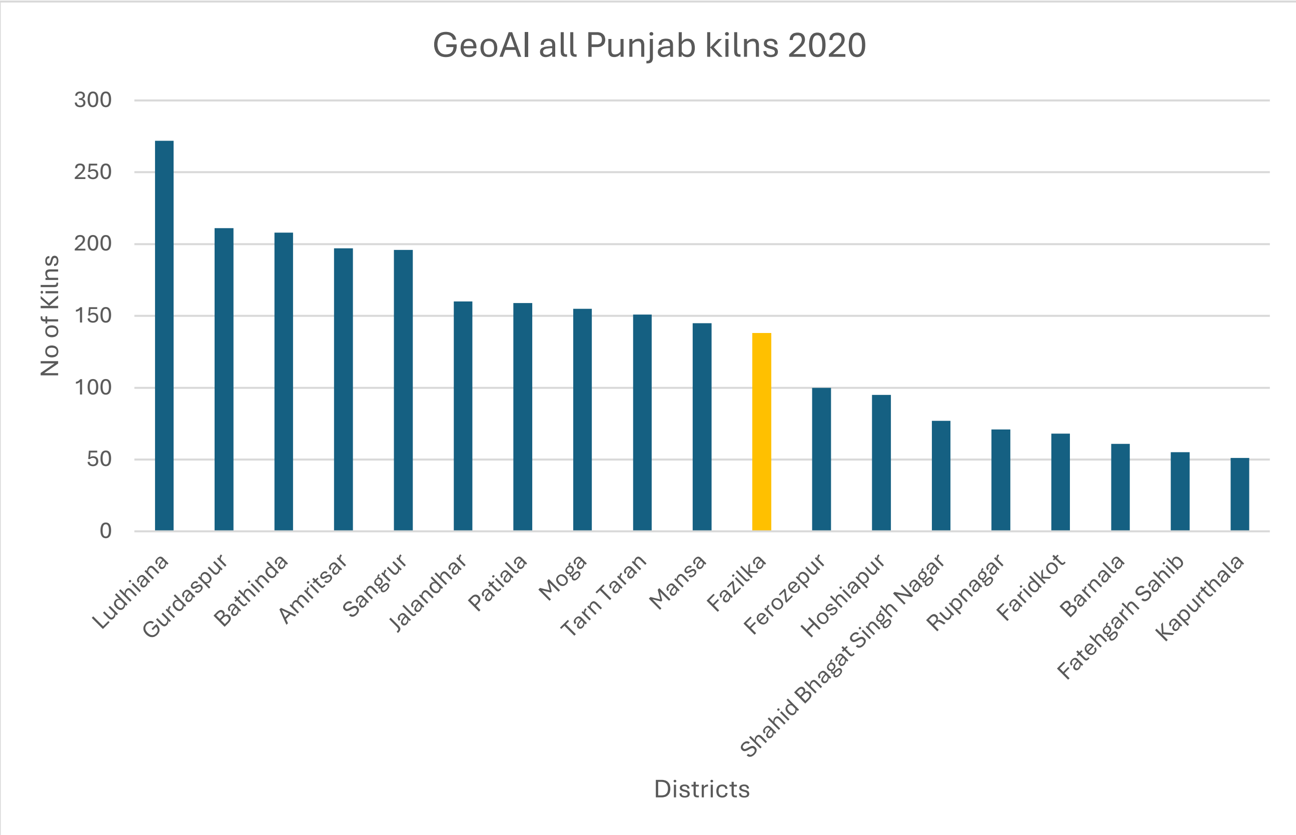


Figure 11.1: A map showing the join polygon of Ferozepur (Firozpur)

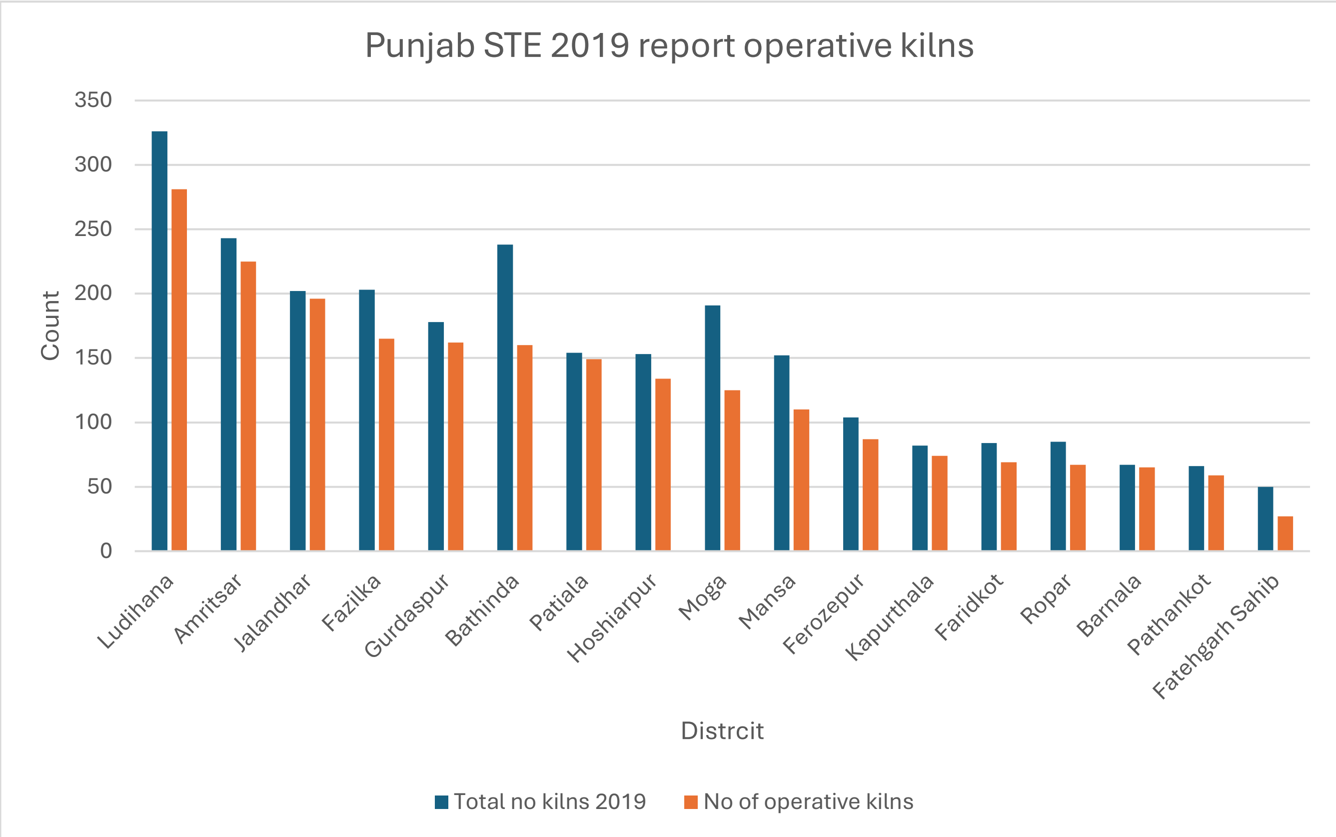


is the 2nd most brick kiln within one district in the GeoAI database compared to the STE report where it ranks 11th. Even accounting for the years between the reports this is a significant jump. The STE report claims after accounting for the 17 brick kilns closed by the government Ferozpur contained 87 brick kilns. Our research shows a count of 238 kilns. As seen in these figures below the STE report separates these two regions as two separate districts while the figure below shows how the GeoAI report combines these two regions into one district explaining the significant statistical difference between the STE result for Ferozepur and the GeoAI result.



Consequently, Fazilka is not found in the set of districts that brick kilns can be attributed to, the author has added the district to the map by segmenting the kilns across the region of Fazilka. Before this alteration, the GeoAI data portal ranked Ferozepur as the second highest kiln populated district with 238 kilns. When correcting for these differences across districts and superimposing the GeoAI district boundaries on the STE 2019 report results in the data between the STE 2019 report and the GeoAI brick kiln database sharing similar rankings.

The STE report also provided information on kilns they had shut down, but this data did not contain any spatial references to identify which kilns have been shut down except for the districts in which the closures occurred. However, alongside liberation data from the projects partner NGO's and the GeoAI 2024 Punjab database, the author has three sources of closures and liberation for brick kilns. It should be noted however a liberation at a kiln does not mean the kiln is now clean or fully shut down as kilns can go dormant and reappear or continue operating despite shut down orders (The Tribune, 2018). Furthermore, alongside brick kilns opening and closing unless officially shut down by the government of Punjab, as the STE report implies brick kilns can be shut down permanently with certainty (STE, 2019), liberated workers can also be pushed back into modern slavery and poor labour practises by desperation due to systemic issues within their social environment (Jackson et al, 2018). Consequently, the author stresses a difference between kilns that have experience liberation in our data and the concept of an entirely liberated brick kiln. Liberations are viewed as moments in time not absolute. When viewing the total number of operative kilns provided by the STE 2019 report (STE, 2019) which is calculated as total number of kilns minus kiln permanent closures, the district distribution of kilns changes.



Geo AI data analysis: Punjab 2020-23

According to our model the 5 districts with the highest number of brick kilns are Ludihana (272), Firozpur (238), Gurdaspur (211), Bathinda (208) and Amritsar (197). Totalling to 41.2% of all Punjabs brick kilns. Ludihana and Amritsar both have fewer kilns in the recent GeoAI database than in the STE report, but Bathinda has gained a significant number of kilns with a 30% increase at 208 brick kilns identified by the GeoAI platform. This data requires caution when compared one to one however due to some discrepancies in measurements discussed above. As Fazilka is not found in the GeoAI categories of districts for Punjab with brick kilns possibly merged with Firozpur as it was previously part of this district before being established as its own district in 2011.

This difference may also explain the 173.56% (rounded to 2 decimal places) change. Combining the STE estimates for Firozpur and Fazilka outputs 252 which would signify a decrease in the region for brick kiln activity. Noticing this the author went back through the GeoAI data and segmented brick kilns in Firozpur between the two regions. The district polygons loaded from Esri India used both Firozpur and Fazilka as polygons but in the GeoAI data only Firozpur was an option for the district variable. The author filtered the data.

down to the two district polygons and the Firozpur GeoAI brick kiln results. The author calculated 138 of the original Firozpur GeoAI brick kilns belonged in the Fazilka region helping explain the variance between the STE and GeoAI results. Using this new data Firozpur had a 14% brick kiln increase with 100 kilns.

Having noticed this data discrepancy, the author checked the 2019 STE report compared to the GeoAI database for other data changes before interpreting analysis. Three key trends were noticed concerning differences in data. First, the same area could have significantly different names and spellings across reports and grey literature echoing the issues Bromley (2009) had in Darfur concerning different names for the same location. For example, in the 2020 GeoAI data the district known as Ferozepur in the STE 2019 report is spelt Firozpur. This example is obvious but the difference between Rupnagar and Ropar is less clear. The author mitigated data interpretation mistakes between the 2019 and 2020 data sources by running filters for district polygons and brick kiln district attributes to see if the data matched sufficiently. Second, the GeoAI 2020 database uses district areas and names that do not appear in the STE 2019 report and cannot be accounted for by differences in spelling or name. These differences mean the author has conducted segmentations of the districts to best match across the databases.

As discussed above Firozpur (GeoAI, 2020) is an example of this as not only are the names for the district of Firozpur different between data sources but the GeoAI merges Firozpur and Fazilka while the STE 2019 report separates these districts. Third, connected to the district segmentation the STE 2019 report has Pathankot as a district of Punjab which does not appear in the GeoAI documentation. The author again checked the GeoAI data and found parts of Gurdaspur in the GeoAI district polygon layer are mappable to Pathankot. Alternatively, Tarn Taran and Sangrur are examples of districts which appear in the GeoAI data but do not feature in the STE 2019 report. Correcting for this difference was more difficult as the GeoAI database cannot map the 2019 STE report due to a lack of locational data. Instead, the following method was used to estimate kiln population for these areas in 2019 and mitigate the data discrepancy. Finally, Shahid-Bhagat-Singh-Nagar is featured in the GeoAI database but not present in the STE 2019 report, it is not a combination of two districts but three, making the method used for estimating quantities of kilns for Tarn Taran and Sangrur even less authoritative. Shahid-Bhagat-Singh-Nagar was made a district in 1995 from parts of Jalandhar and Hoshiapur districts. For the sake of consistency, the kiln quantity estimation method using percentage change and extrapolation is also applied to this discrepancy but should be viewed as less authoritative than both the 2 district estimations and the direct district conversions.

Step 1:
Combine kiln counts for both districts that are included in the GeoAI 2020 data. For Tarn Taran this was Amritsar and for Sangrur it was Patiala. This provides the total number of kilns for the area of discrepancy.

Step 2:
Calculate the total percentage of kilns from the target area against the overall area of discrepancy. For example, total percentage of kilns in Tarn Taran against the total in Amritsar and Tarn Taran using the 2020 GeoAI data.

Step 3:
Apply the percentage to the target area to estimate how many kilns from the total area of discrepancy belong to the estimation target.

Step 4:
Adjust the kiln count for the districts making a note of why the change has been applied to the database.

It is important to mitigate this data difference as the combined districts are within the same state of Punjab creating a closed system in which removing districts from the database will give an inaccurate understanding of the brick kiln landscape in Punjab. However, this approximation method is not without its limitations and assumptions. First, this method assumes a uniform distribution and does not account for percentage change and time series analysis due to a lack of data. The assumption of a uniform distribution relies on the kiln population proportion between Patiala and Sangrur being similar in 2019 and 2020, the relatively short gap of a year makes this a reasonable assumption, but it does impact the confidence of the estimation if a significant change in the distribution of kilns occurred between the two years. Last of all, this estimation can be used for analysis but should be considered as less authoritative than Punjab districts that mapped across the two reports without the need for estimation. These changes result in the following table.
Due to the estimations and district segmentations certain areas have a significant quantity change between 2019 and 2020. This difference will be minimised between the analysis of 2020 and 2024 as both sets of data provide locational data removing the need for estimations.
Another consideration is this altered data set produces 20 districts that brick kilns can be registered to. This is in comparison to 17 districts in the STE 2019 report and 20 districts in the GeoAI database. This means analysis between 2019 and 2020 is less reliable than analysis between 2020 and 2024 which uses the same districts.

District	STE 2019 Operative	GeoAI 2020	Change	Conversion required
Ludihana	281	272	-9	None
Amritsar	91	197	+197	134 moved to Tarn Taran 2019 (Estimate)
Jalandhar	159	160	+1	42 moved to Shahid-Bhagat-Singh-Nagar 2019 (Double district estimate with Hoshiarpur)
Fazilka	165	138	-27	District segmentation with Firozpur
Gurdaspur	162	163	+1	48 kilns moved to Pathankot 2020 (District segmentation)
Bathinda	160	208	+48	None
Patiala	67	159	+92	82 moved to Sangrur 2019 (Estimate)
Hoshiapur	94	95	+1	42 moved to Shahid-Bhagat-Singh-Nagar 2019 (Double district estimate with Jalandhar)
Moga	125	155	+30	None
Mansa	110	145	+35	None
Ferozepur (Firozpur)	87	100	+13	District segmentation with Fazilka
Kapurthala	74	51	-23	None
Faridkot	69	68	-1	None
Rupnagar (Ropar)	67	71	+4	Name check
Barnala	65	61	-4	None
Pathankot	59	48	-11	Received 48 kilns from Gurdaspur 2020 (District segmentation)
Fatehgarh-Sahib	27	55	+28	None
Tarn Taran	134	149	+15	Received 134 kilns from Amritsar 2019 (Estimate)
Shahid-Bhagat-Singh-Nagar	76	77	+1	Received 42 kilns from Gurdaspur and 42 kilns from Hoshiarpur (Double district estimation)
Sangrur	82	196	+114	Received 82 kilns from Patiala 2019 (Estimate)

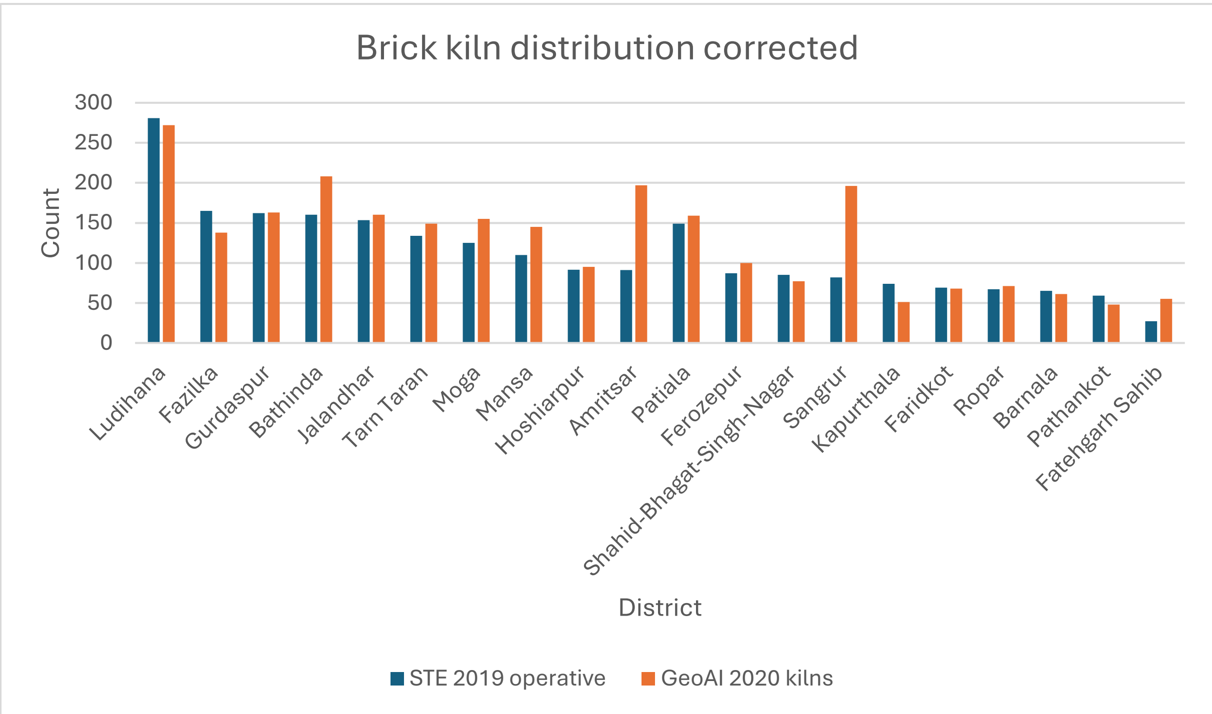
Figure 14- A table showing the corrected kiln population results from the conversion between STE 2019 and GeoAI 2020 data.

The following chart shows the brick kiln distribution across Punjab districts with the merging of the GeoAI and Punjab STE 2019 report. The author has favoured the GeoAI district mapping where possible as this will facilitate analysis between the 2020 and 2024 Punjab data as both use the GeoAI district boundaries. Focusing on 2020 kiln estimations the author compares the top 5 STE 2019 districts against these changes.

Top 5 STE 2019 districts compared to data altered brick kiln database.

Ludihana is consistent across the STE 2019 report for both total kilns (count before kiln closures) at 326 and number of operative kilns at 281 as well as tracking first in the GeoAI 2020 database with 272 brick kilns. It ranks first in both reports and is associated as a district highly populated by brick kilns. Within the grey literature Ludhiana also ranked as a key location for brick kiln clusters (Sameeksha, 2024). It has no data inconsistences in terms of district segmentation, alternate names or brick kilns potentially falling into other districts between STE 2019 report and the GeoAI 2020 database.

Amritsar 2019 was district segmented with Tarn Taran to produce a 2019 kiln estimate as Tarn Taran only had data from the GeoAI 2020 source. 34 brick kilns were moved from Amritsar's 2019 count to estimate the 2019 count for Tarn Taran. Amritsar drops from 2nd highest population of brick kilns by district in 2019 to 11th. This alteration produces a significant percentage change between 2019 and 2020 of 116.4% (rounded to 1 decimal place). However, caution should be exercised when considering these figures that result from estimation rather than direct analysis of district segmentation through the GIS application data. This rate of change can be judged against the 2024 kiln data and the Li et al, 2019 brick kiln aging database.
Jalandhar drops down to rank 5, losing 37 kilns to estimate Shahid-Bhagat-Singh-Nagar as one part of the double district segmentation estimate. Despite this alteration Jalandhar still gains 6 kilns from 2019 to 2020. The two district segmentation method for Shahid-Bhagat-Singh-Nagar presented the challenge of not knowing how to separate the kilns taken from Jalandhar and Hoshiarpur. The author decided to split the estimated brick kilns by proportion of kilns in 2020. Jalandhar has 48.2% (rounded to 1 decimal place) of the share of brick kilns between Jalandhar (48.2%), Hoshiarpur (28.6%) and Shahid-Bhagat-Singh-Nagar (23.2%).
Fazilka has been discussed above as a main source of data discrepancy. Both the difference in name and the district segmentation significantly change the results of the number of brick kilns found in Fazilka for the 2020 data. For 2019 the data remains consistent, and no changes are made.
Gurdaspur features in both the 2019 STE report and the GeoAI 2020 database however a collection of brick kilns from the GeoAI 2020 database likely belong to the area of Pathankot featured in the STE 2019 report. This removes 48 brick kilns from Gurdaspur, this result was calculated using the district segmentation method discussed for Firozpur as the author required a kiln count for 2020. Due to all the data being present the author is confident with this data alteration and can adopt this approach for Gurdaspur and Pathankot when considering the 2024 data.



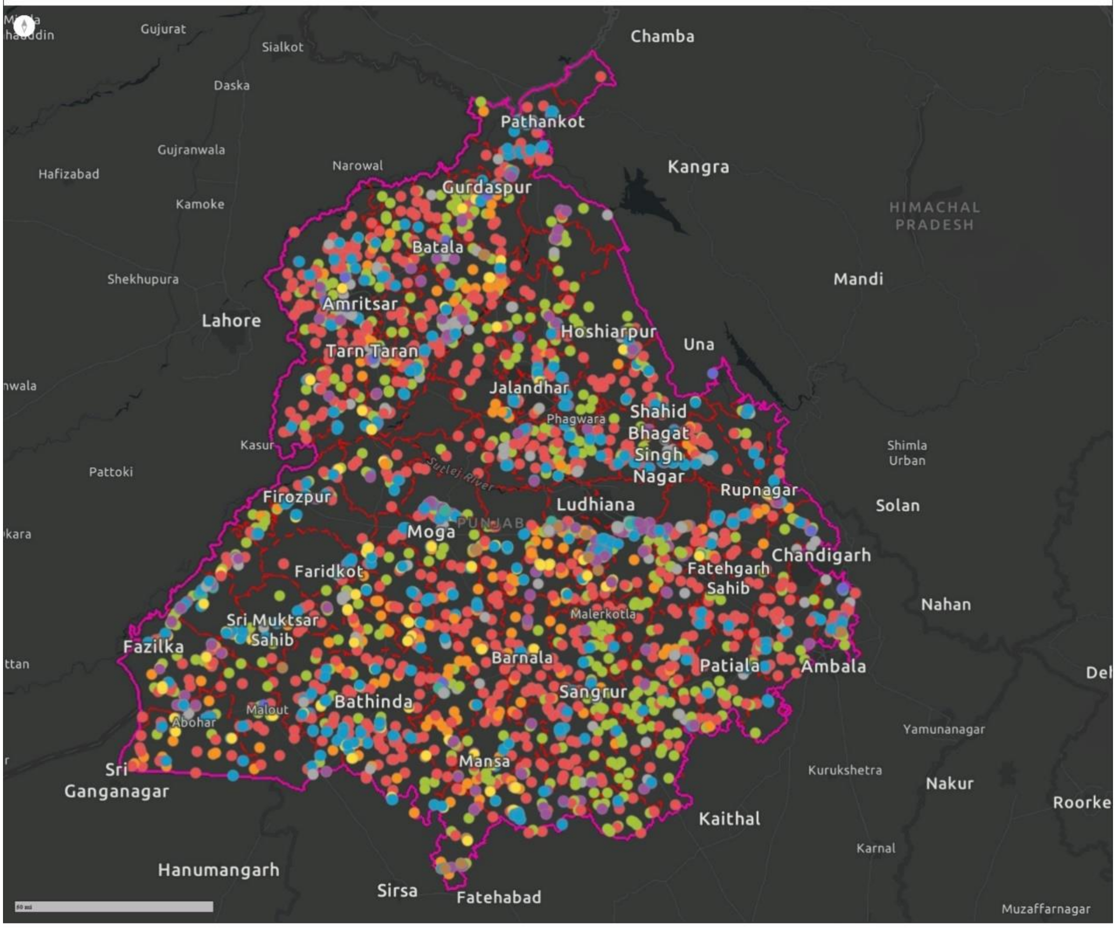
Top 5 GeoAI 2020 districts compared to data altered brick kilns database.

Ludhiana again stands consistently at first it loses on brick kilns to other districts through estimation or district segmentation.
Gurdaspur features in both the 2019 STE report and the GeoAI 2020 database however a collection of brick kilns from the GeoAI 2020 database likely belong to the area of Pathankot featured in the STE 2019 report. This removes 48 brick kilns from Gurdaspur, this result was calculated using the district segmentation method discussed for Firozpur as the author required a kiln count for 2020. Due to all the data being present the author is confident with this data alteration and can adopt this approach for Gurdaspur and Pathankot when considering the 2024 data.
Bathinda has rose one rank to be the second most brick kiln populated district. An extra 48 brick kilns have been identified in the GeoAI 2020 data. No data alterations were required as the STE 2019 report and GeoAI 2020 database both contain Bathinda.

Amritsar also rose one rank placing third. 134 brick kilns were moved from Amritsar's 2019 count to estimate the 2019 count for Tarn Taran. This produces a significant percentage change between 2019 and 2020 of 116.4% (rounded to 1 decimal place). However, caution should be exercised when considering these figures that result from estimation rather than direct analysis of district segmentation through the GIS application data. This rate of change can be judged against the 2024 kiln data and the Li et al, 2019 brick kiln aging database.
Sangrur also has a high rate of change between 2019 and 2020. The data from the GeoAI portal is accurate with Sangrur having 196 brick kilns but the 2019 value is estimated. This results in a potential variability in the actual number of kilns in 2019 comparative to the estimate.

The GeoAI database for Punjab 2020-23 contains 2733 brick kilns. The data corrected combination of the STE and GeoAI districts maps 2568 kilns, including data for another 135 brick kilns that can be mapped to the GeoAI 2020 data but cannot be estimated or district segmented to generate data for the STE 2019 report. This results in an accuracy of 93.96% for attributing brick kilns to districts. The 2020 and 2024 GeoAI data use the same locational data resulting the opportunity for direct comparison. 2733 kilns are scoped in Punjab with each kiln ranked across 5 regulation factors as discussed in the methodology. The following figures show the visualisation of all brick kilns across the state of Punjab. The figure on the left depicts kilns by regulation score from 0 for a completely compliant brick kiln within our 5 factors and 11111 for a kiln that is non-compliant on each of the five factors. The figure on the rights shows all the kilns in the Punjab 2020-23 database that scored a 0. From the 5-factor model only 15.5% (rounded to 1 decimal place) of brick kilns in Punjab score a 0 which despite being low supports other regulation studies with Mondal (et al, 2018) detecting 90% violation of kiln-to-kiln overlap. The three most significant factors for regulation are kiln type (62.10% of kilns are likely to be non-compliant), kiln to kiln overlap (43.80% of kilns are likely to be non-compliant) and kiln to road proximity (19.7% of kilns are likely to be non-compliant).

Figure 15,0: A map showing all Punjab kilns from 2020-23 with regulation score

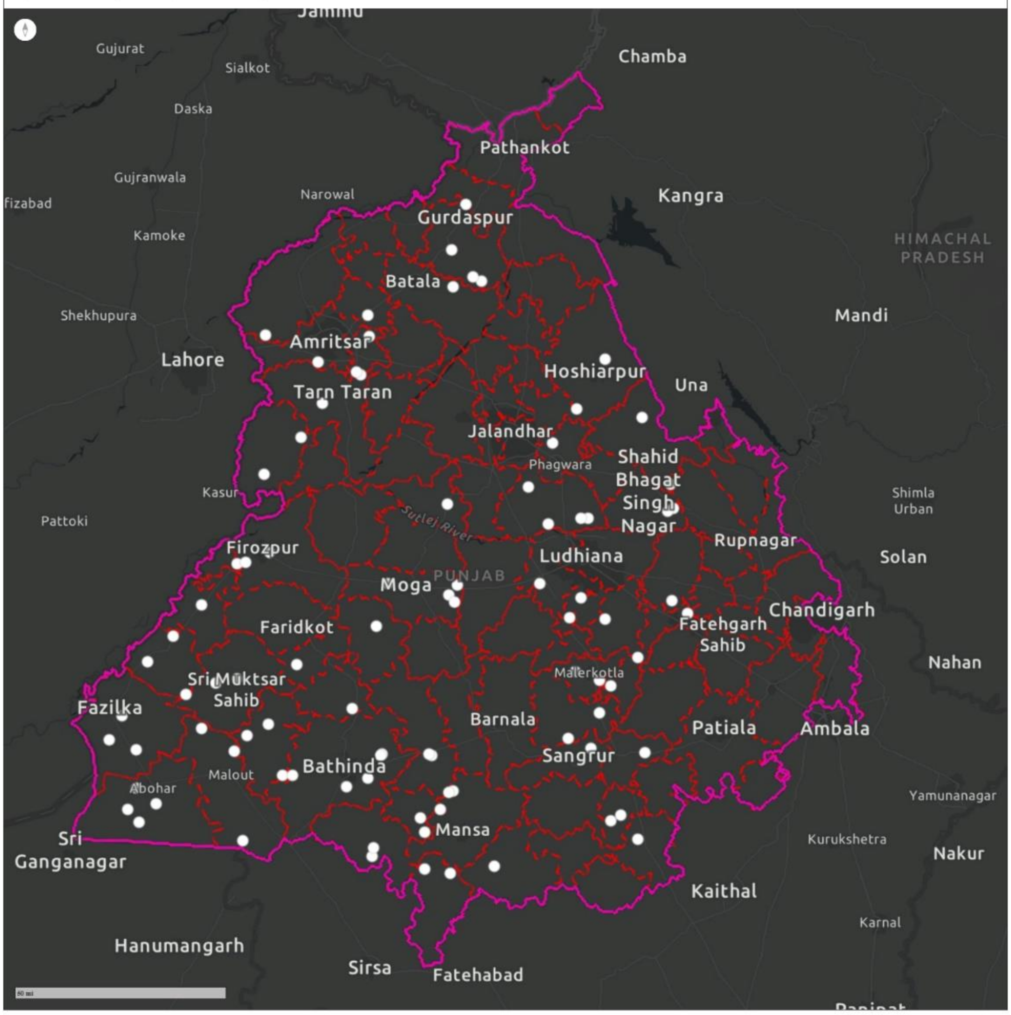


Kiln_Punjab_Regulation_Compliance_updated_KO_fixed_2020 - Age
110 · 111 · 10 · 11 · 100 · 101 · 0 · 1 · 1,011 · 1,111 · Other

Target-State Population Projections for India 2011-2036 (Release 2023) - StatePopProjection2023

Pun-Sub-District Population Projections for India 2011-2036 (Release 2024)

Figure 15.1: A map showing all clean Punjab kilns from 2020-23



Kiln_Punjab_Regulation_Compliance_updated_KO_fixed_2020 - Age
110 · 111 · 10 · 11 · 100 · 101 · 0 · 1 · 1,011 · 1,111 · Other

Target-State Population Projections for India 2011-2036 (Release 2023) - StatePopProjection2023

Pun-Sub-District Population Projections for India 2011-2036 (Release 2024)

4.1.2 Punjab 2020-23 regulation compliance overview

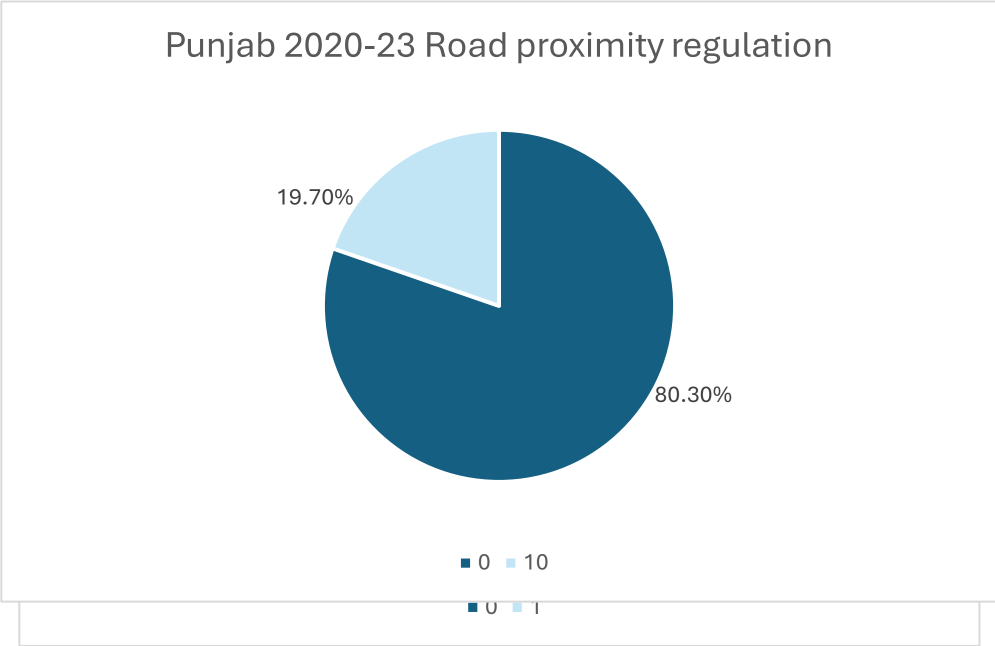
Marx and Goward (2013) discussed that satellite imagery methods could be used not only to document human rights violations but act as monitoring systems providing active deterrence. Research on the efficacy of this deterrence property of remote sensing is limited. The theory from Marx and Goward considered that the presence of continuous remote sensing imagery could deter human rights violations however this would only be effective with the support of the UN or another powerful multi-national actor (Levinger,2009) and that the human rights violation could be physically sensed. This second point is the main factor influencing the brick kilns as MSHT itself cannot be physically sensed by satellite imagery. Rather there are visual clues which suggest the increased prevalence of modern slavery and these can be investigated. This study aims to see if researchers can connect regulatory factors that can be monitored from satellite imagery to a likelihood of modern slavery occurring. This link to regulatory factors helps increase the authority of our surveillance system as there is appetite to enforce it due to interest from the state and on the ground NGOs.

There are laws and regulations in place that make it possible to refer a non-compliant kiln to the regulatory authority.
This mitigates a big weakness of surveillance, by making the geospatial intelligence directly inform the regulation. This has been acknowledged with the geospatial imagery from this wider project considered as more authoritative than government records. This research goes beyond surveillance and instead builds a near real time database of brick kilns by status, location and activity. This provides a powerful tool for regulators to identify, track and audit brick kilns which are difficult to locate due to the scale of the study area.

The three most significant regulatory factors for identifying non-compliant kilns were kiln overlap, kiln to road proximity and kiln type. Town and city regulations seem to largely be followed by most brick kilns across Punjab with towns having a 98.3% compliance rating and cities having a 93.5% compliance result. Out of the three most significant regulation factors brick kiln type captures the most non-compliant kilns (62.10% of kilns non-compliant in this factor), then kiln to kiln overlap captures the second highest number (43.80% of kilns non-compliant in this factor) and last kiln to road regulation captures 19.7% of non-compliant kilns. A brick kiln only needs to fail on one of these regulatory factors to be considered non-complaint.

Regulation factor 1: Kiln overlap

It is stated in the Punjab Pollution Control Order that brick kilns must be 1000 metres from each other (Punjab Pollution Control Board, 1989; Mondal et al, 2018). The author has discussed how a combination of near table analysis and buffer processing were used to characterise kilns as compliant or non-compliant with this regulation. Compliant kilns are awarded a 0 on their regulation score while non-complaint kilns are designated a 1.

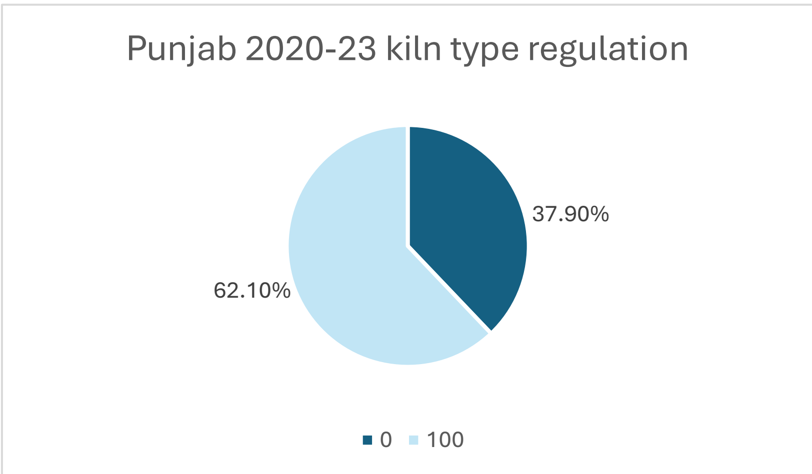


Regulation factor 2: Kiln to road overlap

The same document (Punjab Pollution Control Board, 1989) rules that a brick kiln may not be within 100 metres of a road. The distance measurements from kilns to roads was already provided by the GeoAI platform so the author wrote a simple if statement in excel to categorise kilns as complaint or non-complaint. Non-compliant kilns were designated a score of 10. While clean kilns were awarded another 0. This binary classification and code system meant the author could quickly identify the regulations broken by each kiln quickly. For example, a kiln that only breaks regulation factor 2 would be coded at “10” while a kiln that broke both regulatory factors 1 and 2 would be coded an “11”.

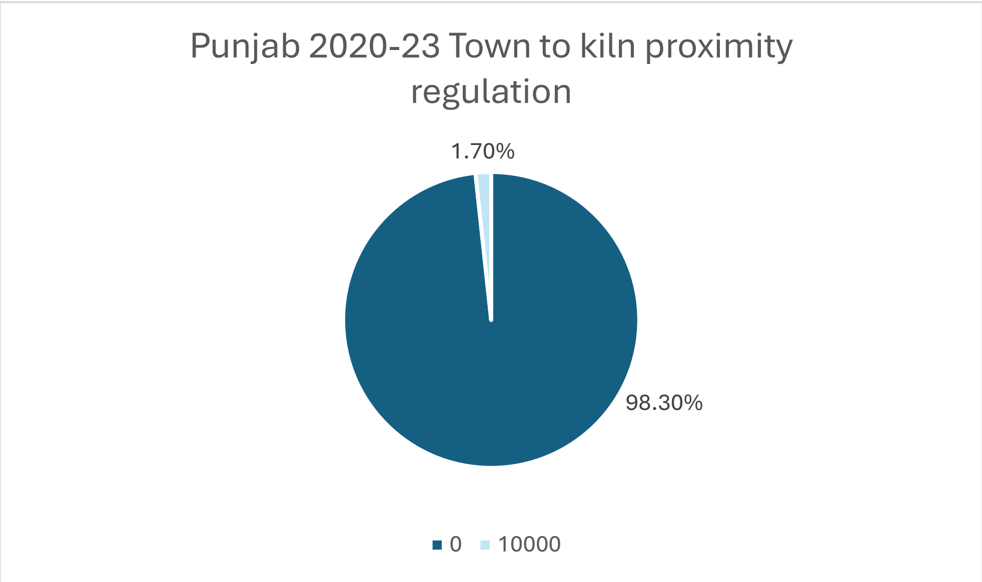
Regulation factor 3: Kiln type

This factor measures if a brick kiln has transitioned to zigzag technology. Zigzag kiln technology is cleaner and more resource efficient (Hussain et al, 2021l Abbas et al, 2022) therefore the government have emphasised an effort to convert kilns to zigzag systems. This data was included in the GeoAI database where satellite imagery was used to differentiate between different types of brick kilns (Boyd et al, 2021). The author filtered out any kilns which were tagged as doubtful for kiln type to mitigate for inaccuracies and misclassified data. Kilns that were not classified as zigzag were designated a regulation score of 100.



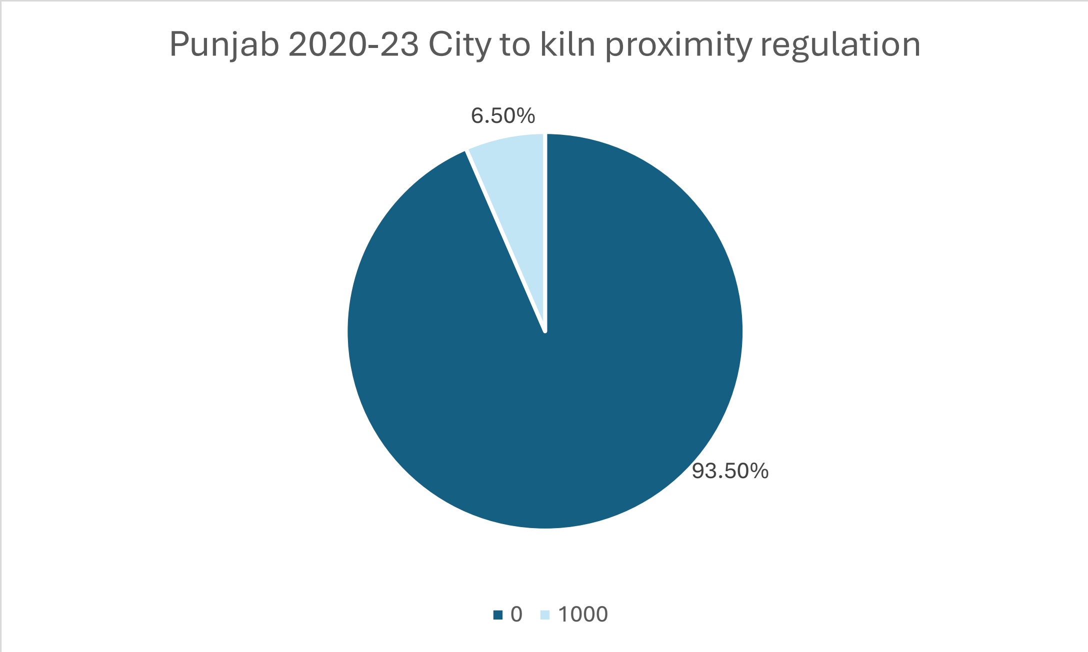
Regulation factor 4: Kiln to town proximity

Kiln to town proximity is recorded as one of the regulations within the Punjab pollution control order. It specifies a kiln must be more than 500 meters (originally 750 meters before the 1999 amendment order) from any town (Punjab Pollution Control Board, 1989). Distance measurement data for the relationship between kilns and towns was not available on the GeoAI dataset. Furthermore, the author could not automate distance measurements through a near analysis or generate near table analysis due to the towns size and shape. It would have been possible to generate polygon layers from the town shapes manually, but this seemed less efficient that the authors method of checking kiln to town distance using buffer analysis and interpreting proximity to kilns visually. The author used a mixture of imagery hybrid basemap and the Sentinel 2 land cover land use map discussed earlier to identify built up areas. Occasionally these built-up areas were difficult to distinguish between town and city, when this occurred the author googled the name of the nearest labelled place to try and figure out the classification of the urban space. These results were successful, but the author had difficulty between different spellings and wordings of the same location. Kilns that failed this regulation were designated a regulation score of 10,000.

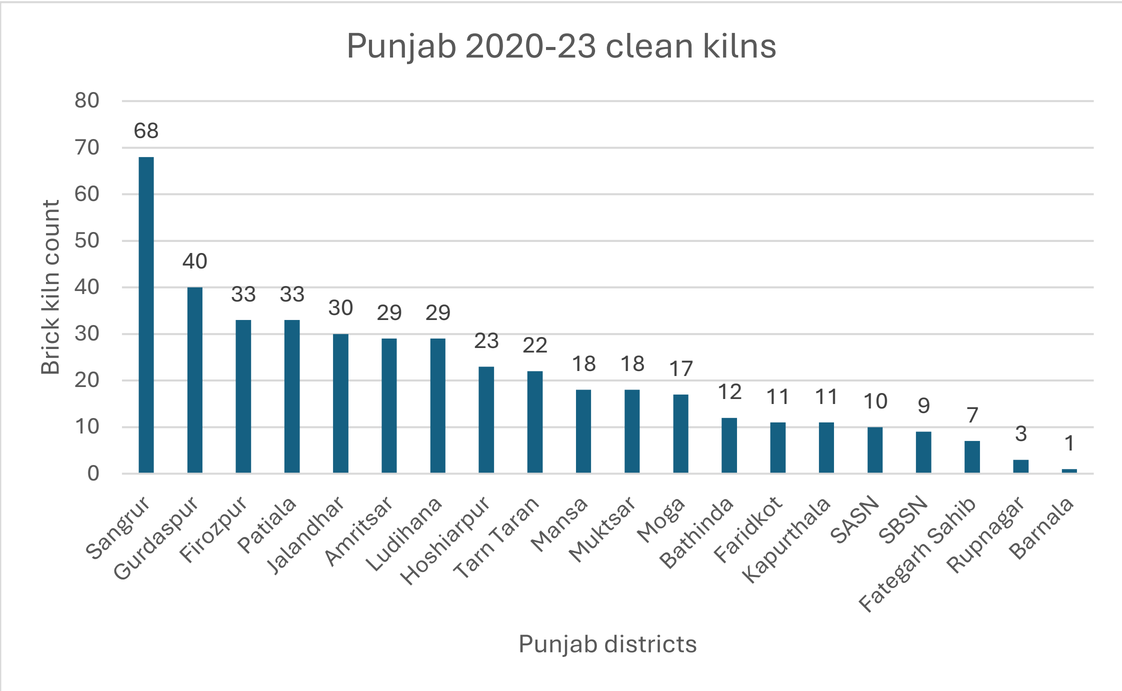


Regulation factor 5: Kiln to city proximity

Kiln to city proximity is the last factor considered in this model. Previous studies by researchers like Boyd et al (2021) have discussed the trend of brick kilns clustered around cities. However, from this papers model It seems these clusters are largely outside of the regulatory zone. The contention here identified by Boyd et al (2018) is that if the brick kilns are using local supply lines to aid the development of urban growth, then they need to be close to the cities while still being far away enough to be regulatory compliant.
These proximity regulations do also run counter to the guidance on modern slavery by the ILO. Models for modern slavery should consider the contentions between distance away from cities, roads and other key areas of infrastructure being good for climate change and air pollution regulation while the same distance regulations can be negative for access to transport and the remoteness of a working environment which the ILO consider risk factors that lead to modern slavery. Kilns were tracked using the same method as regulation factor 4 with kilns that are non-complaint scoring a 1000.



Clean kilns by district

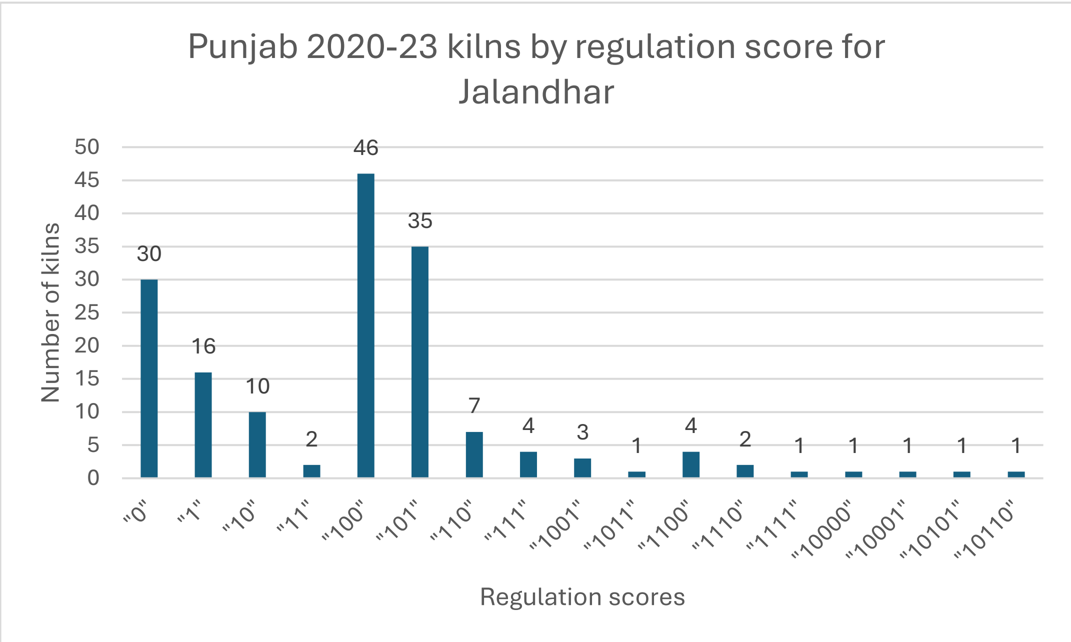


Regulation score overview

The author explored the regulation score data using five districts randomly selected using a random number generator. The five districts sampled are Jalandhar, Hoshiarpur, Mansa, Ropar, and Tarn Taran. The purpose of this analysis is to link kiln aging to the Punjab 2020 and 2024 data without having to analyse all 2733 kilns. This section starts with a broad overview of the brick kiln aging (Li et al, 2019) data results before moving on to detailed spatial and visual analysis.

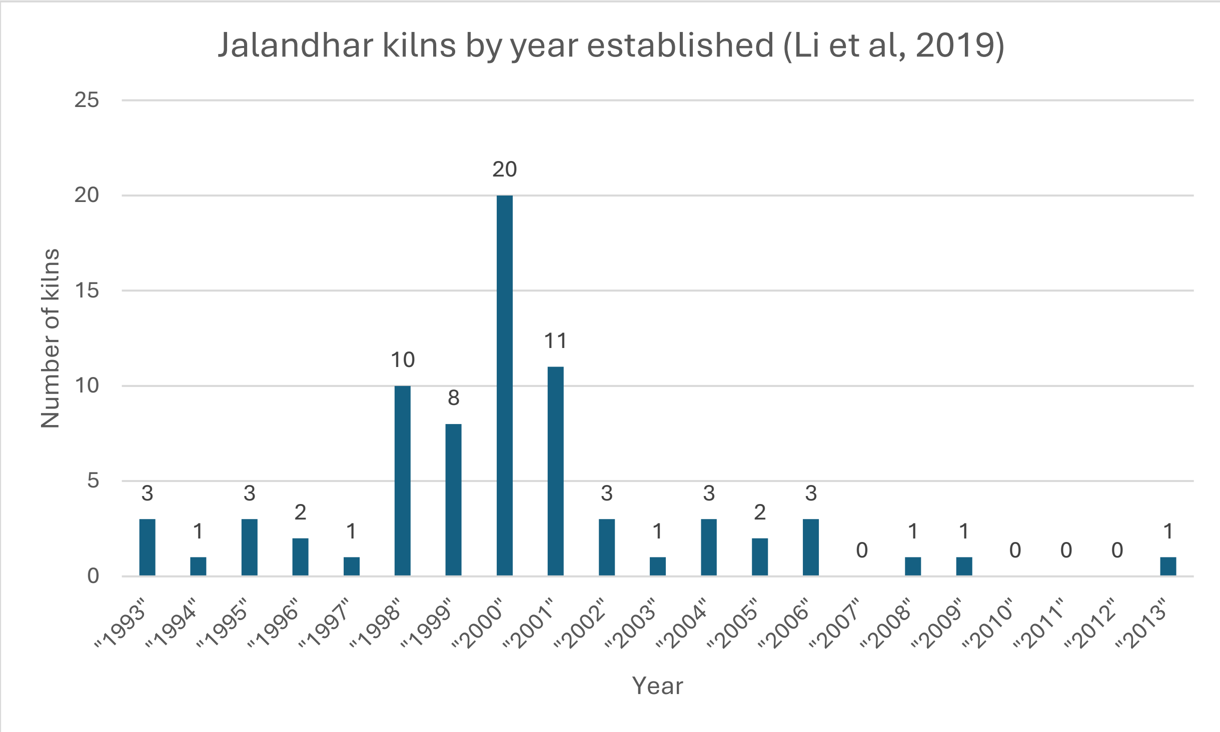
Jalandhar

The GeoAI database segments Jalandhar into 6 subdistricts: Shahkot, Nakodar, Phillaur, Jalandhar I, Jalandhar II, and Adampur. The Jalandhar district contained 160 brick kilns in 2020 and 120 in 2024. The Punjab STE estimated the amount of brick kilns operational in the district was 196 in 2019 (STE,2019) calculated after shutting 6 kilns permanently. After the author altered the data to fit better with the districts analysed by the GeoAI data discussed in section 4.1 this number was 159.
In 2020-23 using the GeoAI data Jalandhar had only 30 out of 159 kilns that passed all five regulatory factors included in this study. It should be noted that the actual Punjab regulation from the Punjab pollution control board considers 8 factors and as a brick kiln only needs to fail one regulatory factor to be non-compliant it is reasonable to assume non-compliance is even greater than the figures provided in this study.



No liberations took place in Jalandhar, so the aging database was used instead to analyse trends between regulatory compliance and brick kiln activity. In the Li et al (2019) kiln aging dataset which records kilns from 1991 to 2018 19.07% (8966) of 47021 results are not aged. Despite this the aging dataset helps figure out if kilns should or should not be held to certain regulation standards. Furthermore, despite a lack of time signature the aging database can be used to see if kilns have shut down since 2020 as they may appear on the aging database and not the GeoAI portal for 2020 or 2024 data.
The aging database captures 184 brick kilns for Jalandhar sharing 146 of them with the

GeoAI portal. Of these 146 brick kilns 75 of them have a time signature specified by year that Li (et al, 2019) estimate the brick kiln was built.



An additional 93 were built before 2018 but have no time signature data. These kilns with time signatures can be tracked for their regulation compliance. The Punjab pollution control order was published in 1998. Therefore, it is possible that 10 kilns are exempt from regulatory oversight. Below are statistics for the 75 brick kilns that were successfully aged by Li (et al, 2019) and linked to their regulation score if one is assigned. A regulation score would not have been assigned for brick kilns that are only in the Li (et al, 2019) aging database which resulted in 16 brick kilns not being assigned a regulation score.

Assuming the regulation deadline is in line with the Punjab pollution control order (1998), any kiln established before 1998 should be viewed as potentially exempt of these regulations. However, for certain regulations like zigzag conversion and kiln overlap often kilns need to make efforts to uphold these restrictions even if they were established before 1998. 10 of the Jalandhar kilns were established before 1998 and should be compared against 2024 data to see if these kilns were shut down. If they were this could suggest kiln closures.

The following visualisation used a join analysis to combine data from the GeoAI 2020 database and the aging data from Li (et al, 2019) using a buffer of 0.1 metres to capture slight variations between the point layers. This led to 146 kilns being linked shown in figure X and Figure Y.

Year	Jalandhar regulation score by year of brick kiln									
1993	100	0	1							
1994	100									
1995	10110	100	1							
1996	10001	100								
1997	110									
1998	101	101	0	100	101	100	0	110	0	101	
1999	0	0	1	0	0	11	101	101			
2000	10	0	101	1	100	100	0	101	0	101	110
	0	110	101	1	0	1	100	101	0		
2001	101	100	0	101	101	100	100	101	100	1	0
2002	0	100	100								
2003	101										
2004	1	100	0	1							
2005	0	1									
2006	0	100	100								
2008	101										
2009	1										
2013	0	10									

Figure 19.3: A map showing Jalandhar brick kilns and regulation score

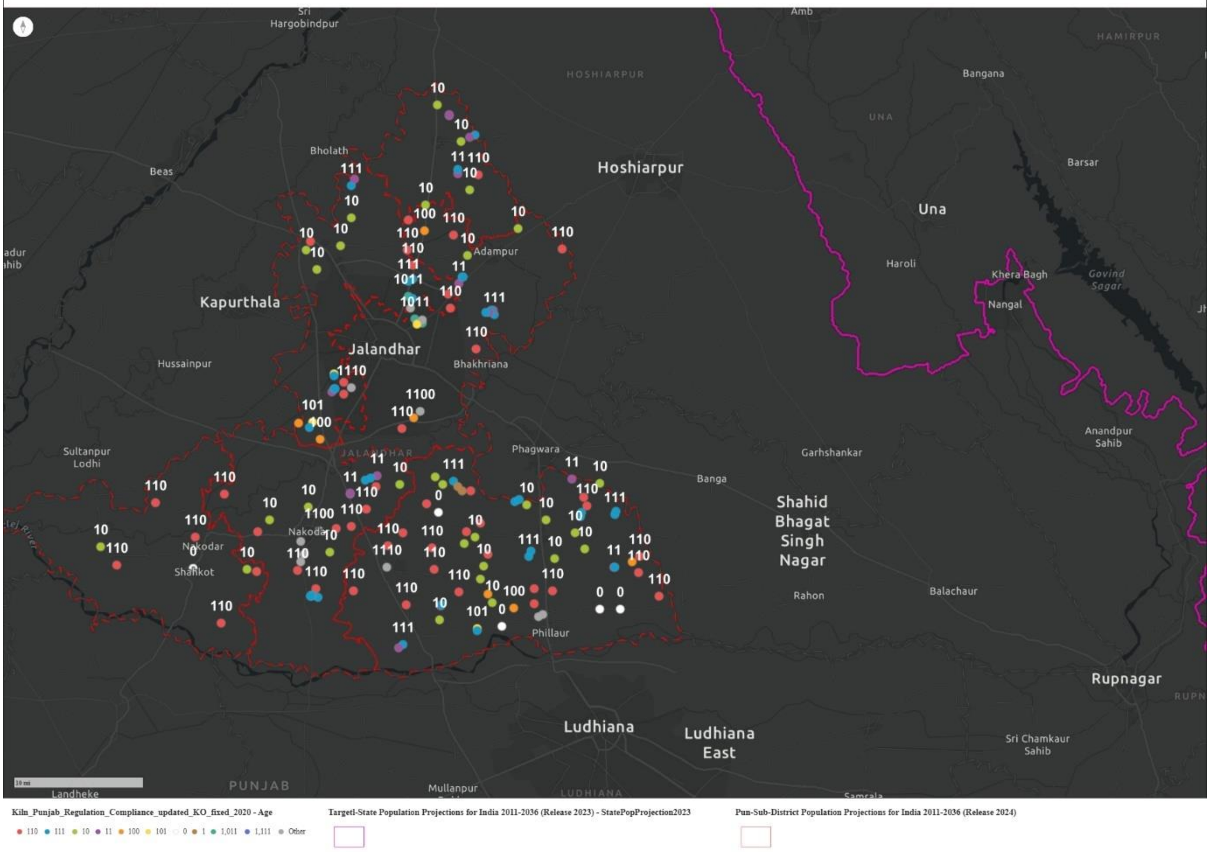
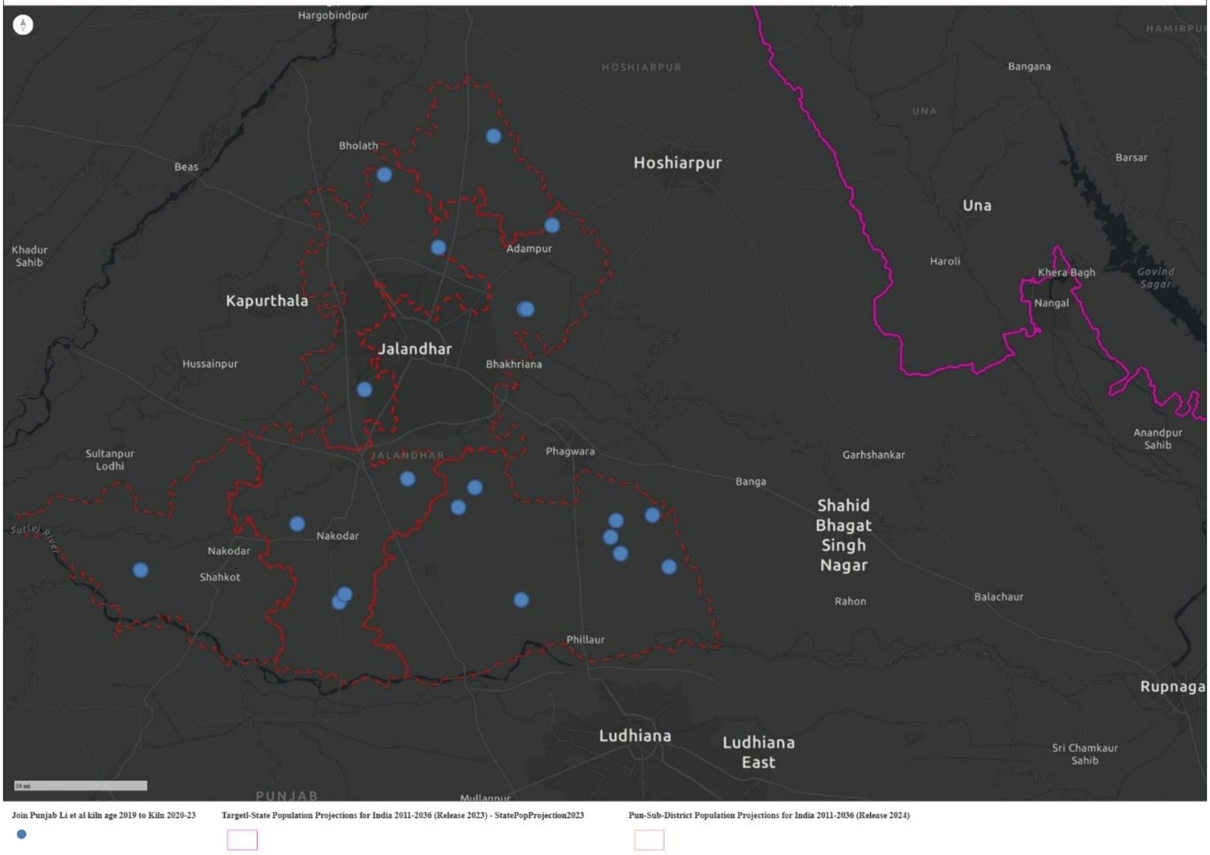


Figure 19.4: A map showing Jalandhar brick kilns and regulation score with year = 2000 selected



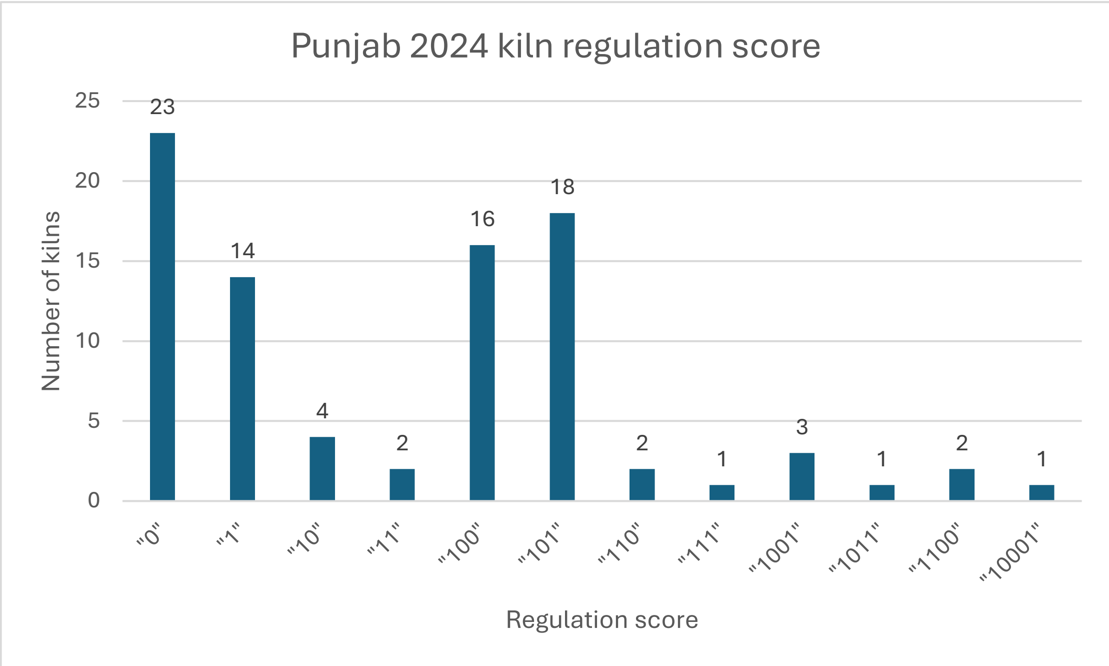
While Jalandhar contains no liberation data by using the 2024 Punjab kilns database, we can see how many of these 146 kilns were shut down and compare those figures to the regulation score of each kiln. 87 of the original 146 kilns are present in the 2024 data. The 59 brick kilns that are shut down have the following regulation scores.

Regulation score	Count
0	7
1	2
10	6
11	0
100	30
101	17
110	5
111	3
1110	0
10100	1
10111	1
Unclassified	8

Many of the shut kiln’s link to factors representing road regulation and zig zag conversion. seven of the kilns that were shut scored a 0 on the regulation model, the score of 0 is assigned for kilns passing all 5 regulation checks. There are 5 kilns that scored this pass mark. This suggests that these kilns are compliant with regulations.
Due to no liberation data being available for Jalandhar the author mixes the 2024 brick kiln data showing kiln closures with the regulation score model. Highly regulated kilns are expected to be less likely to use modern slavery as this high level of compliance suggests better working conditions as formalised kilns may attract more regulatory oversight making the use of modern slavery riskier and more difficult as more eyes are drawn to the kilns. On the other side it is expected that kilns which do not invest in clean technology and resist the cost of compliance may also attempt to cut costs in other areas including within the

workforce.
The kiln industry is significantly informal and unorganised this lack of visibility and detection encourages the use of coercive practises due to a lack of retaliation and punishment for these crimes. Formal kilns are also vulnerable to the court of public opinion and stakeholder pressure. A highly visible kiln is easier to pressure by NGOs and the government to improve standards. While these improved standards have largely been focused on environmental factors recently labour standards also have become a key focus of regulation.

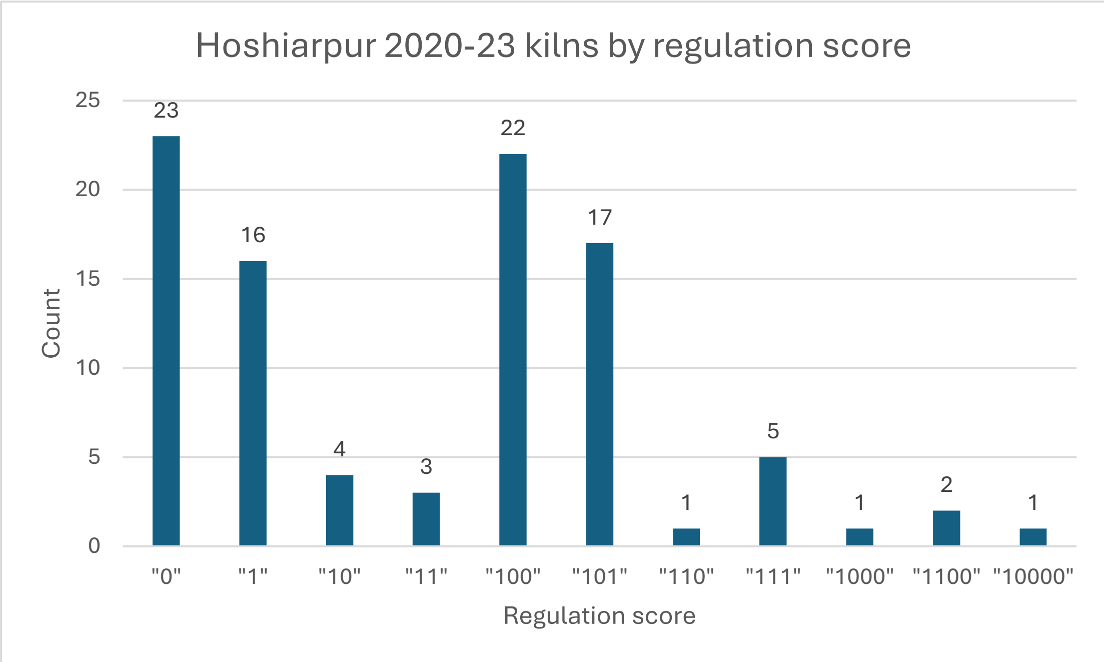
Regulation scores for kilns in Jalandhar operational in 2024 are below in figure 19.6.



Based off the Li (et al, 2019) data the first kilns established in Jalandhar are established in 1993 with no data in 1991 or 92. Shahkot and Phillaur are the first districts to establish brick kilns. In 1995 two kilns in Nakodar are established with one of these being present in the GeoAI data. In 1996 Jalandhar 1 had a kiln established. By 1998 the only kiln that did not have a kiln established was Adampur the most northern sub-district of Hoshiarpur. The year 2000 saw all the sub-districts develop brick kilns that have been successfully aged and linked to regulation scores. The Li (et al, 2019) time series data ranged from 1984 to 2018. While Landsat data has been collected since the 1970's with the Li (et al, 2019) database sensing brick kilns from 1984 many of the brick kilns were found to be less than 10 years old with only 20% of kilns being older than20 years old in the Li (et al, 2019) study

Hoshiarpur

The GeoAI platform segments Hoshiarpur into 5 sub-districts, these are Hoshiarpur, Garshankar, Tanda, Dasua and Mukerian. The Hoshiarpur district contained 134 operative kilns according to the STE report (2019) after altering this 2019 data to estimate a kiln count for Shahib-Bhagat-Singh-Nagar this resulted in 94 kilns estimated for 2019. In the GeoAI 2020 data 95 kilns are found in the district and the 2024 data shows 94 brick kilns.
The spatial query returned 23 kilns with a regulation score of 0 with 20 of these kilns still operating in 2024. The GeoAI brick kilns for Hoshiarpur are shown below by regulation score. Two liberations took place in Hoshiarpur and the 2024 data is combined with these liberations statistics to understand the changes in brick kilns.



Year	Hoshiarpur brick kiln regulation score by year established									
1993	100	0	0							
1994	100	101	100							
1995	100	100								
1997	0									
1998	0	100	101							
1999	1	0	101	101	0	100	100	100	100	100
2000	1100	0	100	0	111	10	101	10	111	111
2001	0	10	101	1	100	111	100	10	1	
2002	0									
2003	1	10	101	101						
2004	110	1								
2007	0	1	1							
2010	1									
2011	101									
2012	0									
2013	0									
2015	0									

Based on the Li (et al, 2019) data, 9 brick kilns from Hoshiarpur may be exempt from brick kiln regulatory compliance. After the 1998 regulations are established, the data shows brick kilns being aged to the early 2000's that score a 0 within the 5-factor regulation score model.

Below the three liberation cases for Hoshiarpur are explored and compared to the 2024 data. Between these two data sources trends can be established between what regulations and regions within Punjab are most likely to experience liberation and how many of those liberations result in findings of modern slavery practises. This analysis is limited by the amount of liberation data currently available to researchers at the Rights Lab. For accuracy only the liberations inside Punjab and confirmed with the brick kiln data from the GeoAI portal are considered as part of this research.

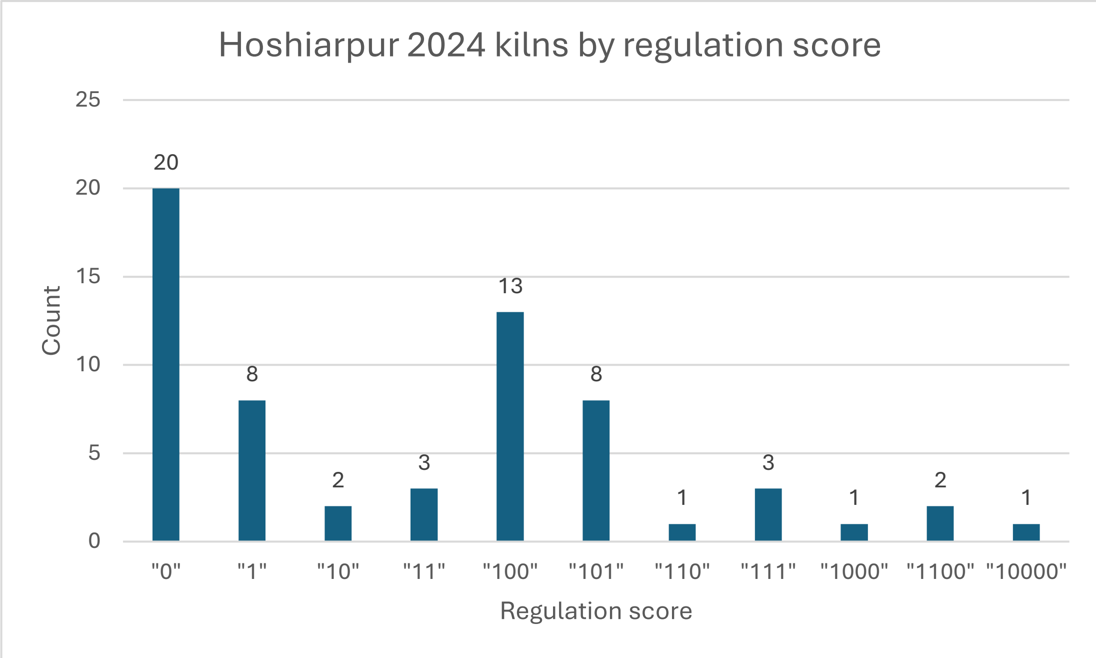
The first liberation took place in 2023 on 23/8/2023. 8 people total were liberated. Both liberations take place within close distance from each other occurring in the same district of Hoshiarpur. This district was Dasua, it consists of 45,277 households with an average household size of 5 and holds a total population of 213,696.

Liberation 23/8/2023 (Regulation score = 1)	
Category	Count
Male	4
Female	4
Total Liberated	8
6-14 Male	2
15-18 Male	1
19+ Male	2
18+ Female	3

The second liberation also seems to be located at the same kiln as seen in figure A. This provides an opportunity to see if the liberation impacted the second investigation by the partner NGO. In the 2024 liberation report for this kiln 6 people were documented. The youngest person was between 6 – 14 years old. This suggests child labour is still employed at the kilns despite this liberation from the partner NGO. this is concerning as these reports are only separated by less than half a year.

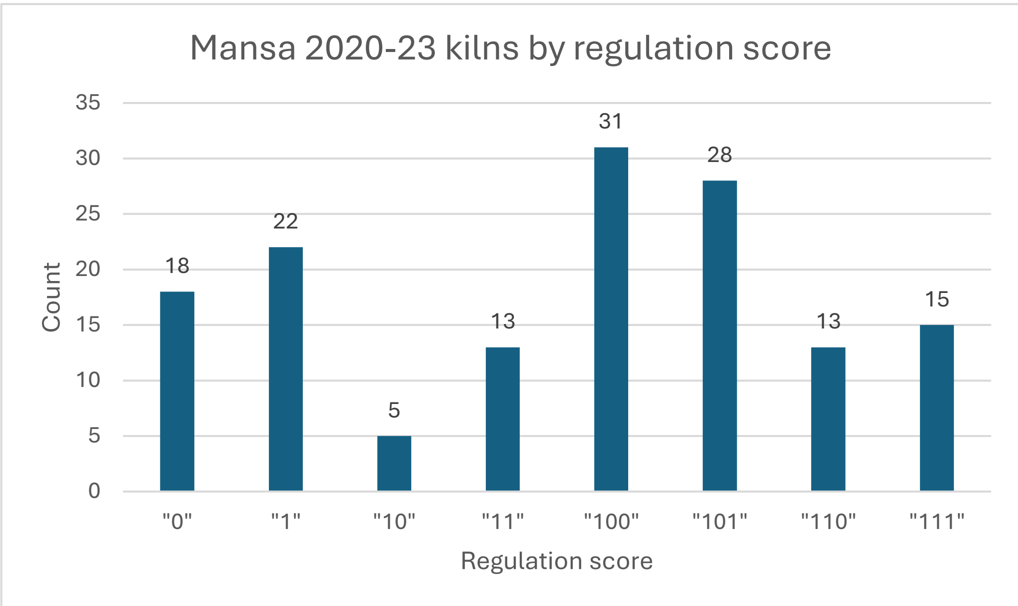
Liberation 21/2/2024 (Regulation score = 1)	
Category	Count
Male	4
Female	2
Total Liberated	6
6-14 Male	2
6-14 Female	1
15-18 Male	1
19+ Male	1
19+ Female	1

More research is required on the transparency between kiln liberation operations and ensuring brick kilns are dissuaded from child labour. It is the authors understanding that in the first liberation report the workers experiencing modern slavery will have left the kiln. However, less than half a year later more child labour and modern slaves are found in the kiln.



<u>Mansa</u>

Three sub-districts are contained within the district of Mansa, Sardulgarh, Budhlada and Mansa. In 2019 the STE report contained 110 brick kilns and in 2020 the GeoAI identified 145 kilns. The current estimate for brick kilns found in the 2024 data is 129. Within the 129 kilns 16 of them are classified as regulation score 0 compared to 18 overall in the GeoAI 2020 data. Despite liberations in all the sub-districts with some occurring near these clean kilns none of the clean kilns have experienced liberation or been audited by the partner NGO to confirm a presence or lack thereof of modern slavery. Below kilns in Mansa are depicted with their regulation score.



The Li (et al, 2019) data captures 129 kilns that mapped on to the regulation database with 103 of these kilns providing an age value. A breakdown of these kilns a provided below in figure X. 9 kilns were established before the 1998 regulations. Following that in figure XX the liberations that have been recorded in this district are reviewed and analysed. The spatial distribution of the kilns are presented in the following figure.

Year	Mansa brick kiln regulation score by year established														
1994	1														
1996	100	100													
1997	100														
1998	110	1	1	101	111										
1999	100	110	100	111	11	1	110	1	101						
2000	1	11	1	11	11	1	111	0	100	111	100	1	11	10	
2001	100	0													
2002	100														
2003	111	100													
2005	110														
2006	1														
2007	101	11	1	0	100	100									
2008	11	101	101	101	101	100									
2009	1	110	101	1	1	101	11	101	101	0	110	111			
2010	110	1	101	101	101	101	0	100							
2011	10	100	101	111	100	111	100	100	100	101	0	11	100	0	0
2012	100	1	1	100	110	100	100	110							
2013	0	11	0	0	100	0	1	0	11	0					
2015	100														

These liberations are split between two sub-districts of Mansa. Two liberations are recorded Budhlada and four are recorded in Mansa. The liberations in Budhlada are reviewed first with Mansa second.

Liberation 1/6/2023 (Regulation score = (1) Budhlada	
Category	Count
Male	5
Female	6
Total Liberated	11
0-5 Male	1
0-5 Female	1
6-14 Female	1
6-14 Male	1
15-18 Male	1
15-18 Female	2
19+ Male	2
18+ Female	2

Liberation 5/6/2023 (Regulation score = 111) Buhlada	
Category	Count
Male	33
Female	25
Total Liberated	58
0-5 Male	11
0-5 Female	7
6-14 Male	5
6-14 Female	4
15-18 Male	3
15-18 Female	1
19+ Male	14
18+ Female	13

Liberation 16/1/2021 (Regulation score = 111) Mansa	
Category	Court
Male	5
Female	7
Total Liberated	12
0-5 Male	1
0-5 Female	2
6-14 Male	2
6-14 Female	2
15-18 Female	1
19+ Male	2
18+ Female	2

Liberation 2/3/2023 (Regulation score = Unclassified) Mansa	
Category	Court
Male	8
Female	5
Total Liberated	13
0-5 Male	2
0-5 Female	2
6-14 Male	1
6-14 Female	1
19+ Male	5
18+ Female	2

Liberation 11/3/2023 (Regulation score = (1) Mansa	
Category	Count
Male	17
Female	12
Total Liberated	29
0-5 Male	5
0-5 Female	2
6-14 Male	5
6-14 Female	3
19+ Male	7
18+ Female	7

Liberation 12/4/2023 (Regulation score = 111) Mansa	
Category	Count
Male	7
Female	4
Total Liberated	11
0-5 Male	2
0-5 Female	3
6-14 Male	1
6-14 Female	2
15-18 Male	1
19+ Male	1
18+ Female	1

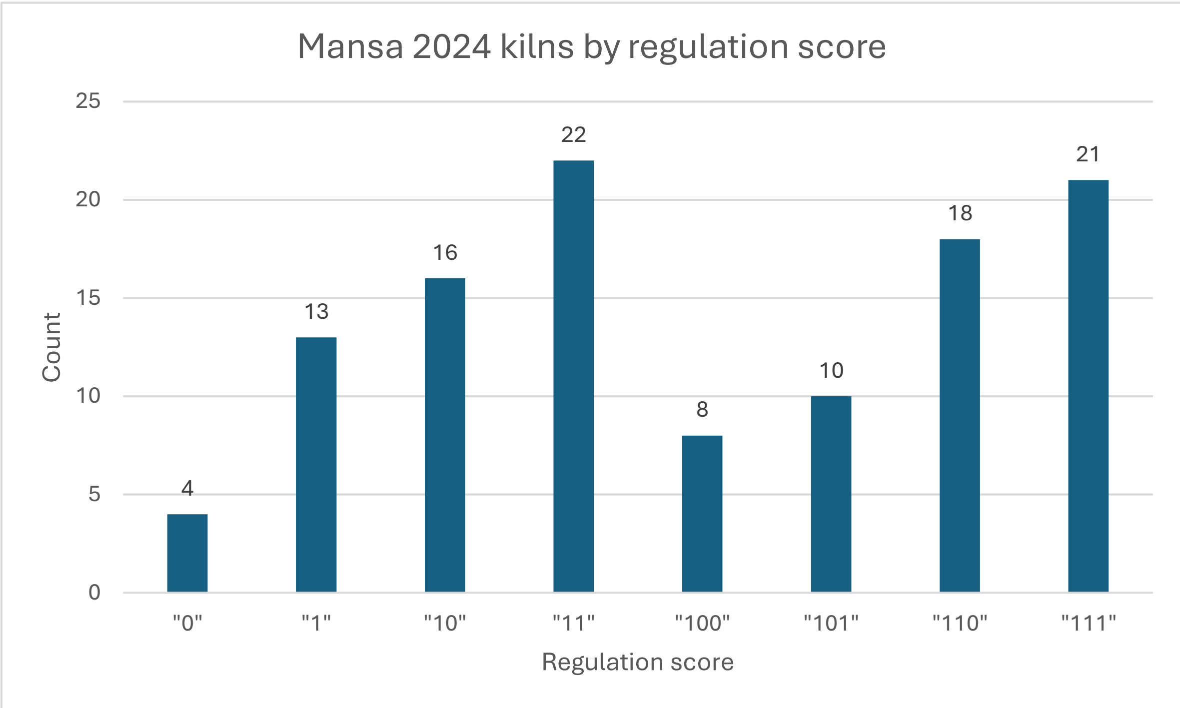
A total of 65 people were recorded in these investigations of brick kiln workers in Mansa. This is in direct violation of sustainable development goal 8 and specifically target 8.7.1 which tracks the percentage of children (aged 5-17 years old) engaged in child labour. Using this definition of child labour at least 38 people have been identified as being vulnerable to child labour within the Mansa brick kilns. For Budhlada the risk for modern slavery is even greater in 2 brick kilns 66 people are recorded in the liberation data. Using the UN SDG definition of child labour from SDG 8 target 8.7.1 an additional 38 children are subject to illegal child labour.
The kiln in Mansa liberated on 2/3/2023 could not easily be matched to a brick kiln regulation code. 2 kilns seem to be close to the location point for the liberation, but they seem to be too far away to be explained by the location point being slightly off target. The liberation record dating the last inspection in early 2023 means it is possible the kiln has completely shut as the dead grass area seems to suggest. It is also possible that the liberation location point is meant to be referring to one of the two other kilns in the figure to the left below. No GeoAI 2020 data points or 2024 data points are present near the location of the liberation report for this kiln.

All these kilns associated with liberation are operational in 2024 apart from Mansa sub-district liberation date 2/3/2023. This liberation data supports a range of growing evidence for modern slavery practises including child labour. Statistics from anti-slavery, an international human rights organisation, document that children are a third of the total population in the brick kilns with 65 – 80% of children between the ages of 5 – 14. These young children work 9 hours in the summer months and 7 hours in the winter. The older children were reported to work longer days, 12 hours a day in summer and 10 hours a day during winter.
Due to the environmental conditions of the brick kilns leading to health issues for brick kiln workers. The work in the brick's kilns would be categorised as one of the worst forms of child labour. Workers also report a lack of education opportunities for their children which feeds a cycle of relying on the brick kilns for employment.

Below is a summary of the regulation scores of kilns shut down between 2020 – 2024.

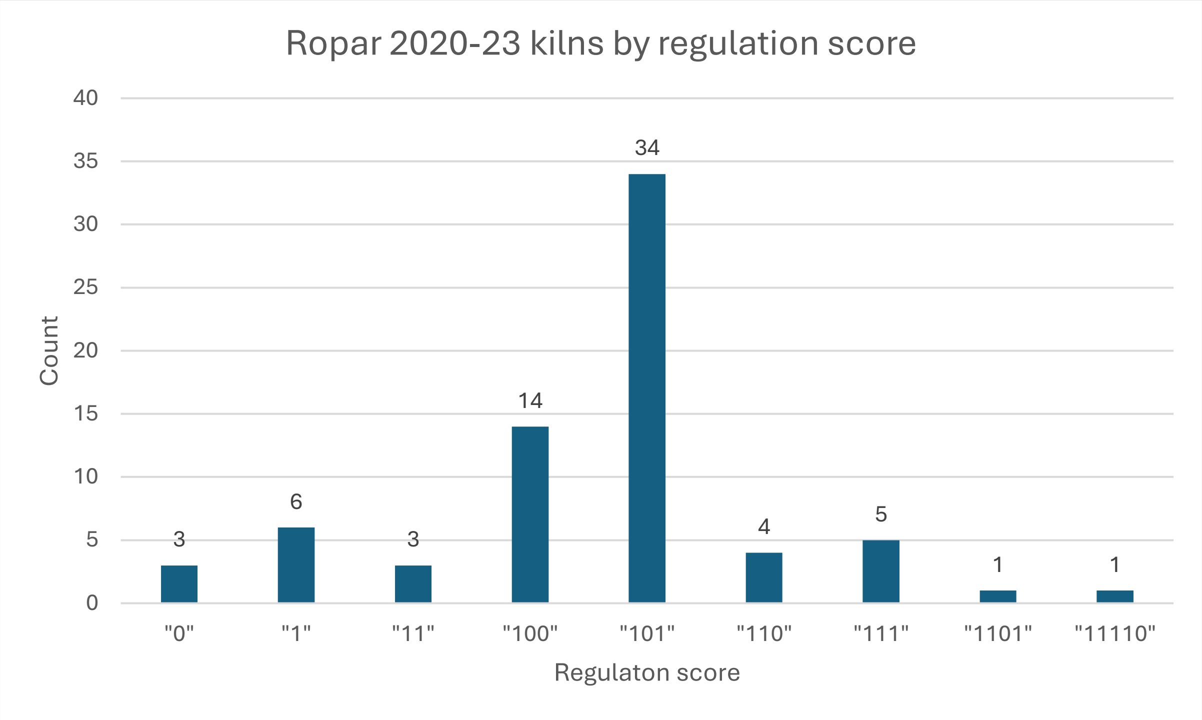
Regulation score	count
0	1
1	0
10	0
11	0
100	4
101	0
110	4
111	3
1000	0
1001	0
1010	0
1011	0
1100	0

Mansa 2024 kiln overview



Ropar

Ropar (also known as Rupnagar) is made of up of four sub-districts. These are Morinda, Sahib, Rup Nagar, Nangal and Anandpur Sahib. 67 kilns were estimated in the 2019 STE Report with no alterations made by the author. In the GeoAI 2020 data this increased to 71. Analysis from the 2024 GeoAI dataset shows a further increase to 76. Several 2024 kilns also are found just outside of the sub-district boundaries with Mordinda containing no brick kilns as of the 2020 and 2024 data. No liberations have taken place in this district.
The lack of brick kilns in Morinda being present in the GeoAI 2020 data is an interesting finding, made more significant by a lack of data for brick kilns in Morinda in the Li (et al, 2019) data that matches to the point locations of the GeoAI 2020 and 2024 data.



The lack of liberation data means analysis of regulation compliance and kilns shut down through inference of it not appearing in the 2024 data is the best approach for understanding brick kiln change in Ropar. The 2024 data shows an increase in total kilns for Ropar, but this does not mean kilns were not shut. In the figure below a summary of kiln regulation scores present in 2020 but not in 2024 are recorded. One kiln was shut between 2020 – 2024 with a regulation score of 100.

Year	Ropar kilns by regulation score and year established													
1993	101	100													
1994	0	100													
1995	101														
1996	100	111													
1997	100														
1998	101	111	101	100	110	101	1								
1999	101	1	101	100	101	101	101	101							
2000	100	101	100	101	101	101	101	100	100	1	101				
2001	11														
2003	1	101													
2005	101														
2006	101	111	111	11											
2007	101	101													
2008	101														
2009	101														
2011	101	101													
2012	101														
2013	0														
2015	101														

Two kilns are recorded through the Li (et al, 2019) data but are not matched to any brick kilns suggesting they have shut down since 2020. Visually interpretation of these two kilns is used to determine the status of operation. The dense vegetation encroaching into the brick kiln in Figure X suggests the kiln has been shut and abandoned. There is no evidence of brick stacks or workers. This is more evident in Figure XX in which dense vegetation surrounds the central chimney and covers the brick kiln. The aging data shows that figure XX has been established since 2001 but clearly has been abandoned for multiple years.

Due to a significant lack of data of kilns from 1991 – 2024 Morinda stands out in this research as a point of critical research. Attempts were made to find answers to why Moridna was, so data sparse and brick kilns were so uncommon but within the scope of the literature and spatial data no answers were found. Consequently, Morinda is a key frontier for deeper social and geographical research on the brick kilns as understanding the absence of brick kilns is just as significant as their presence. For the rest of Ropar district, the data is much more populated across the three sources the thesis utilised.

The lack of liberation data means analysis of regulation compliance and kilns shut down through inference of it not appearing in the 2024 data is the best approach for understanding brick kiln change in Ropar. The 2024 data shows an increase in total kilns for Ropar, but this does not mean kilns were not shut. In the figure below a summary of kil regulation scores present in 2020 but not in 2024 are recorded. One kiln was shut between 2020 – 2024 with a regulation score of 110.

It looks like the kiln is completely removed with no signs of a central chimney or any structure to confirm this future research could use Google Earth Engine to track the development of the brick kiln across time.

Figure 22.2: A map showing an abandoned kiln in Ropar based on vegetation presence

outputLayer:

Join_Count	1
Latitude	30.95
Longitude	76.58
Year	1,998
kiln_type	bull_trench
STATE_UT	Punjab
District	Rupnagar
Unique_Kiln_ID	K334
Regulation_score	110
Kiln ID reference	
Kiln 2024	

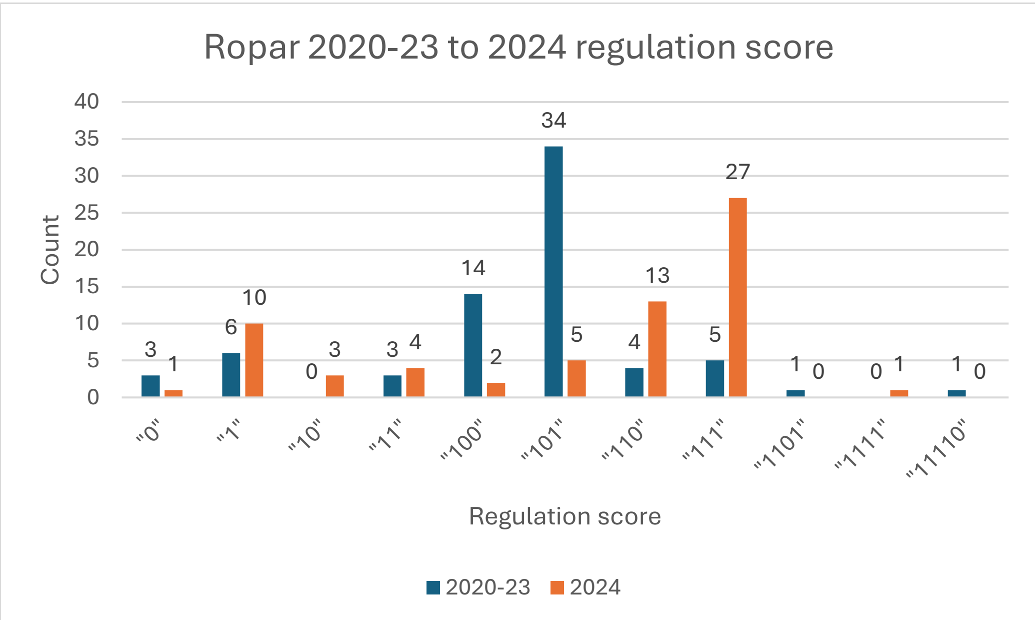
Join Punjab Li et al kiln age 2019 to Kiln 2020-23

Targetl-State Population Projections for India 2011-2036 (Release 2023) - StatePopProjection2023

Pun-Sub-District Population Projections for India 2011-2036 (Release 2024)

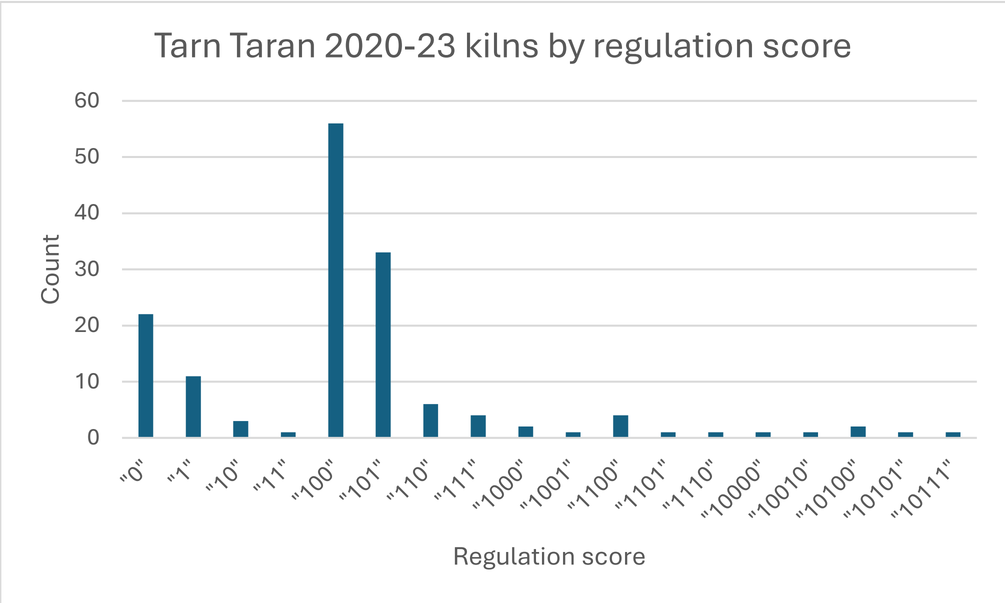
Ropar 2020-23 to 2024 regulation score

The figure below shows regulation score changes between the 2020-23 and 2024 Punjab datasets. This graph suggests a determined effort to shut down regulatory non-compliant kilns.



Tarn Taran

Tarn Taran is situated near the district of Amritsar. It is split into four sub-districts, Bhikhiwind, Patti, Tarn Taran, and Khadur Sahib. The author estimated the 2019 brick kiln quantity by calculating a ratio of brick kilns between Amritsar and Tarn Taran using the 2020 GeoAI data and then applying this ratio to total Amritsar kilns for 2019. This method assumes a similar distribution of kilns between 2019 and 2020 for the two kilns. The estimate provided 134 brick kilns for 2019 with 149 kilns in 2020. The 2024 data sensed 132 kilns. These results for 2020 and 2024 suggest the estimate for 2019 is in line with expectations. Three brick kilns that score a 0 are within the boundaries of the sub-districts of Tarn Taran. One liberation has taken place in Tarn Taran despite proximity to other liberations found in Amritsar.



The one liberation that was recorded in Tarn Taran took place on 1/3/2021 in the north of the sub-district of Patti. 15 children were recorded in this brick kiln. This kiln scores a 110 for regulation. Violating both road proximity and zigzag conversion

Category	Count
Male	7
Female	8
Total Liberated	15
6-14 Male	1
6-14 Female	3
15-18 Male	1
19+ Male	5
18+ Female	5

As only one liberation took place in Tarn Taran the 2024 data is used to draw trends between regulation score and closed kilns. So far in other districts regulation scores involving road proximity and kiln type are significant with links to modern slavery practises like child labour. All the kilns recorded for liberation in this sample are a combination of the first three regulations: kiln overlap, kiln to road proximity and kiln type.

Year	Tarn Taran brick kilns by regulation score and year established										
1993	11	111	110	100							
1994	111	111	111	1110	0						
1995	110	10	11								
1996	10	100									
1997	110	111									
1998	101	1	10	111	111	111	100				
1999	110	110	10	110	10	111	10110	110	110	10	1110	110
2000	11	10010	11	10000	110	110	111	110	10			
2001	110	110	10	11	101	101	10	10	110	111	110	
2002	111	111										
2005	110	110										
2006	10	11	10	110								
2007	111	111	111									
2008	10	111										
2009	110	10										
2010	111	111	10									
2011	110	110	110	100	11							
2012	110	111	111	110								
2013	110	110	110	0	110	110	10	110	110			
2015	0											

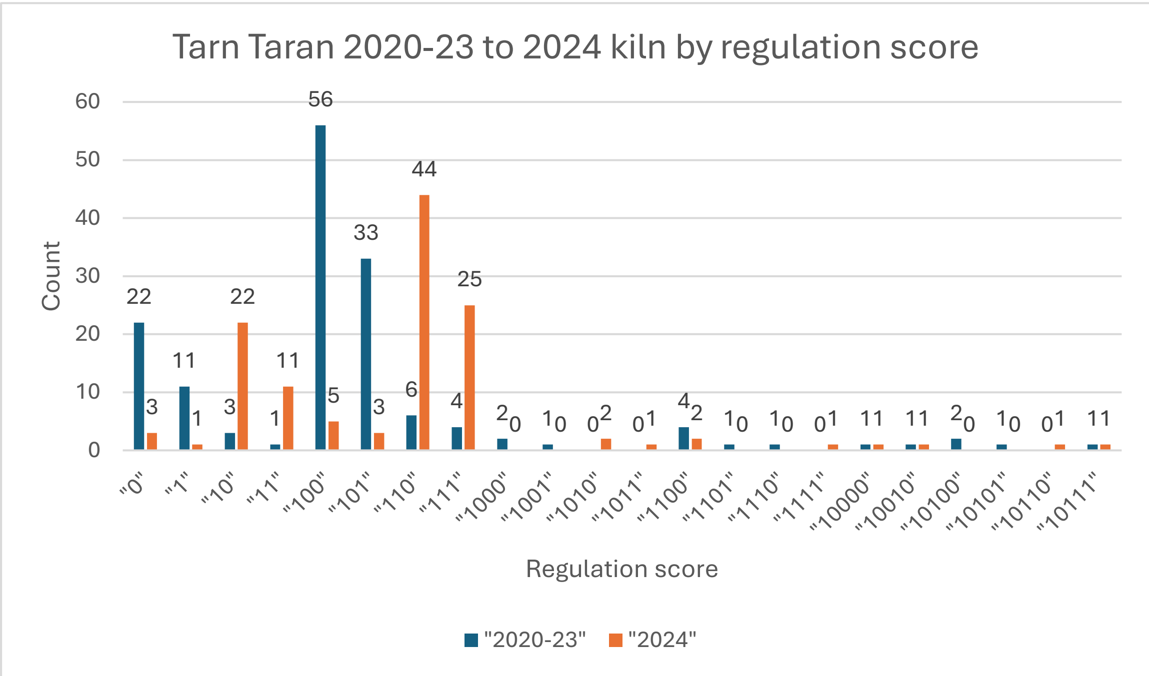
Regulation score	count
110	7
111	7
1110	2
10101	1
10110	1

16 kilns are potentially exempt from the regulation factor model.

The main period of growth for brick kilns according to the Li (et al, 2019) data was between 1998 – 2001 with Mansa also having a significant boost in brick kiln growth from 2009 – 2013. This 1998 – 2001 period follows the publication of the new proximity regulations for brick kilns. 8 liberations took place across three of the five districts sampled. Of these 8 liberations a total of 163 people were documented and liberated with 82 of 163 (50%) from the ages of 0 – 18. The largest number of documented workers in a single kiln was 58. The mean average number of workers per kiln for the sample is 20. None of the liberations in this sample were from a kiln with the clean designation granted to regulation score = 0 kilns. This does not mean that kilns that are scored a 0 in the model are all guaranteed to be free from modern slavery practises but out of 89 clean kilns only 1 (discussed later in the liberation results) was the subject of liberation by the partner NGO.
Another finding is liberations have occurred multiple times as the same kiln. It is concerning that within the span of half a year one of the kilns visited twice reported modern slavery practises both times, with child labour being explicitly used and documented. This suggests further attention and research is needed on the process of these liberation practises and the Indian government needs to address structural issues that drive people to this type of labour.

Regulation score	Total count across 5 districts sample
0	1
10	2
11	2
100	8
101	1
110	30
111	18
1110	4
10101	1
10110	1
10100	1
10111	1

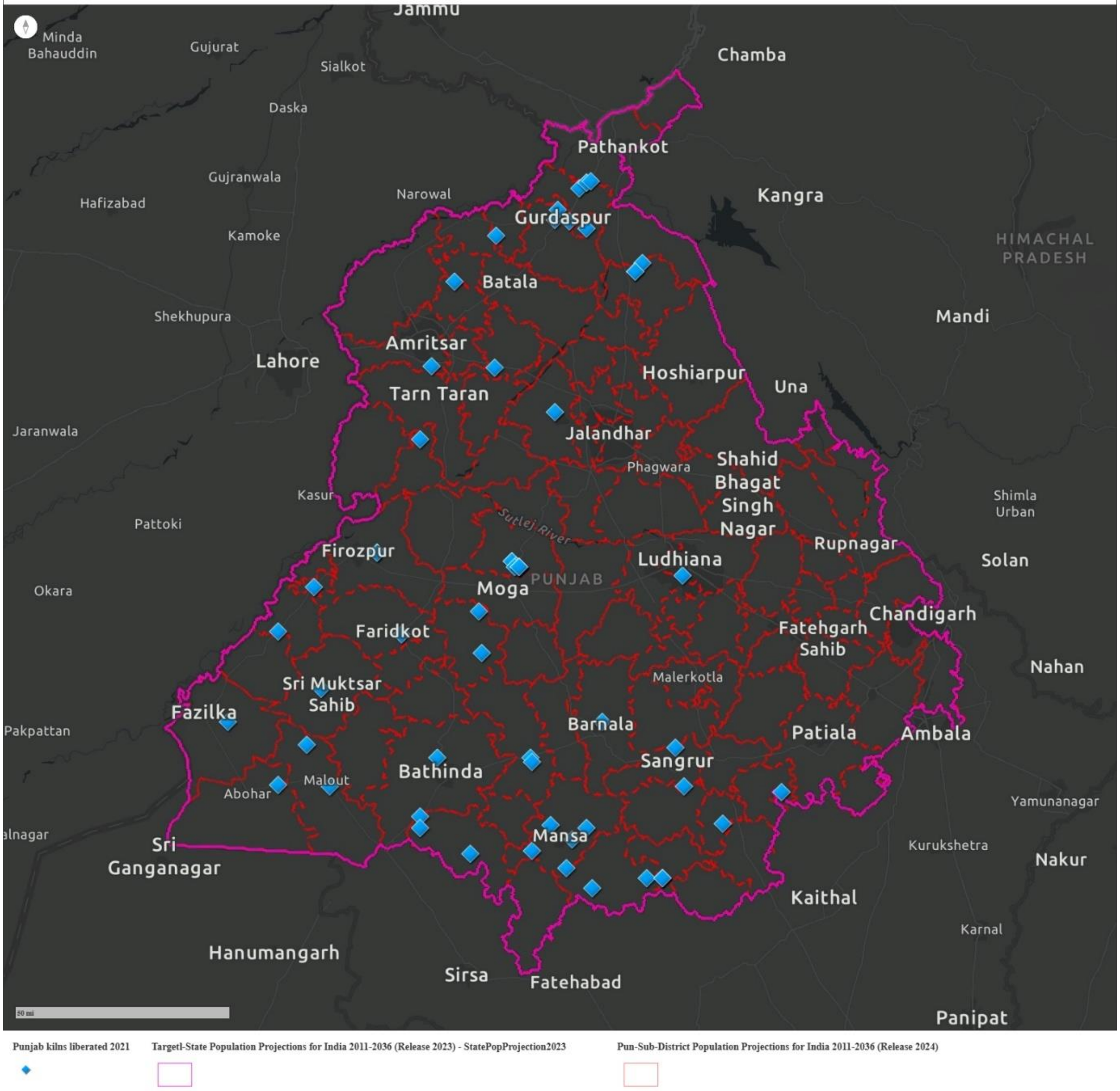
Tarn Taran 2020-23 and 2024 brick kiln regulation scores



4.1.3 Liberation results

Liberation data helps track regulation compliance against known instances of modern slavery within the brick kilns. However, there are a limited number of liberation reports from which to draw these trends. This section will review the known sites of liberation, kiln operation and regulation score to gain insights into the links between regulatory compliance and modern slavery. In the section above the author discussed several examples of recent kiln liberations and the links to modern slavery practises such as child labour. In this section an overview of every liberation case verified by the GeoAI 2020 database is reviewed

Figure 24.1: A map showing liberation points and their distribution



As seen in figure 24.1 liberation efforts have largely focused on the North, West, and South of Punjab with districts like Ludhiana, Rupnagar, Jalandhar and Hoshiarpur being untouched by these efforts. There is an interesting trend between brick kilns returning a regulation score of 0 and the areas of liberation. This proximity without investigation suggests two possibilities.

1- The partner NGO are also using regulation compliance as a proxy for modern slavery and poor labour rights and have no focused efforts on kilns that are compliant

2- The clean kilns for the 5-regulation model are also compliant with the remaining three factors included in regulation of brick kilns and are likely registered and regulated frequently making liberation either unneeded or less needed.

As seen in the figure above, liberation attempts have gained momentum in the last few years within Punjab. This improvement largely coincides with research interest in the brick belt and brick kiln industry of India and South Asia more broadly with many papers working on the task of tracking brick kilns for environmental and social wellbeing reasons being published around the early 2020's. This data was produced in early 2024 so 2024 is underrepresented but 2023 shows a strong growth in successful liberations. In the following figure an overview of all liberations in Punjab is shown.

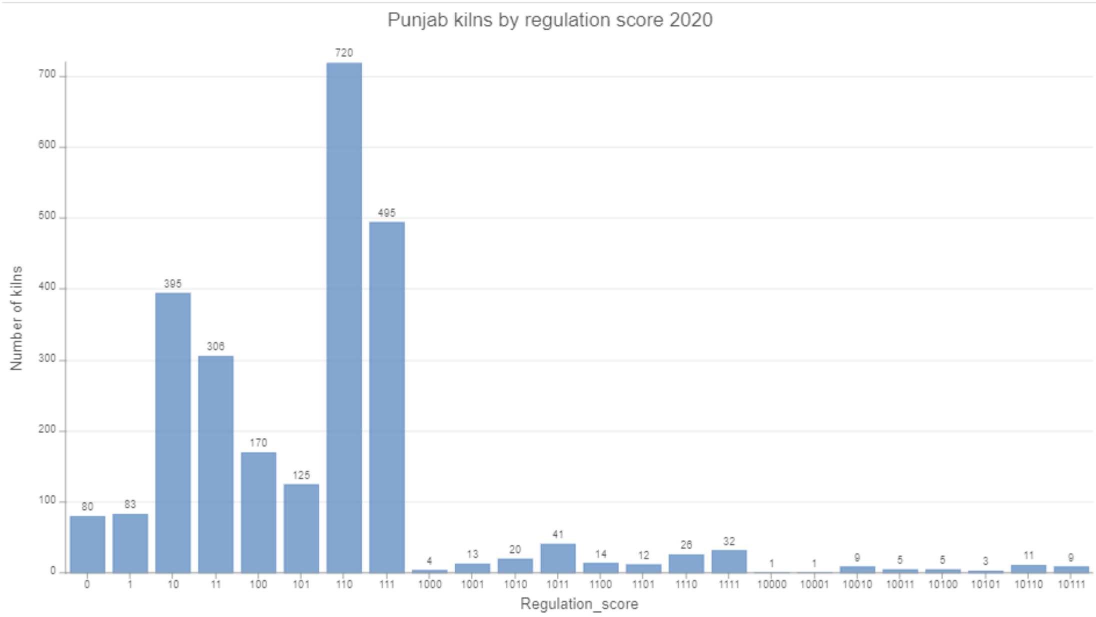
Year Established	Liberation Year	District	Regulation score	Liberated	Status
NA	2022	Amritsar	100	4	Active
1999	2021	Gurdaspur	100	13	Active
NA	2022	Gurdaspur	100	7	Active
2008	2021	Gurdaspur	100	5	Active
2004	**2020**	**Gurdaspur**	**0**	**6**	**Active**
1999	2023	Gurdaspur	101	15	Active
1999	**2023**	**Amritsar**	**0**	**2**	**Active**
NA	2023	Amritsar	10100	1	Active
NA	2021	Tarn Taran	100	15	Active
2010	2024	Moga	1101	6	Active
2010	2024	Moga	1101	6	Active
2013	2024	Moga	1001	6	Active
NA	2023	Hoshiarpur	1	8	Active
NA	2024	Hoshiarpur	1	6	Active
2012	2023	Moga	101	35	Active
1997	2023	Firozpur	111	21	Active
1993	2023	Firozpur	1	6	Active
1993	2024	Firozpur	1	7	Active
2013	**2023**	**Fazilka**	**0**	**1**	**Active**
NA	**2023**	**Muksar**	**0**	**10**	**Active**
NA	**2023**	**Muksar**	**0**	**10**	**Active**
2000	2022	Bathinda	100	14	Active
NA	2023	Bathinda	1000	59	Active
2006	2023	Bathinda	111	52	Active
NA	**2023**	**Bathinda**	**0**	**7**	**Active**
2000	2023	Mansa	1	29	Active
2000	2023	Mansa	111	12	Active
2009	2023	Mansa	111	11	Active
1998	2023	Mansa	1	11	Active
1999	2021	Sangrur	1	10	Active
2010	2023	Sangrur	100	72	Active
NA	2023	Sangrur	100	23	Active
1995	**2023**	**Sangrur**	**0**	**60**	**Active**
NA	2023	Barnala	1010	22	Active
2000	2019	Patiala	1	4	Active
NA	2021	Faridkot	101	16	Active
No kiln data	2022	Pathankot	No data	7	Doubt
No kiln data	2023	Mansa	No data	13	Inactive
NA	2023	Mansa	111	58	Active
1999	2023	Gurdaspur	100	15	Active
NA	**2023**	**Moga**	**0**	**104**	**Active**
NA	2023	Gurdaspur	1000	3	Active
NA	2023	Gurdaspur	1001	16	Active

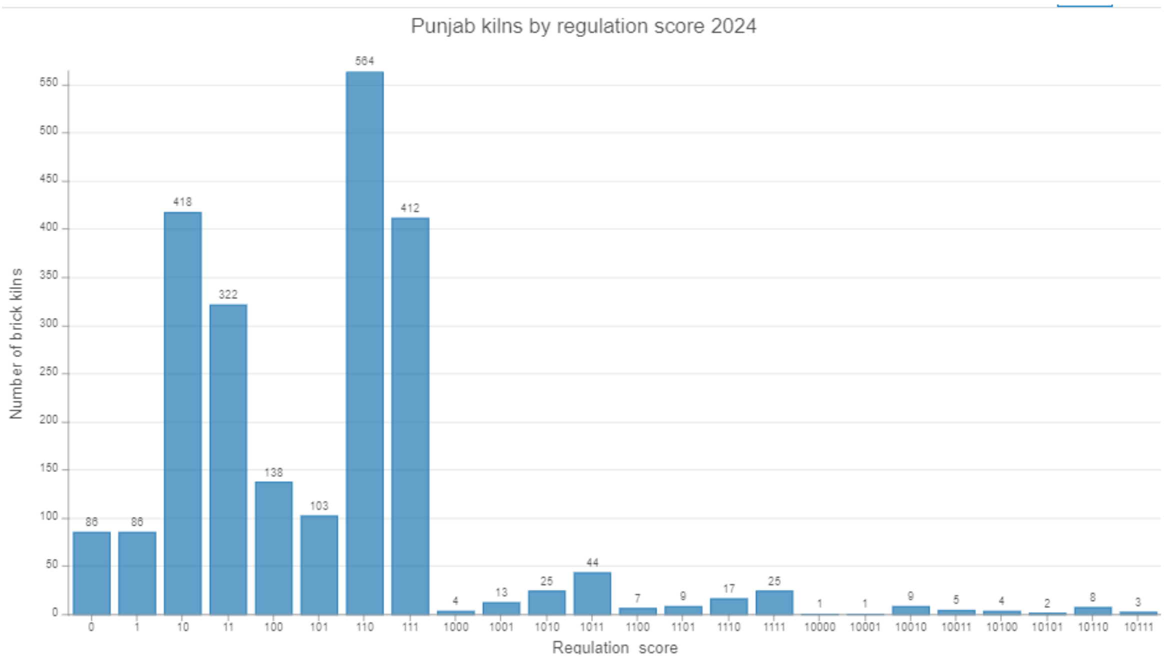
These results showing clean kilns containing liberated workers including children suggests a deeper analysis of regulation compliance is required to determine the efficacy of this model. For a majority of the brick kilns returning a 0 and containing a liberation record the number of liberated persons is relatively low compared to the overall liberation data shown above. However, Moga 2023 and Sangrur 2023 with 104 and 60 liberated persons recorded respectively urges caution when stating outcomes from this model.

This liberation report returning a modern slavery status for a clean kiln especially when that kiln uses child labour suggests the need for further ground truthing and analysis of regulation. Possibly this result suggests an 8-factor regulation model would capture a factor of non-compliance, but it is also possible that a kiln can be fully compliant with government regulation for the Punjab pollution control order (1198) and still use modern slavery. Furthermore, the liberation data only reporting kilns that do use modern slavery with no indication on if kilns have been audited where no liberations were required. This creates a risk of survivorship bias to the liberation data where only kilns with liberations are focused on. For example, it is not possible with the liberation data available to this study to track if a kiln was audited but did not use modern slavery practises.
Overall, the lack of liberation data for clean kilns despite liberations being spatially correlated with clean kilns as it is clear the distribution of clean kilns and liberations are similar, suggests these kilns are less likely to use modern slavery but without these clean kilns being investigated the kiln in Bathinda suggests caution is required from researchers when approaching analysis in modern slavery and regulation.
Three clean kilns are also not included in the 2024 data. Producing 4 kilns that potentially follow all regulations in the model and are still at risk of modern slavery. A kiln not appearing in the 2024 data is not necessarily a sign of wrongdoing on behalf of the kiln as kilns can also be dormant due to other reasons than official closures.

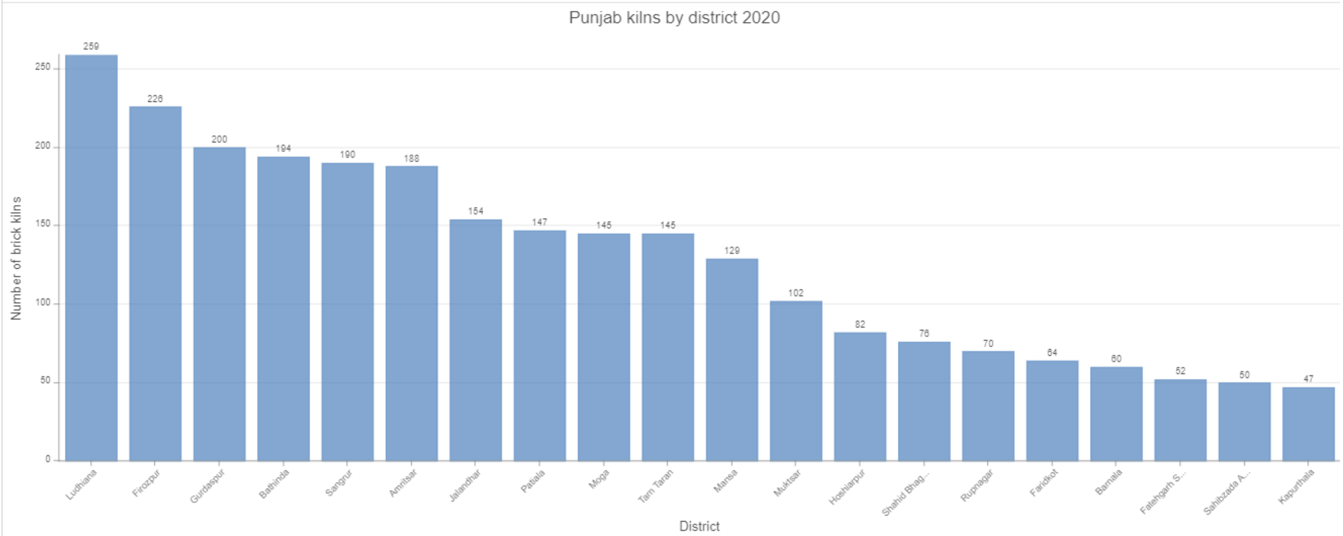
4,2 Punjab regulation model 2024

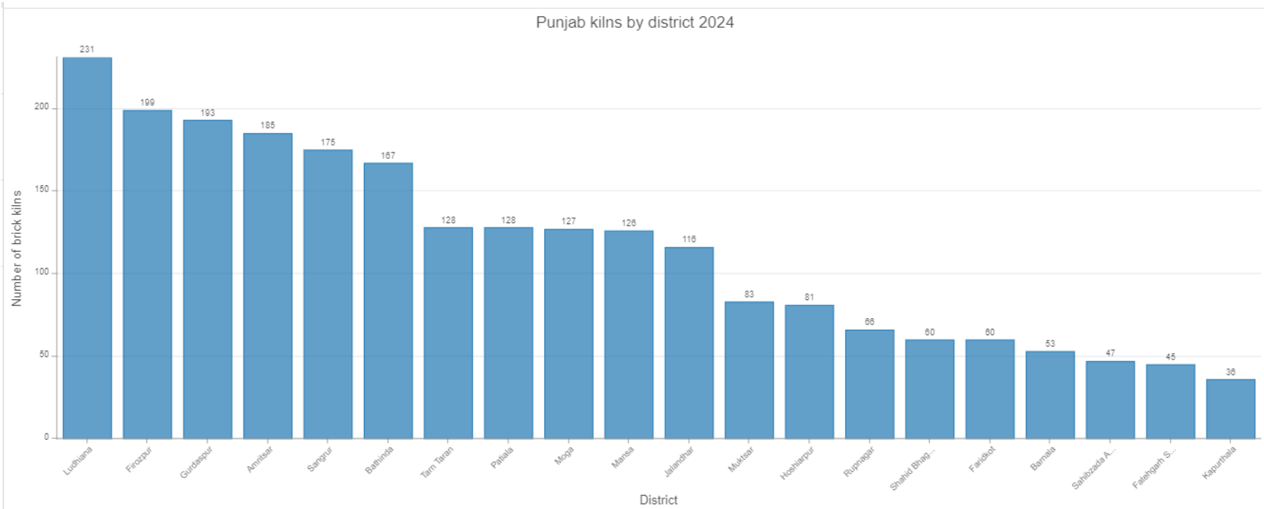
During the process of research, the team of researchers at the Rights Lab also managed to map a 2024 dataset to the state of Punjab. The arrival of this dataset during the research time of this study has led the author to feature this updated database where possible. For example, as seen above the 2024 data can be used to track kilns that have been shut down and this shut down can be used to infer if that kiln was registered or informal. The 2024 database can also be used to track regulatory compliance for the new kilns established in 2024, but this was not within the research scope due to the limitations of the study including time resources and number of researchers dedicated to this project.
However, the overview of the 2024 database sets the stage for other researchers to further explore the links between kilns active in 2024 and their ties to modern slavery practises. Below regulatory compliance is tracked for the GeoAI 2020 kilns that remain active in 2024.





The distribution of regulation scores has largely remained the same. Road proximity violations have risen along with kiln overlaps. Below is a comparison between district distribution. Ludhiana features as the most brick kiln populated district.


Punjab kilns by district 2020
Number of brick kilns
0
50
100
150
200
250
259
226
200
194
190
188
154
147
145
145
129
102
82
76
70
64
60
52
50
47
Ludhiana
Firozpur
Gurdaspur
Bathinda
Sangrur
Amritsar
Jalandhar
Patiala
Moga
Tarn Taran
Mansa
Muktsar
Hoshiarpur
Shahid Bhag...
Rupnagar
Faridkot
Barnala
Fatehgarh S...
Sahibzada A...
Kapurthala
District


Punjab kilns by district 2024
Number of brick kilns
0
50
100
150
200
231
199
193
185
175
167
128
128
127
126
116
83
81
66
60
60
53
47
45
36
Ludhiana
Firozpur
Gurdaspur
Amritsar
Sangrur
Bathinda
Tarn Taran
Patiala
Moga
Mansa
Jalandhar
Muktsar
Hoshiarpur
Rupnagar
Shahid Bhag...
Faridkot
Barnala
Sahibzada A...
Fatehgarh S...
Kapurthala
District

Kiln to kiln overlap regulation.

The Punjab 2024 dataset helps the author check how kiln compliance with regulation factors has changed from the 2020 – 23 dataset and the updated 20204 dataset. First, it can provide insight into the kilns that are no longer operational due to being shut down or abandoned. Second, it shows how clean kilns from 2020 – 23 can become non-compliant with brick kiln regulation as new kilns are built around them. Meaning kiln overlap compliance can be modified for a brick kiln just by the surrounding area of that brick kiln changing. Third, the 2024 dataset may have captured kilns that were missing from 2020 – 23 database.

The 2024 Punjab database can be visualised in two different ways. First, the 2024 Punjab database can be visualised as its own location point layer in which all Punjab 2024 kilns are mapped to the basemap. This means the layer includes kilns that were not present in the 2020 – 23 data. The other method is to use a merge layer so only kilns that are in both the 2020-23 and 2024 data are spatially joined together. This second method allows for a quick automation of checking which kilns are both originally part of the 2020-23 data and may have shut down and provides a count of the kilns that remain operational.

A kiln overlap query between Punjab kilns 2024 and the Punjab kilns 2020-23 database shows the creation of 37 new kilns that violate regulation factor 1. This means kilns are being created that put kilns that were previously clearly this regulation at risk of non-compliance. Depending on the previous regulation factor 1 score for these kilns up to 74 more kilns now break regulation factor 1.

Figure 27.0: A spatial analysis showing near analysis to test kiln overlap between 2020-23 and 2024 Punjab data

37 connections exist within a 1000 metre radius between 2020-23 brick kilns and new 2024 brick kilns. The author filtered out connection distances < 70 metres to stop the GIS analysis from detecting connections between the same kilns. These issues of same kiln detection are due to the slightly different in location point placement between the 2020-23 and 20204 datasets. The author reviewed these connection distances and determined > 70 metres of distance between kilns was sufficient to track new kilns.
The straight-line distance (meters) measure shows the measurement of the line of connection between location points which is used to infer proximity between brick kilns. In the figure below the author loads the 2024 brick kiln results on top of this visualisation to show the capture of the kiln being linked to the 2020-23 kiln

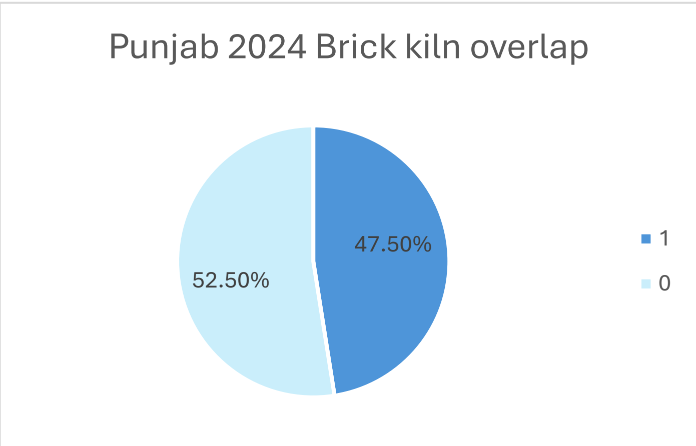
Figure 27.1: A spatial analysis showing near analysis to add 2024 kilns to model without duplication of 2020-23 kilns to mitigate inaccuracies of point location data

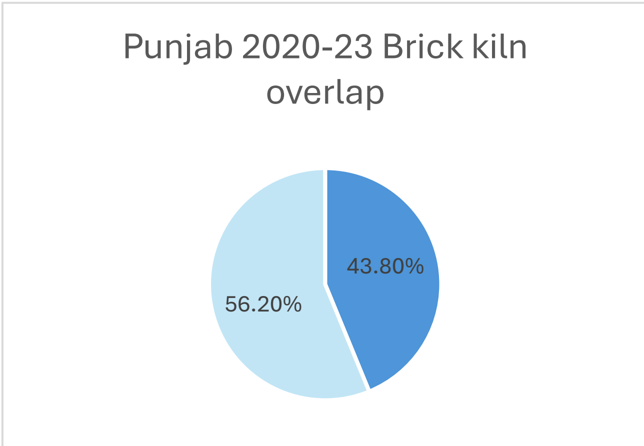
The blue diamond's symbolise kilns captured by the 2024 Punjab kiln dataset. Two of the kilns have regression codes from the 2020-23 data while the 2024 kiln does not show a regression code. This is to help make them visually distinct for analysis. As the red diamond symbology is clear from a distance but covers the original symbology of the 2020-23 kiln regulation score. The author then removed kilns that already output a regulation score of 1 for factor 1 (kiln overlap = 1000 metres) and added any additional overlapped kilns to the model. The manual method for this analysis was chosen because the inaccuracy of the location points combined with some brick kilns being very large means the author is concerned an automated method would misclassify many of the kilns within this database.

For example, the figure below shows a kiln with a location connection distance of 81 metres, but it is clearly the same kiln.

The last example of this has been discussed previously, either explained through competitive kiln owners constructing new kilns or kiln owners expanding their territory kilns that were compliant in 2020-23 have lost that compliance rating.

Figure 27.2: A spatial analysis showing how regulation factor 1 (kiln overlap) is influenced by kiln expansion and kiln competition

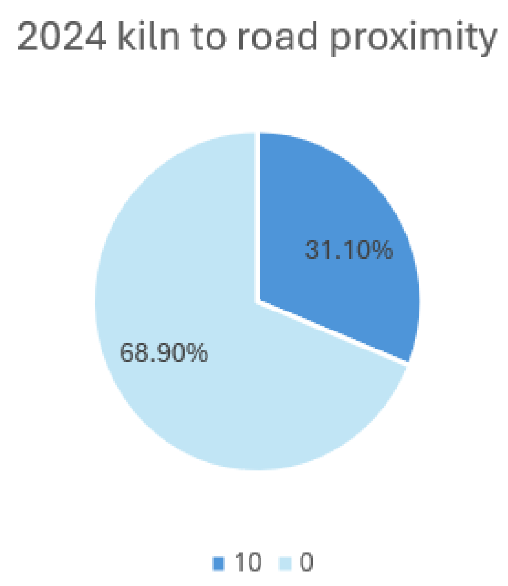


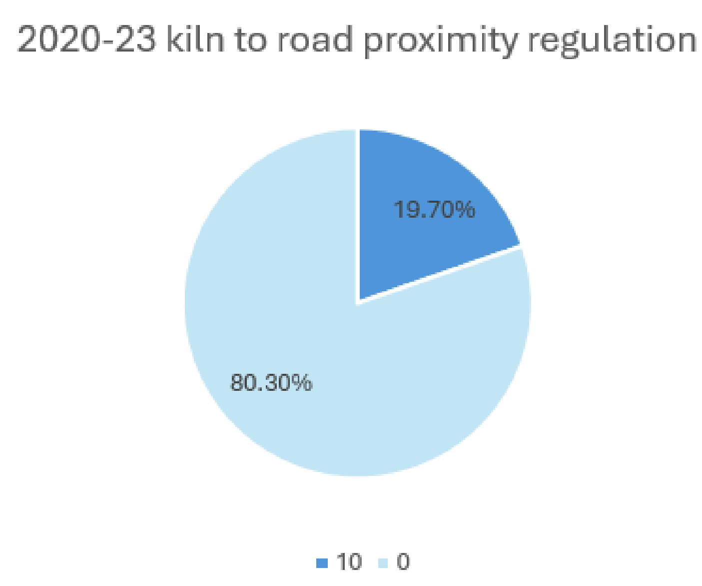


This data shows that the brick kiln overlap regulation is still a significant source of regulation non-compliance. In 2024 47.5% of kilns are non-compliant with the kiln overlap proximity regulation. In 2020 43.8% of kilns are non-compliant. The nature of regulatory compliance means failing on one regulation is enough to make a kiln non-compliant. Previous analysis has shown very few kilns are established before 1988 which means many of these kilns are likely to be breaking regulation.

Kiln to road proximity regulation

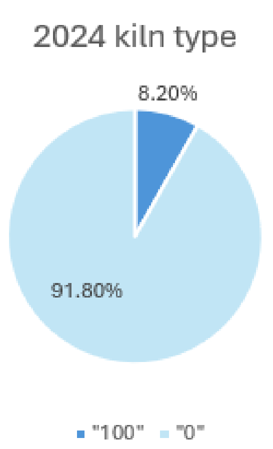
Kiln to road proximity is an important regulatory factor for MSHT practises not only because it can be used to measure kiln compliance but because the ILO consider restriction to transport as a sign on MSHT practises. Kilns must be 100 metres from roads but at the same time distance from roads suggests a lack of mobility. 630 kilns are breaching this rule. In 2024 this decreased to 19.70% or 399 kilns. Unlike kiln overlap which can be manipulated by other brick kilns being built within the regulation zone without a neighbouring kiln necessarily being involved in the process the model does not have a system in which road proximity can be changed without the brick owner building near a road. As this model does not track new road developments.

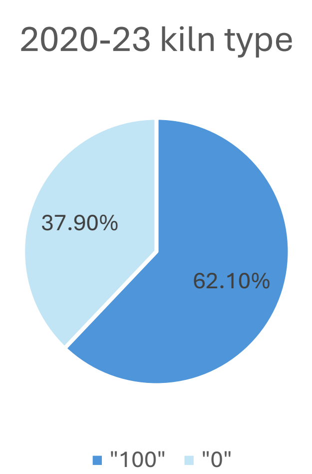




Kiln type

Between 2020-23 data and 2024 data there is a significant improvement in the adoption of zigzag kiln technology within Punjab. This shows significant progress in adoption of cleaner kiln technology likely pushed by the environmental concerns of the Indian government. Kiln transition especially is being focused heavily on the research literature and policy development.





The data from town proximity and brick kilns shows that most kilns are not breaking the town regulation rules. Due to manually assessing these results it is possible a more detailed analysis of town proximities to brick kilns would produce more kilns that violate this regulation. However, the author finds it more likely that town proximity and city proximity are more significantly regulated by the Indian state government like the push for cleaner technology meaning zigzag kilns compliance is also more significantly targeted.
This finding is interesting as it contradicts the expectation of kilns being near the towns and cities from Boyd et al (2018: 2021) research. This means it is likely that kiln clusters are situated just outside of the kiln regulation proximity.

There is a similar trend with the city proximity. The figure below shows that these kiln clusters do likely supply to local areas, but kiln owners are balancing these supply line demands with following kiln regulations. From 2020-23 to 2024 there has been a slight decline in percentage of kilns that fail the regulation factor.

Figure 27.6: A pair of maps showing that town and city proximity is largely complied with

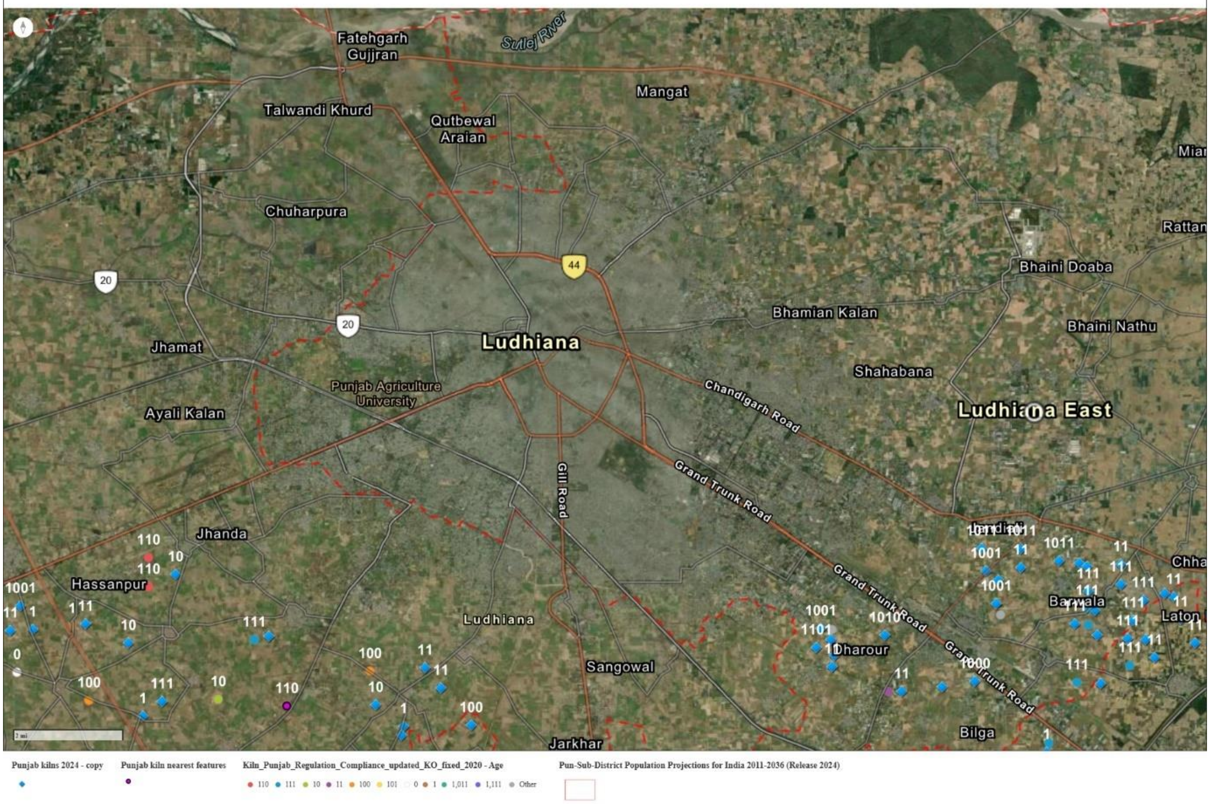
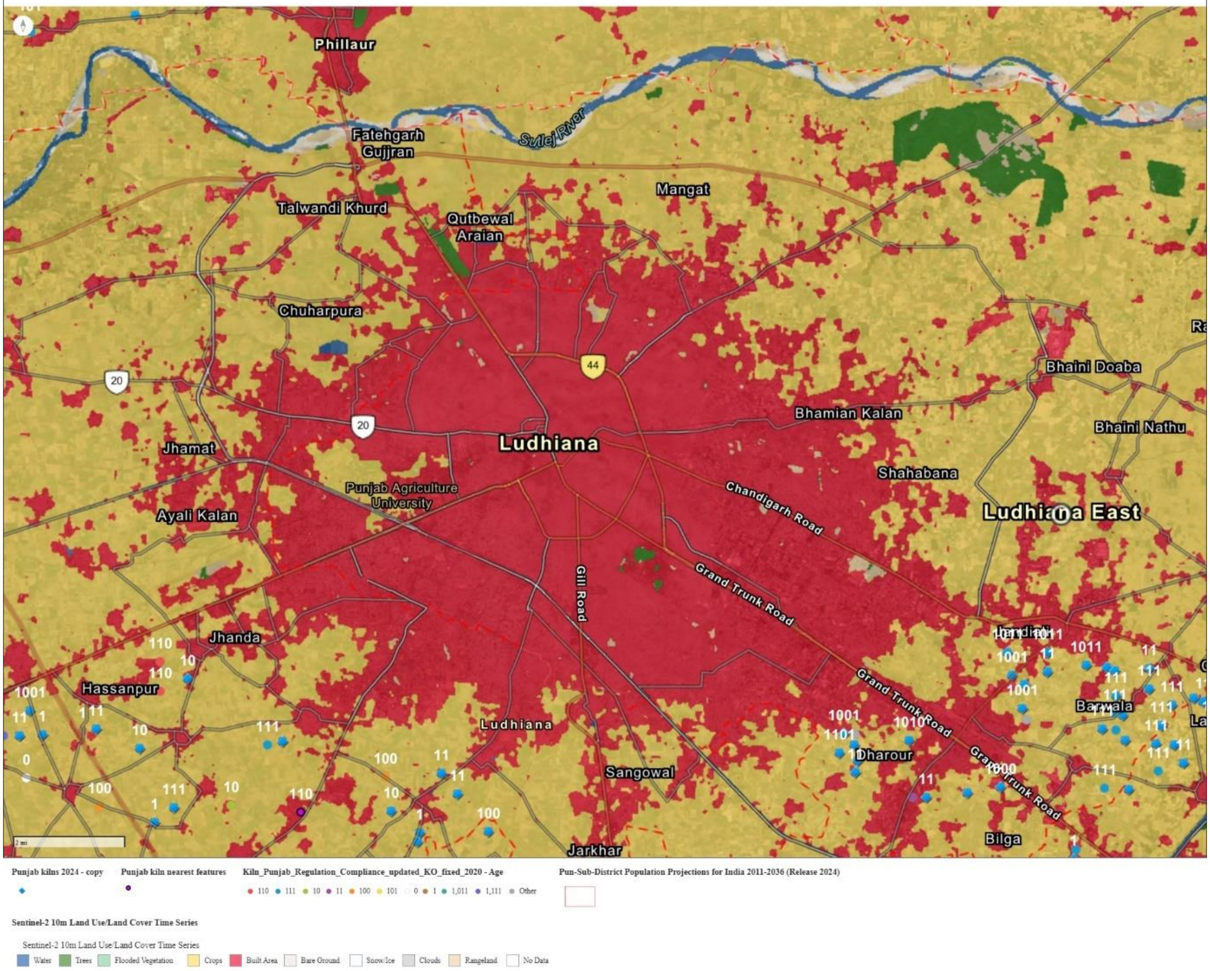


Figure 27.6: A pair of maps showing that town and city proximity is largely complied with



4.3 Haryana

In this section the thesis provides a streamlined overview of Haryana. Haryana is suggested as a key next step for understanding brick kiln operations and the factors which suggest where brick kilns will be established and their likelihood of employing MSHT practises.

<u>brick kiln overview</u>

Due to limitations on research time and resources Haryana is analysed with the top 3 regulation factors from Punjab. These being, kiln to kiln overlap, kiln to road proximity and kiln type. This approach was chosen for two reasons. First, these three factors can be automated and monitored at a much more efficient rate than town and city regulations. Second, these three factors accounted for most brick kilns captured as non-compliant in Punjab.

Below is a snapshot of the analysis conducted for Haryana highlighting the intelligence it is possible to gather using geospatial analysis of the brick kilns.

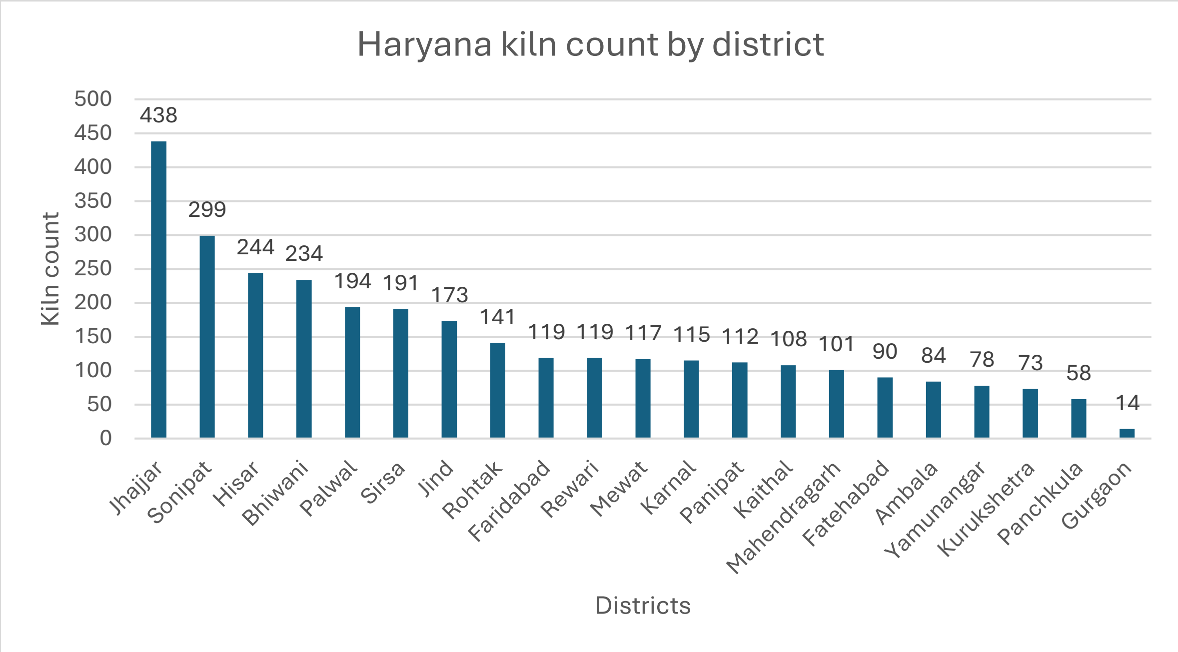
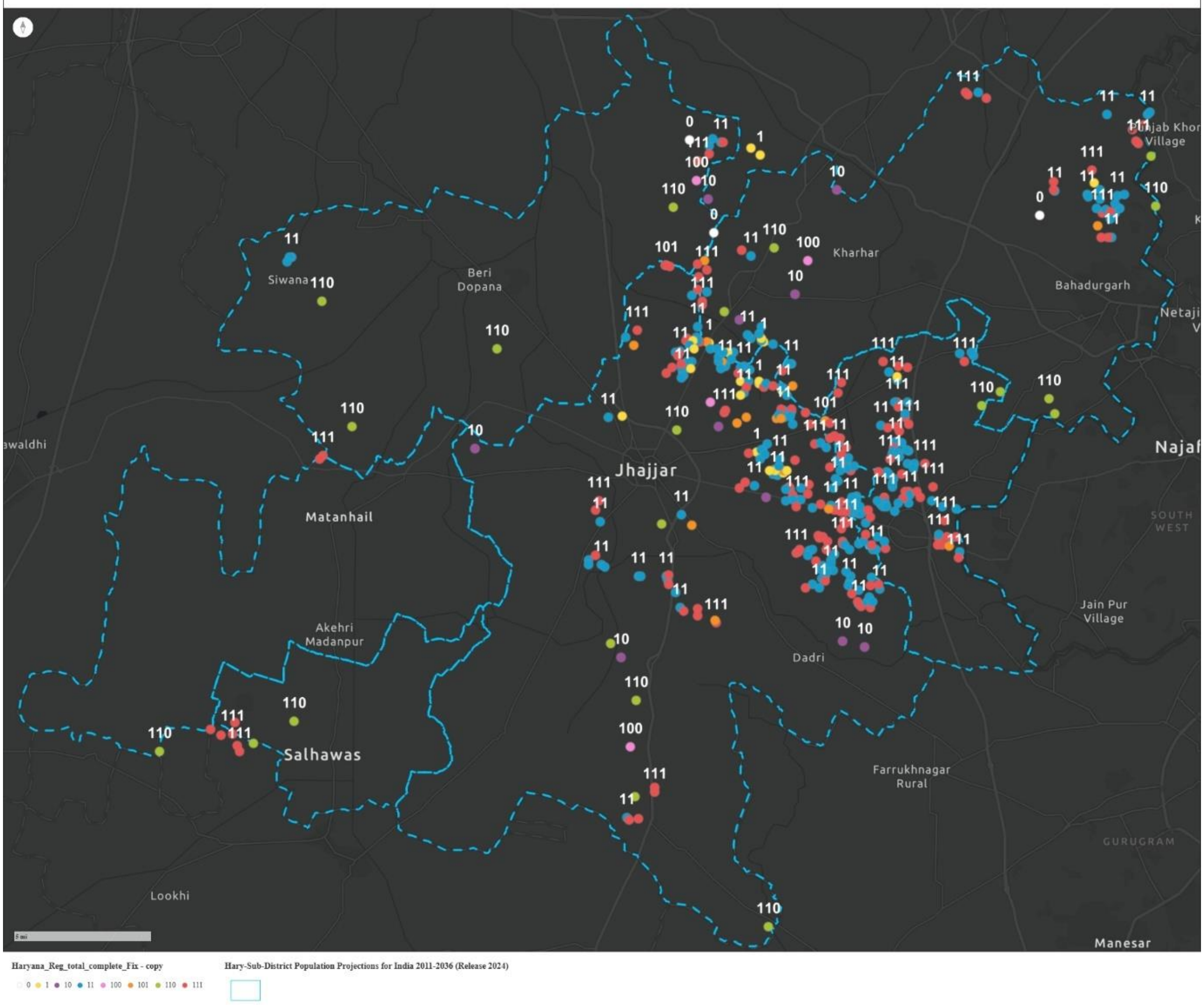
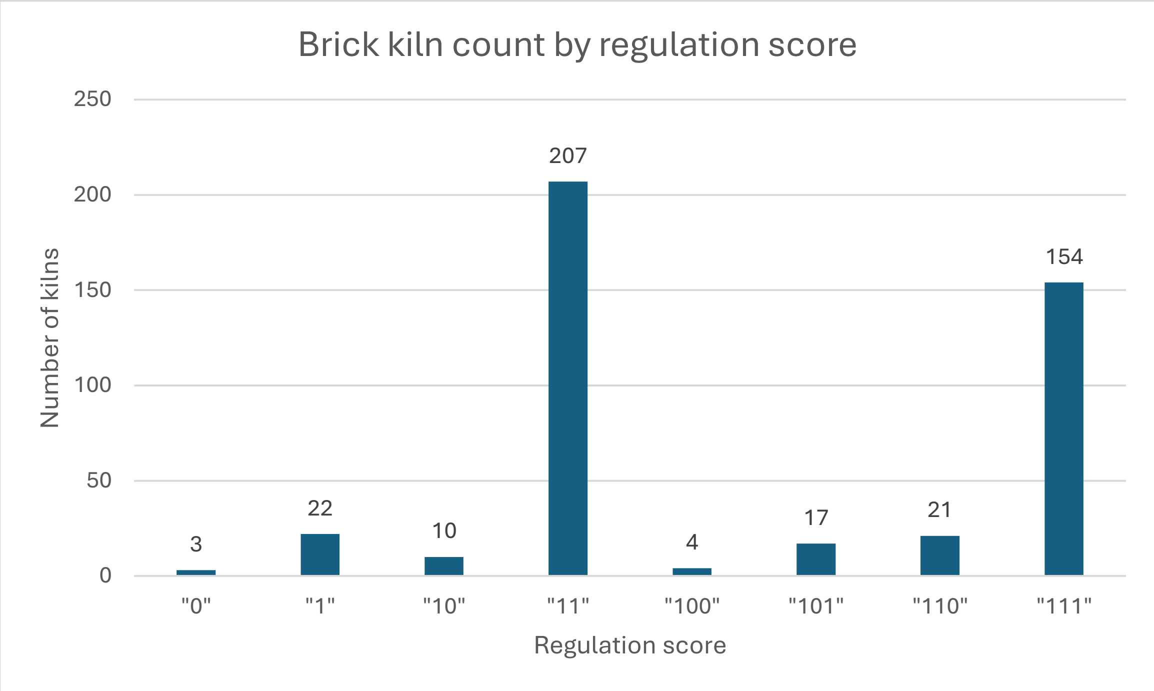


Figure 29.0: A map showing Haryana brick kilns with regulation score for Jhajjar



A significant cluster of kilns exists around 4 sub-districts around the centre of the district. These clusters largely violate kiln to kiln proximity and kiln type regulations. These clusters could suggest violations of town and city regulations, and this is a potential area of analysis for future research.

Only 3 / 438 kilns return a clean regulation score. As only one regulation factor needs to be violated to remove a kiln from the clean designation it is possible a 5 factor or full factor regulation model from the documentation (Punjab Pollution Control Board, 1989; Haryana Government Food and Supplies Department, 1972) would return a much-reduced sample of clean kilns.



Liberation data

Seven data points for liberation are available for Jhajjar with the following breakdown.

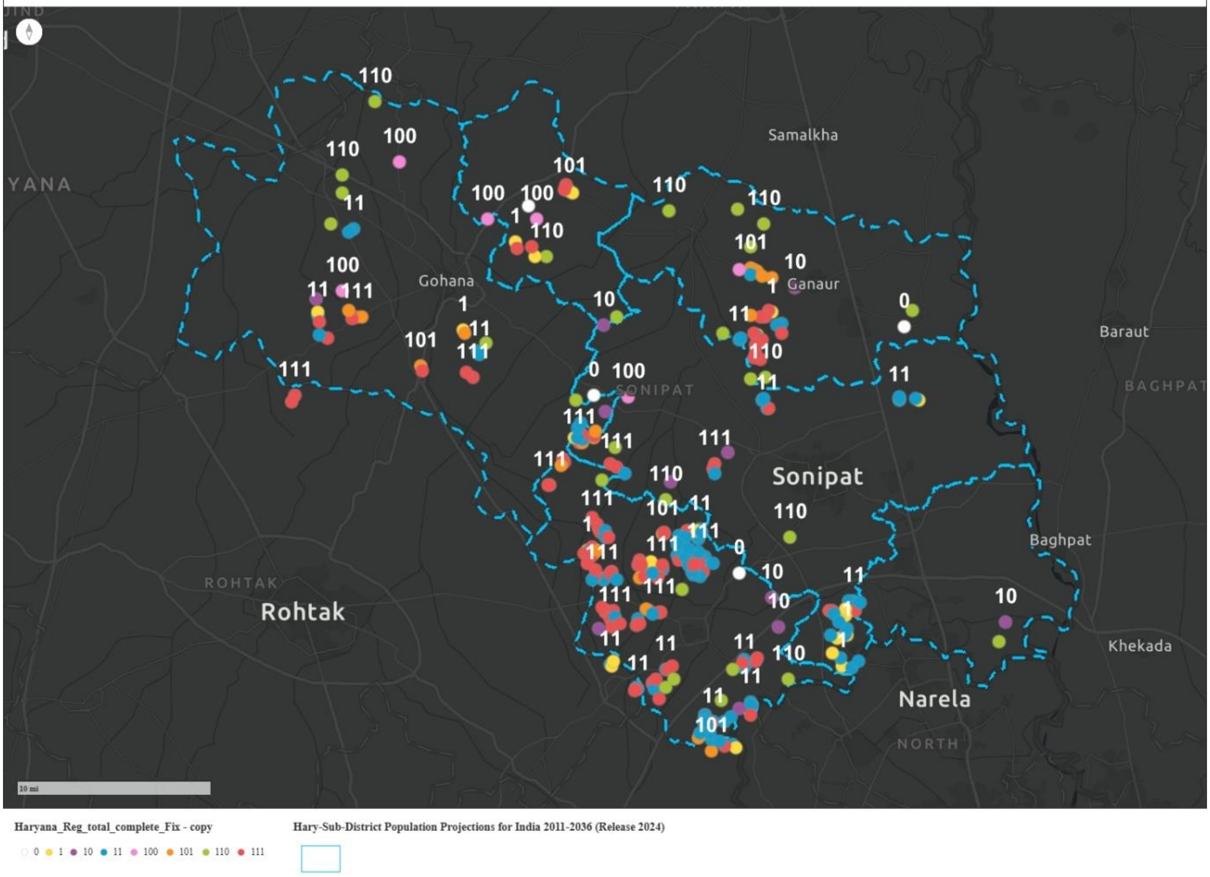
Liberation	Total persons liberated	Lat Long
Jhajjar (Reg score = 100) 2022	5	28.64 / 76.69
Jhajjar (Reg score = 110) 2023	9	28.58 / 76.66
Jhajjar (Reg score = 11) 2024	4	28.67 / 76.69
Jhajjar (Reg score = 111) 2022	3	28.54 / 76.79
Jhajjar (Reg score = 11) 2022	5	28.61 / 76.77
Jhajjar (Reg score = 111) 2023	8	28.53 / 76.78
Jhajjar (Reg score = 110) 2022	1	28.63 / 76.90

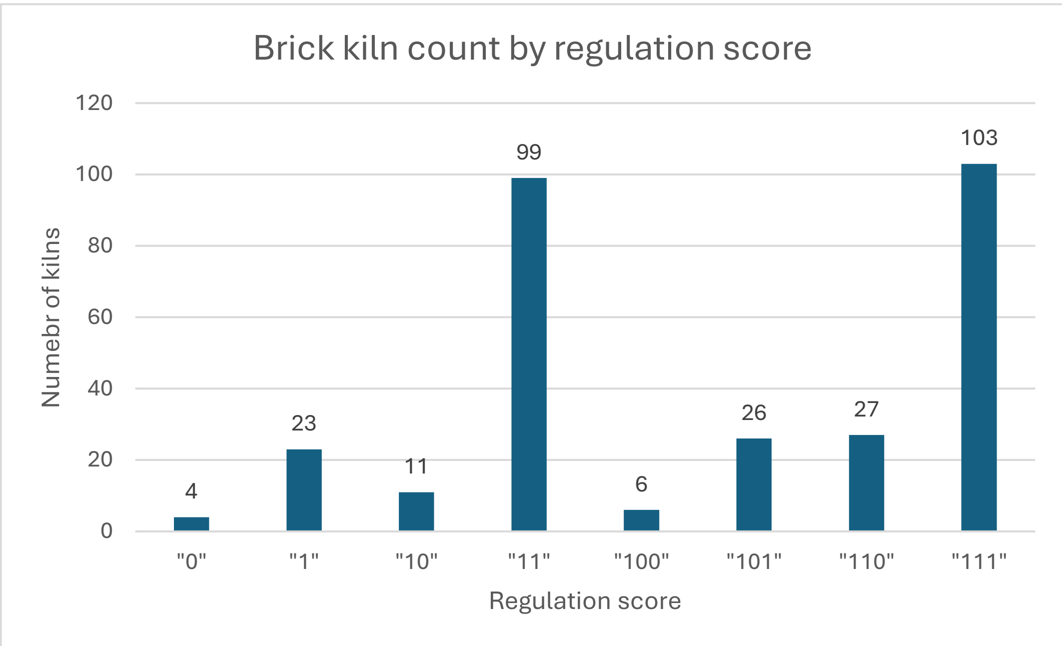
The liberation for Jhajjar regulation score = 11 for 2024 is located near an identified brick kiln. This location point being mislocated is often human error or a slight mistranslation of coordinates. Previously the thesis has covered analysis methods to correct for these errors, and the thesis uses a mix of a near neighbour analysis using near tables and closest point analysis with visual interpretation.

Sonipat

The GIS application enables researchers and MSHT analysts to identify clusters of kilns that violate regulation. From these data points regulation can be used as an entrance into discussions of MSHT practises in the brick belt and auditing kilns for child labour and work conditions. There is no liberation data for this district so regulation score results cannot be

Figure 30.0: A map showing Haryana brick kilns with regulation score for Sonipat





tied to instances of MSHT. Additionally, there is no 2024 data for Haryana as of the time of writing.

Liberation data

Year	Total persons liberated
2020	1
2021	2
2021	5
2021	12
2022	3
2022	1
2022	5
2022	1
2022	5
2023	8
2023	4
2023	9
2023	6
2024	4
2024	26

Liberation analysis conducted in the Punjab section of the thesis is limited by a severe lack of data. Alongside a lack of quality in data the current data collection method lacks a clear communication of if there is a difference between a kiln being visited and not containing child labour or other signs of MSHT (false positive) and kilns that are visited and do contain signs of MSHT. This lack of false positive result makes drawing insights between MSHT prevalence and regulation score difficult.
Moving forward an understanding of kilns that are confirmed as clean both from a regulatory capacity and MSHT standpoint should be distinguished by a metric of analysis to facilitate understanding of the brick kilns.

5.0 Conclusions

This thesis has studied 5835 brick kilns. Despite clear moves to modernise the brick belt and promote regulatory compliance from Punjab and Haryana a lack of a publicly available kiln register makes tracking progress difficult. This data source provided through the Arc GIS online platform aims to democratise and synthesise research findings and data over the last 6 years. The thesis combines Li et al (2019) kiln aging data with the GeoAI platform which tracks kilns across the brick belt with Esri Living Atlas layers to provide a model for tracking brick kilns regulatory compliance remotely.

The remote analysis of regulation for the brick kilns is largely successful with all the brick kilns analysed in either a 5 factor (Punjab 2020-23) or 3 factor (Punjab 2024 and Haryana datasets) regulation model. Kiln to kiln proximity, kiln to road proximity and kiln type seem to be the three most pressing regulatory matters within the model. However, due to a lack of quality and quantity data the additional contribution to the thesis which aimed to model the prevalence of modern slavery produced inconclusive results. A vast majority of clean kilns have no liberation data but as discussed above without a clear distinction between visited and unvisited kilns it is impossible to know if clean kilns have no liberation data because they lack MSHT practises and conditions or because these kilns have not been visited.

Furthermore, it is also possible that the partner NGO is targeting brick kilns that also break regulatory compliance, in which case clean kilns are less likely to be visited. This is however all conjecture and without more data conclusions cannot be drawn. Despite this the method proposed for this paper is scalable and provides a key source of data intelligence for tackling non-compliant brick kilns. The concerns over ethical considerations of remote sensing are addressed by Walker (2020;2021;2022) these concerns need to be balanced against the value of this resource and grounded in the day-to-day operations of remote sensing for human rights research as well as ethical theory.
the brick kilns exist in spaces that are still not consistently well documented, many of the features that influence brick kilns and can be used to extract useful knowledge are not contained within the authoritative data of these countries. This gap in knowledge can be addressed by satellite technology via remote sensing. Furthermore, while issues of surveillance are crucial the proposed study intentionally limits the spatial resolution of the platform to make individual identification significantly difficult.

The thesis reports 15.5% of Punjab 2020-23 kilns are regulatory compliant with this figure rising to 19.2% (adjusted for the 5 regulatory factor model) for 2024. Haryana returns 22% compliance rating but uses a 3 regulatory factor model. Brick kilns only need to fail one regulatory test to be non-compliant and as such it is reasonable to suggest a full regulation compliance model would result in more accurate findings and more brick kilns designated as non-compliant. This ability to designate brick kilns as non-compliant with geospatial analysis provides a makeshift register of brick kilns and this non-compliance can be used to open up investigations of brick kilns to gain further intelligence of kiln operations and links to MHST.

The NGO working with the University of Nottingham described the ability to consistently monitor the brick kilns as a new form of enforcement. An enforcement asset that can successfully monitor and provide more authoritative data to combat the illicit activities occurring within the brick belt. Therefore, from a cost benefit analysis remote sensing provides an effective tool for this research. Researchers must be careful when producing knowledge to take mitigations against the knowledge being weaponised. To improve surveillance for the global south could be interpreted from a neo-colonial or securitisation approach and mitigations must be put in place against this.

This study is unfortunately limited in its analysis by a gap in quality between the secondary data from ArcGIS and the wider University of Nottingham project and the liberation data from Punjab and Haryana. Three main data issues limit the suitability of this data for analysis. First of all, there is a distinct lack of a "false positive" result. For example, if a liberation worker visits a kiln and finds no workers under modern slavery for would this be recorded in the data? In a high quality dataset this would be recorded as a false positive in the sense that the kiln was investigated or visited but no MSHT evidence or practises were uncovered. Without this false positive all the negative values look the same. This is an issue as negative values (no liberation reports) can occur for three main reasons.

- The kiln has not been visited.
- The kiln did not contain any evidence of MSHT or require workers to be liberated.
- The partner NGO are unaware of the status of MSHT within the kiln

This calls into question the approach of the liberations. It seems like liberations are only operating within kilns that are known for MSHT beforehand rather than liberations working alongside regulators to provide a more random inspection element to MSHT.

From an analysis approach without a distinction between truly negative MSHT kilns (if such a thing exists which many researchers and charities doubt) and kilns that have not been visited it is not possible to perform regression analysis or tease out trends between brick kilns.
Second, the liberation efforts are spatially concentrated and partial. This is unsurprising as liberation efforts are only a few years old, but it does mean the data is not mature enough for complex analysis. In an ideal world this GIS model could have identified which regulatory factors are most likely to signify MSHT practises. At the time of writing the data quality prohibits this.
Third of all the lack of high quality liberation data means conclusions to the question of factors of MSHT prevalence are still unknown. From the data it seems clean kilns have had less liberations, but it is also possible that "clean" kilns are harder to access due to no regulatory breach. It is also worth noting as before this regulation model considers 5 of 8 regulatory factors as the other 3 factors were too difficult to map due to inaccessible data for mango fields given the scope of the project.

Despite the negative implications of this the data we were able to analyse and the model that was able to be constructed do suggest new more efficient ways to regulate brick kilns. This research is the first paper to provide a regulation score for Indian states that can be scaled by other researchers as long as they have the regulatory guidelines to hand. To be able to remotely regulate brick kilns and flag suspect kilns is already a significant gain for regulators and the state and with future research and data maturity links between MSHT and the brick kilns may become more apparent.

6.0 Bibliography

AAAS (2007). *High-Resolution Satellite Imagery and Housing Destruction in Ulu, Sudan | American Association for the Advancement of Science (AAAS)*. [online] American Association for the Advancement of Science (AAAS). Available at: https://www.aaas.org/page/high-resolution-satellite-imagery-and-housing-destruction-ulu-sudan [Accessed 29 Sep. 2024].

AAAS (2009). *Satellite Imagery and Possible Mass Graves in Sheberghan, Afghanistan | American Association for the Advancement of Science (AAAS)*. [online] American Association for the Advancement of Science (AAAS). Available at: https://www.aaas.org/resources/high-resolution-satellite-imagery-and-possible-mass-graves-in-sheberghan-afghanistan [Accessed 19 Sep. 2024].

AAAS (2010). *High-Resolution Satellite Imagery and the Destruction of Cultural Artifacts in Nakhchivan, Azerbaijan*.

AAAS (2011). *High-Resolution Satellite Imagery and the Conflict in Chad and Sudan | American Association for the Advancement of Science (AAAS)*. [online] American Association for the Advancement of Science (AAAS). Available at: https://www.aaas.org/resources/high-resolution-satellite-imagery-and-conflict-chad-and-sudan [Accessed 29 Sep. 2024].

AAAS (2012a). *High-Resolution Satellite Imagery and the Destruction of Cultural Artifacts in Nakhchivan, Azerbaijan*. [online] American Association for the Advancement of Science (AAAS). Available at: https://www.aaas.org/resources/high-resolution-satellite-imagery-and-destruction-cultural-artifacts-nakhchivan-azerbaijan.

AAAS (2012b). *Satellite Imagery Analysis for Urban Conflict Documentation: Aleppo, Syria*. [online] American Association for the Advancement of Science (AAAS). Available at: https://www.aaas.org/resources/satellite-imagery-analysis-urban-conflict-documentation-aleppo-syria.

AAAS (2013a). *Conflict in Aleppo, Syria: A Retrospective Analysis | American Association for the Advancement of Science*. [online] www.aaas.org. Available at: https://www.aaas.org/resources/aleppo_retrospective.

AAAS (2013b). *High-Resolution Satellite Imagery and the Destruction of Housing Structures in Negeha, South Darfur*. [online] American Association for the Advancement of Science (AAAS). Available at: https://www.aaas.org/resources/high-resolution-satellite-imagery-and-destruction-housing-structures-negeha-south-darfur.

Abbas, A., Sajid, M.B., Shahzad, N., Din, E.U., Mahmood, M. and Salahuddin, U. (2022). Barriers and drivers for adoption of energy efficient and environment friendly brick kiln technologies in Punjab, Pakistan. *Energy Reports*, 8, pp.15563–15573. doi:https://doi.org/10.1016/j.egyr.2022.11.128.

Adrees, M., Ibrahim, M., Shah, A.M., Abbas, F., Saleem, F., Rizwan, M., Hina, S., Jabeen, F. and Ali, S. (2016). Gaseous pollutants from brick kiln industry decreased the growth, photosynthesis, and yield of wheat (Triticum aestivum L.). *Environmental Monitoring and Assessment*, 188(5). doi:https://doi.org/10.1007/s10661-016-5273-8.

Ahmad, S., Arif, B., Akram, Z., Ahmed, M.W., Khan, A.U., Hussain, M.Z., Rahman, F., Kayani, M.A. and Mahjabeen, I. (2020). Association of intronic polymorphisms (rs1549339, rs13402242) and mRNA expression variations in PSMD1 gene in arsenic-exposed workers. *Environmental Science and Pollution Research*, 27(10), pp.11425–11437. doi:https://doi.org/10.1007/s11356-019-07422-x.

AIRBUS (2024). *Lisbon, Portugal DEFENCE AND SPACE Intelligence Pléiades*.

Akram, Z., Mahjabeen, I., Umair, M., Fahim, M., Kayani, M.A., Fatima, L., Ahmad, M.W., Jahan, S., Afsar, T., Almajwal, A., Alruwaili, N.W., Khawar, I.A. and Razak, S. (2022). Expression variation of OGG1 and HPRT gene and DNA damage in arsenic exposed industrial workers. *PLOS ONE*, 17(9), p.e0273211. doi:https://doi.org/10.1371/journal.pone.0273211.

Aljazeera (2012). *Battle rages for Syria’s Aleppo*. [online] Al Jazeera. Available at: https://www.aljazeera.com/news/2012/7/29/battle-rages-for-syrias-aleppo [Accessed 29 Sep. 2024].

Amnesty International (2004). *Sudan At the mercy of killers -destruction of villages in Darfur*.

Anderson, K., Ryan, B., Sonntag, W., Kavvada, A. and Friedl, L. (2017). Earth observation in service of the 2030 Agenda for Sustainable Development. *Geo-spatial Information Science*, 20(2), pp.77–96. doi:https://doi.org/10.1080/10095020.2017.1333230.

Arbain, A. and Imasu, R. (2019). *ESTIMATING PM 2.5 EMISSION FROM BRICK KILN INDUSTRY OVER NORTHERN INDIA WITH NUMERICAL MODEL AND REMOTE SENSING OBSERVATION*.

Bales, K. (2007). Ending slavery: how we free today's slaves. pp.163–164. Berkeley CA University of California Press.

Bales, K. (2012). *Disposable People : New Slavery in the Global Economy*. Berkeley, California: University Of California Press.

Bales, K. (2016). *Blood and earth : modern slavery, ecocide, and the secret to saving the world*. New York: Spiegel & Grau.

Basiri, A., Haklay, M., Foody, G. and Mooney, P. (2019). Crowdsourced geospatial data quality: challenges and future directions. *International Journal of Geographical Information Science*, 33(8), pp.1588–1593. doi:https://doi.org/10.1080/13658816.2019.1593422.

Basu, K. and Van, P.H. (1998). The Economics of Child Labour. *American Economic Review*, 88(3).

Baul, T. and Ostermann, S.L. (2023). Legal knowledge and child labour in Nepal: Does knowing the law make a difference? *Development Policy Review*, 41(5). doi:https://doi.org/10.1111/dpr.12700.

Bhukuth, A. (2005). Child Labour and Debt Bondage: A Case Study of Brick Kiln Workers in Southeast India. *Journal of Asian and African Studies*, 40(4), pp.287–302. doi:https://doi.org/10.1177/0021909605055776.

Biemann, U. (2005). Remotely Sensed: A Topography of the Global Sex Trade. *Feminist Review*, 80(1), pp.180–193. doi:https://doi.org/10.1057/palgrave.fr.9400216.

Boyd, D.S., Foody, G.M., Brown, C., Mazumdar, S., Marshall, H. and Wardlaw, J. (2022). Citizen science for Earth Observation (Citizens4EO): understanding current use in the UK. *International Journal of Remote Sensing*, 43(8), pp.2965–2985. doi:https://doi.org/10.1080/01431161.2022.2076574.

Boyd, D.S., Jackson, B., Wardlaw, J., Foody, G.M., Marsh, S. and Bales, K. (2018). Slavery from Space: Demonstrating the role for satellite remote sensing to inform evidence-based action related to UN SDG number 8. *ISPRS Journal of Photogrammetry and Remote Sensing*, 142, pp.380–388. doi:https://doi.org/10.1016/j.isprsjprs.2018.02.012.

Boyd, D.S., Perrat, B., Li, X., Jackson, B., Landman, T., Ling, F., Bales, K., Choi-Fitzpatrick, A., Goulding, J., Marsh, S. and Foody, G.M. (2021). Informing action for United Nations SDG target 8.7 and interdependent SDGs: Examining modern slavery from space. *Humanities and Social Sciences Communications*, 8(1). doi:https://doi.org/10.1057/s41599-021-00792-z.

Bromley, L. (2009). Eye in The Sky: Monitoring Human Rights Abuses Using Geospatial Technology. *Georgetown Journal of International Affairs*, 10(1), pp.159–168.

Brooks, N., Biswas, D., Raduan Hossin, Yu, A., Saha, S., Saha, S., Saha, S.K. and Luby, S.P. (2023). Health consequences of small-scale industrial pollution: Evidence from the brick sector in Bangladesh. *World Development*, 170, pp.106318–106318. doi:https://doi.org/10.1016/j.worlddev.2023.106318.

Brown, D., Boyd, D.S., Brickell, K., Ives, C.D., Natarajan, N. and Parsons, L. (2019). Modern slavery, environmental degradation and climate change: Fisheries, field, forests and factories. *Environment and Planning E: Nature and Space*, 4(2), pp.191–207. doi:https://doi.org/10.1177/2514848619887156.

Chandra, G. and Bhatia, S. (2020). *Issues and Concerns in the Field of Remote Sensing*.

Choi-Fitzpatrick, A. (2017). What Slaveholders Think: How Contemporary Perpetrators Rationalize What They Do. *Columbia University Press*.

Cochran, F., Daniel, J., Jackson, L. and Neale, A. (2020). Earth observation-based ecosystem services indicators for national and subnational reporting of the sustainable development goals. *Remote Sensing of Environment*, 244, p.111796. doi:https://doi.org/10.1016/j.rse.2020.111796.

Cockbain, E., Bowers, K. and Dimitrova, G. (2018). Human trafficking for labour exploitation: the results of a two-phase systematic review mapping the European evidence base and synthesising key scientific research evidence. *Journal of Experimental Criminology*, 14(3), pp.319–360. doi:https://doi.org/10.1007/s11292-017-9321-3.

Cockbain, E., Bowers, K. and Hutt, O. (2022). Examining the geographies of human trafficking: Methodological challenges in mapping trafficking's complexities and connectivities. *Applied Geography*, 139, p.102643. doi:https://doi.org/10.1016/j.apgeog.2022.102643.

Coffer, M.M. (2020). Balancing Privacy Rights and the Production of High-Quality Satellite Imagery. *Environmental Science & Technology*, 54(11), pp.6453–6455. doi:https://doi.org/10.1021/acs.est.0c02365.

Crisp, N.H., Roberts, P.C.E., Livadiotti, S., Oiko, V.T.A., Edmondson, S., Haigh, S.J., Huyton, C., Sinpetru, L.A., Smith, K.L., Worrall, S.D., Becedas, J., Domínguez, R.M., González, D., Hanessian, V., Mølgaard, A., Nielsen, J., Bisgaard, M., Chan, Y.-A. ., Fasoulas, S. and Herdrich, G.H. (2020). The benefits of very low earth orbit for earth observation missions. *Progress in Aerospace Sciences*, 117, p.100619. doi:https://doi.org/10.1016/j.paerosci.2020.100619.

D.P. Singh (2005). Women Workers in the Brick Kiln Industry in Haryana, India. *Indian Journal of Gender Studies*, 12(1), pp.83–97. doi:https://doi.org/10.1177/097152150401200104.

Dakua, T., Rahaman, M. and Das, K.C. (2023). An analysis of the spatial and temporal variations of human trafficking in India. *Cogent Social Sciences*, 10(1). doi:https://doi.org/10.1080/23311886.2023.2293315.

David, M., Turi, N., Ain, Q., Rahman, H. and Jahan, S. (2020). Evaluation of environmental effects of heavy metals on biochemical profile and oxidative stress among children at brick kiln sites. *Archives of Environmental & Occupational Health*, 76(7), pp.441–449. doi:https://doi.org/10.1080/19338244.2020.1854645.

De Vos, H., Jongerden, J. and Van Etten, J. (2008). *Images of war: using satellite images for human rights monitoring in*.

DeWitt, J.D., Chirico, P.G., Alessi, M.A. and Boston, K.M. (2021). Remote Sensing Inventory and Geospatial Analysis of Brick Kilns and Clay Quarrying in Kabul, Afghanistan. *Minerals*, 11(3), pp.296–296. doi:https://doi.org/10.3390/min11030296.

Diego-Rosell, P. and Joudo Larsen, J. (2018). Modelling the Risk of Modern Slavery. *SSRN Electronic Journal*. doi:https://doi.org/10.2139/ssrn.3215368.

Donohue-Dioh, J., Otis, M., Miller, J. "Jay, Sossou, M.-A., delaTorres, C. and Lawson, T. (2020). Survivors' conceptualizations of human trafficking prevention; An exploratory study. *Evaluation and Program Planning*, 83, p.101873. doi:https://doi.org/10.1016/j.evalprogplan.2020.101873.

Eil, A., Li, J., Baral, P. and Eri Saikawa (2020). Dirty Stacks, High Stakes : An Overview of Brick Sector in South Asia. *World Bank*, pp.1–123.

Ekmen, O. and Sultan Kocaman (2024). Remote sensing for UN SDGs: A global analysis of research and collaborations. *The Egyptian Journal of Remote Sensing and Space Science*, 27(2), pp.329–341. doi:https://doi.org/10.1016/j.ejrs.2024.04.002.

Enough Project (2017). *The Enough Project*. [online] The Enough Project. Available at: https://enoughproject.org/.

ESA (2024). *QuickBird-2 - Earth Online*. [online] earth.esa.int. Available at: https://earth.esa.int/eogateway/missions/quickbird-2.

Esri (2023). *Buffer (Analysis)—ArcGIS Pro* | *Documentation*. [online] pro.arcgis.com. Available at: https://pro.arcgis.com/en/pro-app/latest/tool-reference/analysis/buffer.htm.

Esri (2024a). *ArcGIS Desktop Help 9.3 - How Near (Analysis) works*. [online] Esri.com. Available at: https://webhelp.esri.com/arcgisdesktop/9.3/index.cfm?TopicName=How%20Near%20(Analysis)%20works#:~:text=The%20Near%20and%20the%20Generate%20Near%20Table%20tools.

Esri (2024b). *Spatial Join (Analysis)—ArcGIS Pro | Documentation*. [online] pro.arcgis.com. Available at: https://pro.arcgis.com/en/pro-app/latest/tool-reference/analysis/spatial-join.htm.

Fakhra Anwar, Muhammad Mohsin and Sana Arshad (2023). A Statistical Survey on the Socioeconomic and Demographic Livelihood of Brick Kiln Workers: A Case Study of Bahawalpur District, Punjab, Pakistan. *Proceedings of the Pakistan Academy of Sciences: A. Physical and Computational Sciences*, 60(4). doi:https://doi.org/10.53560/ppasa(60-4)826.

Fitzgibbon, K. (2003). Modern day slaveru? The scope of trafficking in persons in Africa. *Afr Securit Stud*, 12(81), pp.81–89.

Foody, G.M., Ling, F., Boyd, D.S., Li, X. and Wardlaw, J. (2019). Earth Observation and Machine Learning to Meet Sustainable Development Goal 8.7: Mapping Sites Associated with Slavery from Space. *Remote Sensing*, 11(3), p.266. doi:https://doi.org/10.3390/rs11030266.

Foody, G.M., See, L., Fritz, S., van der Velde, M., Perger, C., Schill, C., Boyd, D.S. and Comber, A. (2015). Accurate Attribute Mapping from Volunteered Geographic Information: Issues of Volunteer Quantity and Quality. *The Cartographic Journal*, 52(4), pp.336–344. doi:https://doi.org/10.1080/00087041.2015.1108658.

GeoAI, Bihar State Pollution Control Board, Development Alternatives, The University of Nottingham and United Nations Development Programme (2023). *GeoAI for Brick kilns in Bihar: Learnings and recommendations*.

Ghose, K. (2015). Addressing the Employment Challenge: India’s MGNREGA’. Employment. *International Labour Ofiice*.

Ghosh, A. and Sarkar, S. (2021). Assessing land use change and potential environmental quality in Chandernagore Municipal Corporation, India. *Environment, Development and Sustainability*, 24. doi:https://doi.org/10.1007/s10668-021-01864-5.

Ghosh, S. (2014). Anti-trafficking and its discontents: women's migrations and work in an Indian borderland. *Gender, Place & Culture*, 22(9), pp.1220–1235. doi:https://doi.org/10.1080/0966369x.2014.970139.

Government of Punjab (1998). *Brick kiln regulation order, 1998*. Attached is the STE report from 2019.

Grootaert, C. and Kanbur, R. (1995). Child Labour: A review . *Development Economic, World Bank*.

Gupta, P. and Bharat, A. (2022). Developing sustainable development Index as a tool for appropriate urban land take · Sustainable Development Index (SDI) · Decision making · Fuzzy analytical hierarchy process (FAHP) · Development suitability Abbreviations SDI Sustainable Development Index DMR Decision Making Rubric GIS Geographic information system. *Development and Sustainability*, 24, pp.13378–13406. doi:https://doi.org/10.1007/s10668-021-01992-y.

Gupta, S., Anand, S., Thanmai, P.L., Reddy, K.M. and Ravisankar, T. (2021a). Spatial Distribution of SDGs Accomplished Under MGNREGA Beyond SDG1. *International Journal of Rural Management*, 19(1), pp.26–44. doi:https://doi.org/10.1177/09730052211037108.

Gupta, S., Anand, S., Thanmai, P.L., Reddy, K.M. and Ravisankar, T. (2021b). Spatial Distribution of SDGs Accomplished Under MGNREGA Beyond SDG1. *International Journal of Rural Management*, 19(1), pp.26–44. doi:https://doi.org/10.1177/09730052211037108.

Gupta, U. and Sharma, R. (2023). Analysis of criminal spatial events in india using exploratory data analysis and regression. *Computers and Electrical Engineering*, 109, p.108761. doi:https://doi.org/10.1016/j.compeleceng.2023.108761.

Guttikunda, S.K. and Calori, G. (2013). A GIS based emissions inventory at 1 km × 1 km spatial resolution for air pollution analysis in Delhi, India. *Atmospheric Environment*, 67, pp.101–111. doi:https://doi.org/10.1016/j.atmosenv.2012.10.040.

Guttikunda, S.K., Goel, R. and Pant, P. (2014). Nature of air pollution, emission sources, and management in the Indian cities. *Atmospheric Environment*, 95, pp.501–510. doi:https://doi.org/10.1016/j.atmosenv.2014.07.006.

Guyer, J.I. and Lambin, E.F. (1993). Land Use in an Urban Hinterland: Ethnography and Remote Sensing in the Study of African Intensification. *American Anthropologist*, 95(4), pp.839–859. doi:https://doi.org/10.1525/aa.1993.95.4.02a00040.

Hamid, A., Riaz, A., Noor, F. and Mazhar, I. (2022). Assessment and mapping of total suspended particulate and soil quality around brick kilns and occupational health issues among brick kilns workers in Pakistan. *Environmental Science and Pollution Research*, 30(2), pp.3335–3350. doi:https://doi.org/10.1007/s11356-022-22428-8.

Haryana Government (1972). *The Haryana Control of Bricks Supplies Order, 1972*.

Hawksley, H. and Pradesh, A. (2014). Why India’s Brick Kiln Workers ‘Live Like Slaves’. *BBC*.

Head, B.W. and Alford, J. (2013). Wicked Problems: Implications for Public Policy and Management. *Administration & Society*, [online] 47(6), pp.711–739. doi:https://doi.org/10.1177/0095399713481601.

Holocaust Memorial Trust (2024). *Holocaust Memorial Day Trust | Darfur today*. [online] Holocaust Memorial Day Trust. Available at: https://www.hmd.org.uk/learn-about-the-holocaust-and-genocides/darfur/today-darfur/.

Hussain, B., Naqvi, S.A.A., Anwar, S., Shah, S.A.R., Hassan, R.H. ul and Shah, A.A. (2021). Zig-zag technology adoption behavior among brick kiln owners in Pakistan. *Environmental Science and Pollution Research*, 28(33), pp.45168–45182. doi:https://doi.org/10.1007/s11356-021-13837-2.

International Labour Organisation (2017). *Global estimates of modern slavery: forced labor and forced marriage.* Geneva: ILO.

Jackson, B., Boyd, D.S., Ives, C.D., Decker Sparks, J.L., Foody, G.M., Marsh, S. and Bales, K. (2020a). Remote sensing of fish-processing in the Sundarbans Reserve Forest, Bangladesh: an insight into the modern slavery-environment nexus in the coastal fringe. *Maritime Studies*, 19(4), pp.429–444. doi:https://doi.org/10.1007/s40152-020-00199-7.

Jackson, B., Decker Sparks, J.L., Brown, C. and Boyd, D.S. (2020b). Understanding the co-occurrence of tree loss and modern slavery to improve efficacy of conservation actions and policies. *Conservation Science and Practise*, [online] 2(5). Available at: https://doi.org/10.1111/csp2.183 [Accessed 3 Jan. 2024].

Jackson, B., Decker Sparks, J.L., Brown, C. and Boyd, D.S. (2020c). Understanding the co-occurrence of tree loss and modern slavery to improve efficacy of conservation actions and policies. *Conservation Science and Practice*, 2(5). doi:https://doi.org/10.1111/csp2.183.

Kelkar, G. (2011). ‘MGNREGA: Change and Continuity in Gender Relations’. *Journal of Economic and Social Development*, 7(2), pp.11–24.

Khan, M.W., Ali, Y., De Felice, F., Salman, A. and Petrillo, A. (2019). Impact of brick kilns industry on environment and human health in Pakistan. *Science of The Total Environment*, 678, pp.383–389. doi:https://doi.org/10.1016/j.scitotenv.2019.04.369.

Knoth, C. and Pebesma, E. (2016). Detecting dwelling destruction in Darfur through object-based change analysis of very high-resolution imagery. *International Journal of Remote Sensing*, 38(1), pp.273–295. doi:https://doi.org/10.1080/01431161.2016.1266105.

Kougkoulos, I., Cakir, M.S., Kunz, N., Boyd, D.S., Trautrims, A., Hatzinikolaou, K. and Gold, S. (2021). A Multi-Method Approach to Prioritize Locations of Labor Exploitation for Ground-Based Interventions. *Production and Operations Management*, 30(12), pp.4396–4411. doi:https://doi.org/10.1111/poms.13496.

Kubasiewicz, L., Watson, T., Norris, S., Chamberlain, N., Nye, C., Perumal, R., Saroja, R., Raw, Z. and Burden, F. (2022). One welfare: Linking poverty, equid ownership and equid welfare in the brick kilns of India. *Animal Welfare*, 31(4), pp.517–528. doi:https://doi.org/10.1017/s0962728600032504.

Küçüksu, A. (2022). Enforcing Rights Beyond Litigation: Mapping NGO Strategies in Monitoring ECtHR Judgement Implementation. *Human Rights Law Review*, 22(2). doi:https://doi.org/10.1093/hrlr/ngac013.

Kumar, S. and Singh, R. (2021). Geospatial Applications in Land Use/Land Cover Change Detection for Sustainable Regional Development: The Case of Central Haryana, India. *Geomatics and Environmental Engineering*, 15(3), pp.81–98. doi:https://doi.org/10.7494/geom.2021.15.3.81.

Laliberté, N. (2015a). Geographies of Human Rights: Mapping Responsibility. *Geography Compass*, 9(2), pp.57–67. doi:https://doi.org/10.1111/gec3.12196.

Laliberté, N. (2015b). Geographies of Human Rights: Mapping Responsibility. *Geography Compass*, 9(2), pp.57–67. doi:https://doi.org/10.1111/gec3.12196.

Landman, T., 2020. Measuring modern slavery: Law, human rights, and new forms of data. *Hum. Rts. Q.*, *42*, p.303.

Larmar, S., O'Leary, P., Chui, C., Benfer, K., Zug, S. and Jordan, L.P. (2017). Hazardous child labor in Nepal: The case of brick kilns. *Child Abuse & Neglect*, 72, pp.312–325. doi:https://doi.org/10.1016/j.chiabu.2017.08.011.

Lavelle-Hill, R., Smith, G., Mazumder, A., Landman, T. and Goulding, J. (2021). Machine learning methods for 'wicked' problems: exploring the complex drivers of modern slavery. *Humanities and Social Sciences Communications*, 8(1). doi:https://doi.org/10.1057/s41599-021-00938-z.

Lee, J., Brooks, N.R., Tajwar, F., Burke, M., Ermon, S., Lobell, D.B., Biswas, D. and Luby, S.P. (2021). Scalable deep learning to identify brick kilns and aid regulatory capacity. *Proceedings of the National Academy of Sciences*, 118(17). doi:https://doi.org/10.1073/pnas.2018863118.

Lerner, M. and Wolfinbarger, S. (2013). *Human Rights Applications of Remote Sensing. Case Studies from the Geospatial Technologies and Human Rights Project. https://www.researchgate.net/publication/275640066_Human_Rights_Applications_of_Remote_Sensing_Case_Studies_from_the_Geospatial_Technologies_and_Human_Rights_Project*. American Association for the Advancement of Science.

Levinger, M. (2009a). Geographical Information Systems Technology as a Tool for Genocide Prevention: The Case of Darfur. *Space and Polity*, 13(1), pp.69–76. doi:https://doi.org/10.1080/13562570902781249.

Levinger, M. (2009b). Geographical Information Systems Technology as a Tool for Genocide Prevention: The Case of Darfur. *Space and Polity*, 13(1), pp.69–76. doi:https://doi.org/10.1080/13562570902781249.

Li, X., Foody, G., Boyd, D. and Ling, F. (2019). *AGING BRICK KILNS IN THE ASIAN BRICK BELT USING A LONG TIME SERIES OF LANDSAT SENSOR DATA TO INFORM THE STUDY OF MODERN DAY SLAVERY*.

Luby, S.P., Biswas, D., Gurley, E.S. and Hossain, I. (2015). Why highly polluting methods are used to manufacture bricks in Bangladesh. *Energy for Sustainable Development*, 28, pp.68–74. doi:https://doi.org/10.1016/j.esd.2015.07.003.

Maithel, S., Kumar, S. and Laichandani, D. (2014). *Factsheet about Brick Kilns in South and South-East Asia* . [online] Shareweb. Available at: https://www.shareweb.ch/site/Climate-Change-and-Environment/about%20us/about%20gpcc/Documents/01%20Fixed%20Chimney%20Bulls%20Trench%20Kiln%20(FCBTK).pdf [Accessed 11 Jul. 2024].

Majumder, S., Roy, S., Bose, A. and Indrajit Roy Chowdhury (2023). Multiscale GIS based-model to assess urban social vulnerability and associated risk: Evidence from 146 urban centers of Eastern India. *Sustainable Cities and Society*, 96, pp.104692–104692. doi:https://doi.org/10.1016/j.scs.2023.104692.

Maniadaki, M., Papathanasopoulos, A., Mitrou, L. and Maria, E.-A. (2021). Reconciling Remote Sensing Technologies with Personal Data and Privacy Protection in the European Union: Recent Developments in Greek Legislation and

Application Perspectives in Environmental Law. *Laws*, 10(2), p.33. doi:https://doi.org/10.3390/laws10020033.

Marcinko, C.L.J., Samanta, S., Basu, O., Harfoot, A., Hornby, D.D., Hutton, C.W., Pal, S. and Watmough, G.R. (2022). Earth observation and geospatial data can predict the relative distribution of village level poverty in the Sundarban Biosphere Reserve, India. *Journal of Environmental Management*, [online] 313, p.114950. doi:https://doi.org/10.1016/j.jenvman.2022.114950.

Marx, A. and Goward, S. (2013). Remote Sensing in Human Rights and International Humanitarian Law Monitoring: Concepts and Methods. *Geographical Review*, 103(1), pp.100–111. doi:https://doi.org/10.1111/j.1931-0846.2013.00188.x.

Members of the Legal Parameters of Slavery (2012). *The Bellagio-Harvard Guidelines on the Legal Parameters of Slavery*.

Miller, J.D. and Yool, S.R. (2002). Mapping forest post-fire canopy consumption in several overstory types using multi-temporal Landsat TM and ETM data. *Remote Sensing of Environment*, 82(2-3), pp.481–496. doi:https://doi.org/10.1016/s0034-4257(02)00071-8.

Mishra, P. (2021). The Making of Urban Peripheries and Peripheral Labor: Brick Kilns and Circular Migration in and beyond Greater Delhi. *South Asia Multidisciplinary Academic Journal*, (26). doi:https://doi.org/10.4000/samaj.7276.

Mishra, P.K., Rai, A. and Rai, S.C. (2020). Land use and land cover change detection using geospatial techniques in the Sikkim Himalaya, India. *The Egyptian Journal of Remote Sensing and Space Science*, 23(2), pp.133–143. doi:https://doi.org/10.1016/j.ejrs.2019.02.001.

Misra, P., Imasu, R. and Takeuchi, W. (2019). Impact of Urban Growth on Air Quality in Indian Cities Using Hierarchical Bayesian Approach. *Atmosphere*, 10(9), p.517. doi:https://doi.org/10.3390/atmos10090517.

Mondal, R., Patel, Z., Jani, V. and Batra, N. (2018). *Scalable Methods for Brick Kiln Detection and Compliance Monitoring from Satellite Imagery: A Deployment Case Study in India*.

Muzafar, A. and Jahangir, A.B. (2017). Reviewing MGNREGA: The cheering method of poverty reduction. *Journal of Global Economics* . doi:https://doi.org/10.4172/2375-%204389.1000250..

Nasim, S. and Sharif, F. (2020). To adopt, or not to adopt, ‘why’ is the question: A case for clean kiln technologies in developing countries. *Journal of Cleaner Production*, 257, p.120553. doi:https://doi.org/10.1016/j.jclepro.2020.120553.

Nazir, U., Ather, M.A. and Taj, M. (2023). Detection of Illegal Kiln Activity During SMOG Period. *2023 International Conference on Robotics and Automation in Industry (ICRAI)*, 8, pp.1–6. doi:https://doi.org/10.1109/icrai57502.2023.10089596.

Nazir, U., Mian, U.K., Sohail, M.U., Taj, M. and Uppal, M. (2020). Kiln-Net: A Gated Neural Network for Detection of Brick Kilns in South Asia. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, 13, pp.3251–3262. doi:https://doi.org/10.1109/jstars.2020.3001980.

Paul, A., Bandyopadhyay, S. and Raj, U. (2022). Brick kiln detection in remote sensing imagery using deep neural network and change analysis. *Spatial Information Research*, 30(5), pp.607–616. doi:https://doi.org/10.1007/s41324-022-00458-1.

Pellenq, C., Gunn, S. and Lima, L. (2021). The psychological health and well-being of children working in the brick industry: A comparative study. *Safety Science*, 140, p.105251. doi:https://doi.org/10.1016/j.ssci.2021.105251.

Pereira, J. (1999). A comparative evaluation of NOAA/AVHRR vegetation indices for burned surface detection and mapping. *IEEE Transactions on Geoscience and Remote Sensing*, 37, pp.217–226.

Pesterfield, C. and Rogerson, M. (2023). Institutional Logics in the UK Construction Industry’s Response to Modern Slavery Risk: Complementarity and Conflict. *Journal of Business Ethics*. doi:https://doi.org/10.1007/s10551-023-05455-4.

Petersen, A. and Tullin, L.-L. (2001). *The Scorched Earth of Darfur Patterns in death and destruction reported by the people of Darfur*.

Pohl, C. and Van Genderen, J.L. (1998). Review article Multisensor image fusion in remote sensing: Concepts, methods and applications. *International Journal of Remote Sensing*, 19(5), pp.823–854. doi:https://doi.org/10.1080/014311698215748.

Prins, E. (2007). Use of low cost Landsat ETM+ to spot burnt villages in Darfur, Sudan. *International Journal of Remote Sensing*, 29(4), pp.1207–1214. doi:https://doi.org/10.1080/01431160701730110.

Punjab Pollution Control Board (1998). *Punjab government brick kiln regulations*.

Purdy, R. and Leung, D. (2012). *Evidence from Earth Observation Satellites*. Martinus Nijhoff Publishers. Maculey "The use of EO technologies in Court.

Quinn, J.A., Nyhan, M.M., Navarro, C., Coluccia, D., Bromley, L. and Luengo-Oroz, M. (2018). Humanitarian applications of machine learning with remote-sensing data: review and case study in refugee settlement mapping. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, 376(2128), p.20170363. doi:https://doi.org/10.1098/rsta.2017.0363.

Rai, S.M., Brown, B.D. and Ruwanpura, K.N. (2019). SDG 8: Decent work and economic growth – A gendered analysis. *World Development*, 113, pp.368–380. doi:https://doi.org/10.1016/j.worlddev.2018.09.006.

Rapp, L. and Santos, C. (2019). Satellite Imagery, Very High-Resolution and Processing-Intensive Image Analysis: Potential Risks Under the GDPR. *Air and Space Law*, 44(Issue 3), pp.275–295. doi:https://doi.org/10.54648/aila2019018.

Ray, R. (2000). Child Labor, Child Schooling, and Their Interaction with Adult Labor: Empirical Evidence for Peru and Pakistan. *The World Bank Economic Review*, 14(2), pp.347–67.

Red Cross (2023). *The Syrian Crisis: how the Red Cross is helping*. [online] British Red Cross. Available at: https://www.redcross.org.uk/stories/disasters-and-emergencies/world/the-syrian-crisis-how-the-red-cross-is-helping.

Reyers, B. and Selig, E.R., 2020. Global targets that reveal the social–ecological interdependencies of sustainable development. *Nature Ecology & Evolution*, *4*(8), pp.1011-1019.

Rogers, C. and Swinnerton, K. (2002). A Theory of Exploitative Child Labor', working paper. *, US Department of Labor, Bureau of International Labor Affairs*.

Rothe, D. and Shim, D. (2018). Sensing the ground: On the global politics of satellite-based activism. *Review of International Studies*, 44(3), pp.414–437. doi:https://doi.org/10.1017/s0260210517000602.

Saini, K.M., Deb, T.K., Mitra, P.P., Ghatol, S.G., Sen, A.K., Saha, N.C. and Das, S.N. (1999). Assessment of degraded lands of puruliya district, west bengal using remotely sensed data. *Journal of the Indian Society of Remote Sensing*, 27(1), pp.23–30. doi:https://doi.org/10.1007/bf02990772.

Sameeeksha (2024). *SAMEEEKSHA*. [online] Sameeeksha.org. Available at: https://sameeeksha.org/index.php?option=com_content&view=article&id=220&Itemid=499#:~:text=The%20state%20of%20Punjab%20is%20among%20the%20leading [Accessed 29 Sep. 2024].

Sarkar, S. (2014). Rethinking Human Trafficking in India: Nature, Extent and Identification of Survivors. *The Round Table*, 103(5), pp.483–495. doi:https://doi.org/10.1080/00358533.2014.966499.

Scoles, S. (2019). Researchers spy signs of slavery from space. *Science*. [online] Available at: https://www.science.org/content/article/researchers-spy-signs-slavery-space [Accessed 18 Jan. 2024].

Shah, A. (2006). The labour of love: Seasonal migration from Jharkhand to the brick kilns of other states in India. *Contributions to Indian Sociology*, 40(1). doi:https://doi.org/10.1177/006996670504000104.

Singh, A.L. and Sarfaraz Asgher, Md. (2005). Impact of brick kilns on land use/landcover changes around Aligarh city, India. *Habitat International*, 29(3), pp.591–602. doi:https://doi.org/10.1016/j.habitatint.2004.04.010.

Steinberg, M.K., Height, C., Mosher, R. and Bampton, M. (2006). Mapping massacres: GIS and state terror in Guatemala. *Geoforum*, 37(1), pp.62–68. doi:https://doi.org/10.1016/j.geoforum.2005.02.003.

Turner, M. (2003). Methodological Reflections on the Use of Remote Sensing and Geographic Information Science in Human Ecological Research. *Human Ecology*, 31(2).

United Nations Development Programme (2023). *GepAI for Brick Kilns in Bihar*.

University of California, Berkley School of Law (2012). *BEYOND REASONABLE DOUBT USING SCIENTIFIC EVIDENCE TO ADVANCE PROSECUTIONS AT THE INTERNATIONAL CRIMINAL COURT Workshop Report*.

Upadhyay, N. (2021). BRIDE TRAFFICKInG In InDIA: ASPECTS, CAuSES AnD PoTEnTIAL SoLuTIonS Table of Contents Introduction 1. Human Trafficking Vis-a-Vis Bride Trafficking: Meaning and Conceptual Understanding 1.1. Definition of Bride Trafficking 1.2. Research Methodology 2. Push and Pull Factors and Root Causes of Bride Trafficking 2.1. Human Rights Violations Faced by Trafficked Brides 2.2. Legal Regime Related to Combatting Bride Trafficking 3. Suggestions for Curbing the Menace of Bride Trafficking Conclusion. *BRICS LAW JOURNAL*, 8(3). doi:https://doi.org/10.21684/2412-2343-2021-8-3-67-92.

Vincent, K., Zhang, S.X. and Dank, M. (2019). Searching for Sex Trafficking Victims: Using a Novel Link-Tracing Method Among Commercial Sex Workers in Muzaffarpur, India. *Crime & Delinquency*, 67(13-14), pp.2254–2277. doi:https://doi.org/10.1177/0011128719890265.

Walker, J.R. (2020). Remote sensing for international human rights advocacy: Critiques and responses. *Journal of Human Rights*, 19(2), pp.183–200. doi:https://doi.org/10.1080/14754835.2019.1702876.

Walker, J.R. (2021). *Grounding the view from nowhere: The role of remote sensing technology in international human rights practise*. [online] Escholarship.org. Available at: https://escholarship.org/uc/item/6np5m9r9 [Accessed 18 Sep. 2024].

Wang, B.Y., Raymondi, N.A., Gould, G. and Baker, I. (2013). Problems from Hell, Solution in the Heavens?: Identifying Obstacles and Opportunities for Employing Geospatial Technologies to Document and Mitigate Mass Atrocities. *Stability: International Journal of Security & Development*, 2(3), p.53. doi:https://doi.org/10.5334/sta.cn.

Watson, R.T. and Webster, J. (2020). Analysing the past to prepare for the future: Writing a literature review a roadmap for release 2.0. *Journal of Decision Systems*, 29(3), pp.129–147. doi:https://doi.org/10.1080/12460125.2020.1798591.

Winkler, I.T. and Williams, C. (2017). The Sustainable Development Goals and human rights: a critical early review. *The International Journal of Human Rights*, 21(8), pp.1023–1028. doi:https://doi.org/10.1080/13642987.2017.1348695.

Wolfinbarger, S. (2016). Remote Sensing as a tool for Human Rights Fact Finding. *The Transformation of Human Rights Fact-Finding*. [online] doi:https://doi.org/10.1080/26410397/2019.1679968.

Wolfinbarger, S., Mcsweeney, K., Desheng, A., Ningchuan, L. and R E V I E W, X. (2012). *People Make the Pixels: Remote Sensing Analysis for Human Rights-Based Litigation*.

Xia, Y., Zhou, Y., Du, L. and Cai, T. (2019). Mapping Trafficking of Women in China: Evidence from Court Sentences. *Journal of Contemporary China*, 29(122), pp.238–252. doi:https://doi.org/10.1080/10670564.2019.1637564.

Zwijnenburg, W. and Ballinger, O. (2023). Leveraging emerging technologies to enable environmental monitoring and accountability in conflict zones. *International Review of the Red Cross*, 105(924), pp.1497–1521. doi:https://doi.org/10.1017/s1816383123000383.

Mres minor corrections report

Name: Liam-Elio Colabuono-McDonagh
Title: Brick by brick: Tracking kiln regulatory compliance and liberation across Punjab and Haryana using remote sensing methods

Correction	Comments	Page	Status
Add a paragraph that summarises your main reflection on what is the impact of changing evidentiary regimes and how it links with technological limitations that change according to time and place	Linked the work of Wolfinbarger to growing support for geospatial technology as a new evidentiary regime of digital forensics and digital evidence. Discussed the role of technological maturity in influencing the adoption of geospatial methods alongside factors of location including education and political will.	25	Complete
Add a paragraph discussing why it is important to use the SDG as the main framework for your thesis and no other ways of dealing with economic development and the environment	Argument for compatibility, most of the research discussed uses the SDG framework as does the work inspiring this work and the work which precedes it from the Rights Lab. India have signed and ratified the SDGs meaning there is no confusion over their commitment to it SDG intersectionality is a main framework of this research as MSHT is poorly studied and needs to be linked to other environmental and social factors to be given visibility.	29	Complete
Reflect on what does it mean to improve surveillance for enforcement in the field of MSHT for the global south	A lack of available data on the brick kilns makes remote sensing the only at scale method for gaining intelligence on MSHT practises However the concept of increasing surveillance especially in the global south comes with some tricky ethical questions Working with local charities and stakeholders can help inform the best decisions to be made for both operational details and the perceived ethics of the research Walker discusses this gap between the day to day operations of remote sensing research for human rights and the perceived ethical issues. The brick kilns mobility, scale of extent and relative data invsibility require the use of remote sensing but researchers must of cognisant of the ethical issues	10 and 119	Complete

	this creates and work to mitigate them.		
Add a paragraph in which you discuss if there is any casual link between deterrence and surveillance	Admittedly the literature between surveillance and deterrence and especially remote sensing lacks statistical data on the efficacy of surveillance for deterrence However The primary role of the remote sensing isn't necessarily for deterrence but rather to gather information to help make identifying and auditing the brick kilns more efficient. The buy in from regulators and the state creates a byproduct of remote sensing for deterrence through both the passive pressure of being watched and the active pressure of enforcement action in the form of regulation and the law via the geospatial intelligence gathered from this platform. I discuss Levinger's (2009) claim that remote sensing for deterrence is only effective if it encourages or compels powerful state and international actors to mobilise. As stated the buy in from regulators already satisfies this condition. The linking of regulatory factors to MSHT likelihood means as soon as kiln is suspected of breaking regulation it can be audited. These auditing efforts can then inform if a certain factor is a sign of MSHT or not. Right now it is not possible to statistically test this as the liberation data quality is not up to standards in terms of amount of data and data maturity.	82	Complete
Ground truthing & datasets: Add a couple of paragraphs that explore how the main limitation for your analysis is derived from the rather scarce and limited data on liberations in Punjab and Haryana- and what are the implications for	Data quality issues were Lack of liberation points and more significantly a lack of a "true negative" and "false positive" value What this means is there is currently no distinction in the liberation data between a kiln that has not been visited and a kiln that does not contain signs or evidence of MSHT There are two possibilities here 1 – No kiln is clean and every kiln	123	Complete

remote sensing analysis.	visited has MSHT practises associated with it and all negative kilns are kilns that have not been visited 2 – There are kilns that were clean of MSHT evidence and they have also been marked as negative when really it's a false positive Another interpretation of theory 1 is that liberation operations only occur at kilns that are flagged for MSHT. This is an issue as some of the kilns marked as clean by my regulation model have had evidence of MSHT. Either way without this distinction and data maturity further statistical analysis attempts were fruitless. However this doesn't mean the whole research project was written off. There is a huge opportunity for regulators to develop this regulation register and the method being based off regulation publications means it should be quite easy to scale across India especially as similar trends across regulation are likely to come up including Proximity regulations Air quality regulations These measurable regulations are well suited to analysis in GIS and the ability to link GIS to mobile applications means regulators could use this regulation register of kilns in the field.		
Redraft figures	Refer to page number to find each figure or refer to figure list	55 56 57 57 58 64 65 65 66 67 68	All reformatted

		69 69 70 71 71 74 74 82 82 89 90 101 105 110 111 112 114 115 116 118	

Paragraphs

Add a paragraph that summarises your main reflection on what is the impact of changing evidentiary regimes and how it links with technological limitations that change according to time and place

The work of Wolfinbarger (2012;2013) with the AAAS and the growing development of remote sensing imagery as legal proof is a window into the role of evidentiary regimes in human rights research. Evidentiary regimes refers to the type of information that is considered authoritative evidence within government, legal or organisational processes. As social concepts change and new technology emerges the way evidence can be used has also changed. Wolfinbarger (2013) discusses the emergence of remote sensing as a tool for human rights fact-finding exploring the issues of ethics and surveillance against the need for the insight required by remote sensing for human rights documentation and litigation. Overall, the impact of the introduction of geospatial technology as part of the new evidentiary regime of data forensics and digital evidence opened new opportunities to hold to account human rights violations at scale.

Geospatial information provided new perspectives and approaches to the ICC to investigate human rights abuses. As shown in the AAAS case studies by Lerner and Wolfinbarger (2013) the documentation of human rights abuses using satellite and drone imagery provided visual evidence to courtrooms. Furthermore, geospatial technology could be used to monitor an area before a suspected human rights violation occurred. The best-case result of this monitoring would be a lasting deterrent against human rights violations providing data in near real-time. Darfur is an example where geospatial technology provided oversight and legal understanding to an inaccessible part of the world. Darfur as previously discussed was inaccessible due to a combination of safety and political factors (Prins, 2008). It was dangerous to study Darfur on the ground and even those brave enough to do so were banned due to new fly rules, the denial of journalists and aid-agencies.

The adoption of new technology into evidentiary regimes is limited by three factors. First, the rate of adoption of the technology, second the ethical concerns and third the complexity and cost of entry. Wolfinbarger (2013) explains that a range of education barriers and technological requirements meant geospatial technology was largely utilised by actors with a multinational scale of capital meaning NGOs and other charities often had to partner with organisations like AAAS. Wang et al (2013) also notes that the new evidentiary regime of geospatial technology was at first ill defined.

Consequently, the adoption of geospatial technology has been slow. As the technology has become more accessible with low code solutions, graphical interfaces and automation the power of geospatial data has been more promising and attractive. This literature shows that while geospatial evidence was valuable to international investigations the adoption of the methodology was not uniform across time or space. Location mattered in terms of education, computational power and political will to pursue geospatial methods.

Page: 25

Add a paragraph discussing why it is important to use the SDG as the main framework for your thesis and no other ways of dealing with economic development and the environment

The SDG framework was chosen due to three reasons. First, the SDG framework has been used in research that inspires the methodology and research design of this work so there is an argument for compatibility. Second, the SDG framework is a well-recognised legal and human rights-based approach that has been signed and ratified by the country of interest in this paper. Third. as the SDGs are meant to be achieved by 2030 this research provides a review of progress on MSHT which is liked to goal 8 of the SDG. Furthermore, I draw on Boyd et al (2018) argument of SDG intersectionality and find the approach is fruitful in this analysis as a significant portion of the brick kiln research is focused on air quality and environmental factors it is useful to link sustainable development goals together to show how a vulnerability in one area can compromise the whole system.

In absence of discussing other frameworks and approaches to economic development and the environment this work instead reviews modern critiques of human rights and SDG based research engaging with the literature to inform best practise in this study.

Page: 29

Reflect on what does it mean to improve surveillance for enforcement in the field of MSHT for the global south

Despite these challenges increased surveillance of the brick kilns via remote sensing practises provides researchers with further insight to the activity within the brick kilns. This supports NGOs focused on investigating MSHT cases to identify the locations of brick kilns and their active status. Knowledge of location and activity of brick kilns can help target enforcement through regulation and law as partnerships between researchers and NGOs have shown in Boyd et al (2021, 2024). Platforms like GeoAI have visualised the pattern of brick kilns providing new data for auditors. Due to the scale of the brick belt and the illicit practise of MSHT remote sensing is the most appropriate method to tackle this challenge which requires clear resource management and the ability to adapt to changes in the brick kiln environment.

The NGO working with the University of Nottingham described the ability to consistently monitor the brick kilns as a new form of enforcement. An enforcement asset that can successfully monitor and provide more authoritative data to combat the illicit activities occurring within the brick belt. Therefore, from a cost benefit analysis remote sensing provides an effective tool for this research. Researchers must be careful when producing knowledge to take mitigations against the knowledge being weaponised. To improve surveillance for the global south could be interpreted from a neo-colonial or securitisation approach and mitigations must be put in place against this.

The concerns over ethical considerations of remote sensing are addressed by Walker (2020;2021;2022) these concerns need to be balanced against the value of this resource and grounded in the day-to-day operations of remote sensing for human rights research as well as ethical theory.
the brick kilns exist in spaces that are still not consistently well documented, many of the features that influence brick kilns and can be used to extract useful knowledge are not contained within the authoritative data of these countries. This gap in knowledge can be addressed by satellite technology via remote sensing. Furthermore, while issues of surveillance are crucial the proposed study intentionally limits the spatial resolution of the platform to make individual identification significantly difficult.

Page: 10 and 119

Add a paragraph in which you discuss if there is any causal link between deterrence and surveillance

Marx and Goward (2013) discussed that satellite imagery methods could be used not only to document human rights violations but act as monitoring systems providing active deterrence. Research on the efficacy of this deterrence property of remote sensing is limited. The theory from Marx and Goward considered that the presence of continuous remote sensing imagery could deter human rights violations however this would only be effective with the support of the UN or another powerful multi-national actor (Levinger,2009) and that the human rights violation could be physically sensed. This second point is the main factor influencing the brick kilns as MSHT itself cannot be physically sensed by satellite imagery. Rather there are visual clues which suggest the increased prevalence of modern slavery and these can be investigated. This study aims to see if researchers can connect regulatory factors that can be monitored from satellite imagery to a likelihood of modern slavery occurring. This link to regulatory factors helps increase the authority of our surveillance system as there is appetite to enforce it due to interest from the state and on the ground NGOs.

There are laws and regulations in place that make it possible to refer a non-compliant kiln to the regulatory authority.
This mitigates a big weakness of surveillance, by making the geospatial intelligence directly inform the regulation. This has been acknowledged with the geospatial imagery from this wider project considered as more authoritative than government records. This research goes beyond surveillance and instead builds a near real time database of brick kilns by status, location and activity. This provides a powerful tool for regulators to identify, track and audit brick kilns which are difficult to locate due to the scale of the study area.

Page: 82

Ground truthing and datasets: Reflect on the impacts of scarce and limited data on liberations

Ground truthing and datasets: Reflect on how a lack of distinction between kilns that have not been visited and kilns that do not contain modern slavery in the liberation dataset limits analysis

In the first section of your dissertation, you need to tell us succinctly about the limitations of making proxies for MSHT.

The scale of the subject area and the dynamic nature of brick kilns means it is advantageous to use remotely sensed imagery and object detection algorithms. However, remote sensing requires an object that can be physically sensed either through visible light and observational analysis or spectral analysis. Modern Slavery cannot be sensed directly. Instead, researchers have used remote sensing to identify areas where modern slavery practises are more likely to be occurring. Brick kilns are known to use MSHT practices (Boyd et al, 2018; 2021) so with that knowledge brick kilns can be used as a proxy of modern slavery. However, there are limitations to this method. First of all, researchers need to work with actors on the ground to assess whether there is a presence of MSHT practices within a specific kiln. Second, to validate these cases requires consistent and high quality data which isn't always possible due to restrictions on access and concerns for workers safety. Third, the limitations of the technology should also be considered. While the object detection and imagery are highly accurate (Boyd et al, 2021) mistakes can occur with false positives needing to be assessed.

For this project the main limitations were a lack of consistent high quality data when reviewing liberation reports from our partner NGO and an inability to ground truth regulatory status against our model as no regulatory register of brick kilns was accessible if it even exists in digital form. In short there was little data to compare this model too which is a limitation of new research. Similar regulatory methods to this study has been used in an air pollution context so the model is based on best practises, but the distant nature of the study area combined with the scale of analysis does create limitations.

Page: 9

Ground truthing & datasets: Add a couple of paragraphs that explore how the main limitation for your analysis is derived from the rather scarce and limited data on liberations in Punjab and Haryana- and what are the implications for

This study is unfortunately limited in its analysis by a gap in quality between the secondary data from ArcGIS and the wider University of Nottingham project and the liberation data from Punjab and Haryana. Three main data issues limit the suitability of this data for analysis. First of all, there is a distinct lack of a “false positive” result. For example, if a liberation worker visits a kiln and finds no workers under modern slavery for would this be recorded in the data? In a high quality dataset this would be recorded as a false positive in the sense that the kiln was investigated or visited but no MSHT evidence or practises were uncovered. Without this false positive all the negative values look the same. This is an issue as negative values (no liberation reports) can occur for three main reasons

- The kiln hasn’t been visited
- The kiln didn’t contain any evidence of MSHT or require workers to be liberated
- The partner NGO are unaware of the status of MSHT within the kiln

This calls into question the approach of the liberations. It seems like liberations are only operating within kilns that are known for MSHT beforehand rather than liberations working alongside regulators to provide a more random inspection element to MSHT.

From an analysis approach without a distinction between truly negative MSHT kilns (if such a thing exists which many researchers and charities doubt) and kilns that have not been visited it is not possible to perform regression analysis or tease out trends between brick kilns.
Second, the liberation efforts are spatially concentrated and partial. This is unsurprising as liberation efforts are only a few years old but it does mean the data is not mature enough for complex analysis. In an ideal world this GIS model could have identified which regulatory factors are most likely to signify MSHT practises. At the time of writing the data quality prohibits this.
Third of all the lack of high quality liberation data means conclusions to the question of factors of MSHT prevalence are still unknown. From the data it seems clean kilns have had less liberations, but it is also possible that “clean” kilns are harder to access due to no regulatory breach. It is also worth noting as before this regulation model considers 5 of 8 regulatory factors as the other 3 factors were too difficult to map due to inaccessible data for mango fields given the scope of the project. This is another area where data quality impacts the study, certain regulatory factors could not be efficiently modelled with data accessibility being an issue throughout the project.

Despite the negative implications of this the data we were able to analyse and the model that was able to be constructed do suggest new more efficient ways to regulate brick kilns. This research is the first paper to provide a regulation score for Indian states that can be scaled by other researchers as long as they have the regulatory guidelines to hand. To be able to remotely regulate brick kilns and flag suspect kilns is already a significant gain for regulators and the state and with future research and data maturity links between MSHT and the brick kilns may become more apparent.

Page: 123