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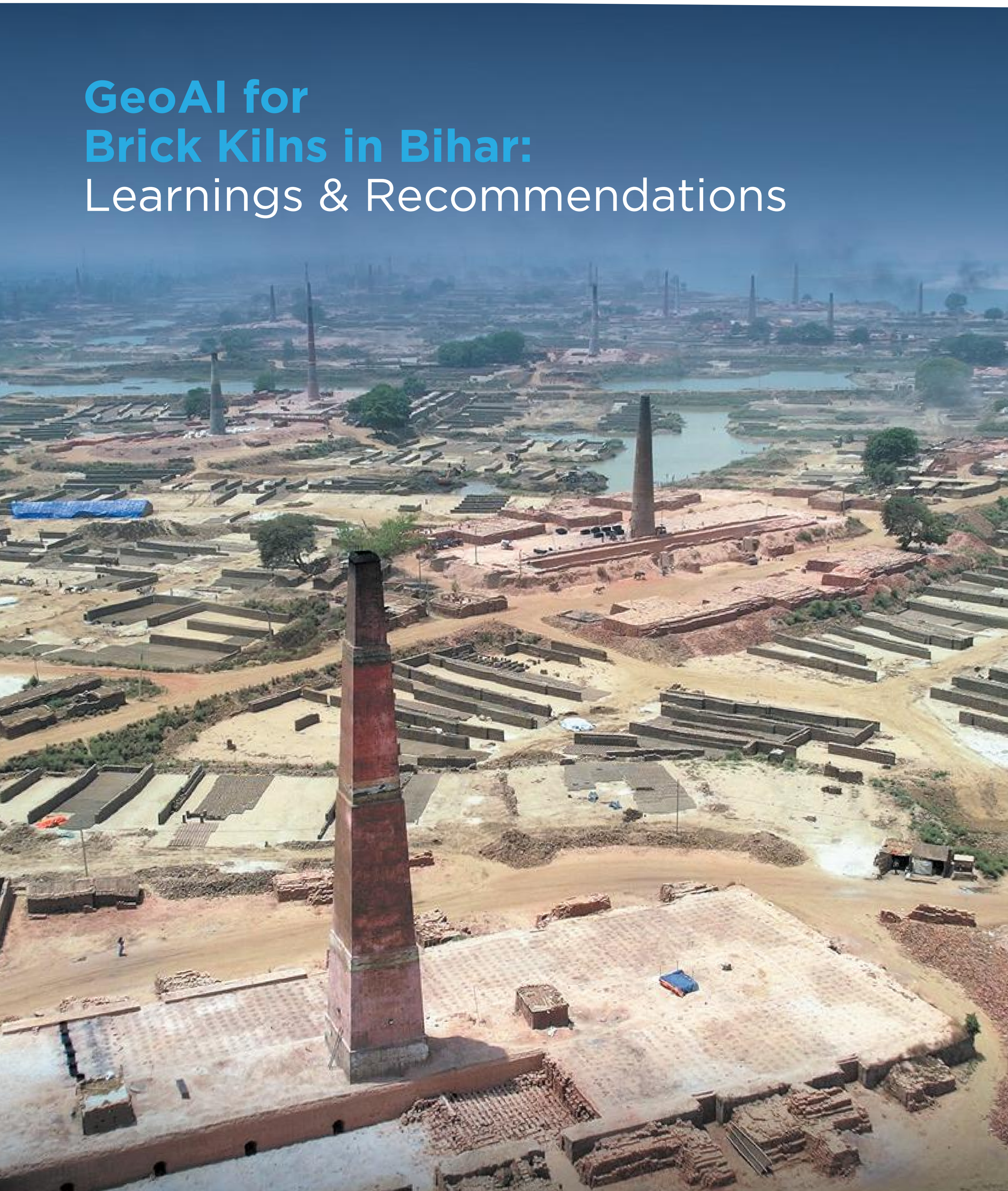
GeoAI for Brick Kilns in Bihar: Learnings & Recommendations



GeoAI for Brick Kilns in Bihar: Learnings & Recommendations

"Nine out of ten people globally breathe polluted air. Air pollution impacts human and environmental health, contributes to climate change, and hampers economic growth. It disproportionately affects poor and vulnerable communities, especially women. Over the last decade, technology has shown great potential to help us combat air pollution. The GeoAI platform, developed through this partnership, combines cutting edge tech with community engagement to monitor pollution hotspots. At UNDP, we continue to work with governments, research institutions, development partners and civil society to ensure a clean and healthy environment for all."

– Isabelle Tschan,
Deputy Resident Representative, UNDP

"I envision a cleaner and healthier future for Bihar. I believe in the power of collaboration and innovation to tackle air pollution. Our state has pioneered collaborative efforts, uniting government bodies, industries and communities in the fight against air pollution. Through groundbreaking initiatives, like Geo AI, we've harnessed the power of innovation to pinpoint pollution sources and enforce targeted action. The data-driven model we've developed is a blueprint for nationwide change – Let's breathe life into a sustainable future for all."

– Dr. Devendra Kumar Shukla,
IFS (Retd.) Chairman, BSPCB

"This report and collaboration represents a major step forward in how we can use Earth Observation data to support important inspection and compliance activities, improve polluting and exploitative conditions in brick kilns, reduce related health issues, and transform local economies: we in the Rights Lab are proud to support this pioneering work to achieve environmental and social sustainability at a vast scale."

– Professor Doreen Boyd,
Associate Director of the Rights Lab, University of Nottingham

One of the most basic needs of people is safe, secure and affordable shelter. For this, building materials are needed that are durable, accessible and yet inexpensive, resource conserving and ecologically beneficial. Over the past decade, the Government of Bihar has built up a highly trust-based and mutually supportive relationship with Development Alternatives to pioneer the innovation, manufacture and delivery of such materials at scale, while minimizing air and other pollution. Aiming at a truly Just Transition for the brick sector through technological innovations and their demonstrated success is expected to help the State Government transform the entire construction sector in Bihar and set an example for widespread replication in India and globally. This GeoAI report and the partnerships with Shakti Sustainable Energy Foundation, University of Nottingham, UNDP and Bihar State Pollution Board is a first step towards ensuring a transformative development of the Bihar brick sector through the use of modern technologies and resource management methods.

– Dr. Ashok Khosla,
Chairman, Development Alternatives

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Acknowledgements

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Key Insights

Brick Kilns as SDG Objects of Intersectionality

- Brick kilns are SDG Objects of Intersectionality where extreme poverty meets extreme environmental degradation.
- As second largest users of coal, brick kilns cause carbon emissions, air pollution, land degradation and depletion of water table.
- Brick manufacturing sector contributes to 8%-14% of air pollution across Indo-Gangetic plains also referred as ‘Brick Belt’ of India.
- Brick kilns are hard to regulate as they are small industries in large numbers and spread across large geographies of Indo-Gangetic plains.

Detecting Brick Kilns from Space

- GeoAI technology is a novel approach combining geospatial technologies and artificial intelligence to detect objects from satellite imagery.
- GeoAI platform developed by UNDP and the Rights Lab at the University of Nottingham provides intelligence around brick kilns using machine learning algorithms and geospatial analytics.
- Locations of more than 47,000 brick kilns along the Indo-gangetic plains are detected with 96% accuracy with this technology in India
- GeoAI leveraged digital volunteering and citizen science to generate training data sets for machine learning algorithms.
- Value added insights such as degree of compliance to environmental regulations such as distance criteria, technology classification etc are also generated with GeoAI technology.
- GeoAI platform brings coordinated action from diverse stakeholders – regulators, government agencies, civil society, and volunteer groups to tackle the complexity around brick kilns.
- A user-friendly mobile and web application supports government agencies in Bihar to conduct field inspection and regulate brick kilns.
- Ground Inspection data feeds back into GeoAI algorithms to improve accuracy and generate value added insights.

Figure:
Image of Brick Kiln in India

Key Insights

Field Inspection

- Field inspection with GeoAI mobile app provides optimized route maps to navigate to brick kilns and collect field data along with photographs
- In Bihar 1680 kilns across five districts were inspected to verify brick kilns technologies, production capacity, fuel utilization and labor working conditions.
- 96% of brick kilns detected by GeoAI are found on the field at the location detected. 75% were found operational.
- 65% were classified accurately by AI algorithms as Zigzag vs FCBTK. This accuracy improves by feeding more field data into the algorithms.
- Based on field inspection, an average brick kiln produces 35,086 lakh bricks annually.
- Two-thirds of brick kilns were found to be operating with Zigzag technology showing higher regulatory compliance on ground.
- 64% of brick kilns have medium production capacity of 15,000-30,000 bricks per day. About 33% have a small capacity of less than 15,000 bricks per day of which almost half are FCBTK kilns.
- Fuel efficiency is low in many kilns because of low charging frequency - more than half the brick kilns are charging at more than prescribed 15 min frequency.
- More than 40% brick kilns are not sprinkling water on the ash layer causing fugitive emissions from kilns.
- Zig zag brick kilns have better compliance to licenses and operational practices as compared to FCBTK kilns.
- 85% of brick kiln workers belong to SC & ST categories. 13% are women workers. Majority of the workers are migrant labor.
- 94% brick kiln worksites have portable drinking water, 51% have toilets and only 8% have shade facilities for workers.

Policy Recommendations

- Business as usual will not help in tackling the air pollution crisis.
- The potential of data innovations in catalyzing new intelligence and coordinating action should be leveraged at all levels of action to improve air quality.
- A national platform backed by suitable investments can help foster innovation and experimentation at an accelerated pace.
- State Pollution Control Boards to stop issuing new licenses for fired brick kiln technology while also cancelling the mining lease of non-Zig Zag kilns.
- Financial incentives for brick kilns owners to switch to tunnel kilns, gas based kilns, fly ash technology or zig zag technology
- Capacity building of brick kilns owners and workers are urgently required in zig zag kiln construction, improve fuel efficiency, reduce fugitive emissions
- Market Incentives to promote fly ash bricks and alternate building materials such as pre-fabricated walls, geopolymer bricks, hollow concrete blocks, compressed stabilized earth blocks
- Improvement of working conditions for labourers, provision of social security and social justice services to brick kiln workers in a targeted manner is of paramount importance.
- Skills training for brick kiln workers to switch to better employment opportunities should be actively promoted.

01

SECTION 1:

Introduction

01 Introduction

India is the second largest producer of bricks globally and with its ever-growing demand for infrastructure and housing, brick production is rapidly expanding. Brick manufacturing also has a large contribution to GreenHouse Gas (GHG) and black carbon emissions and with it, adverse repercussions on the environment, especially from an air quality perspective. To understand this scale, nearly 8% of all air pollution in the Delhi-NCR regions is contributed directly by brick kilns in India, which is almost a quarter of the pollutants from the country's industrial sector [1]. A quick search of air pollution on Google leads to visuals of large-scale black smoke emitting chimneys – these are often photographs of brick kilns at work.

Almost all the world's population (99%) is exposed to air pollution levels, which causes over 4.2 million death every year[2]. Pollutants emitted from such kilns have public health concerns. These include particulate matter (PM), carbon monoxide (CO), ozone (O3), nitrogen dioxide (NO2) and sulphur dioxide (SO2) and breathing them can lead to a range of respiratory and cardiovascular diseases. Increasing concentrations

[1] https://www.undp.org/india/blog/how-geoai-platform-helping-target-brick-kiln-hotspots-air-pollution
[2] https://www.who.int/health-topics/air-pollution#tab=tab_1

Figure 1.1 (a):
Aerial view of Brick Kiln in India

Figure 1.1 (b):
Smog in an Indian City

of green-house gas emissions are leading to warmer climates, which affects changes in the atmosphere, land and water. Intensification of this is leading to sporadic and adverse climatic events like forest fires, coral bleaching in oceans, accelerating ice melting, rising sea levels amongst many other symptoms of climate change.

Air pollution also adversely affects the health of ecosystems. Oxides of nitrogen (NOx) harm terrestrial and aquatic ecosystems by introducing excessive amounts of nutrient nitrogen resulting in overabundance of algae, decreasing oxygen available for fish and other aquatic life. Similarly, over land, climate change induced intensification of natural disasters and large-scale habitat degradation are a major threat to wild animals, leading to a high rate of extinction of rare, endangered, and threatened species.

Air pollution also generates economic loss especially due to lower labor productivity, avoidable health expenditures, and crop and forest yield losses[3]. In 2018, a report quantifying the cost of air pollution from fossil fuels estimated a $2.9 trillion cost, equating to 3.3 percent of the world's GDP[4].

Such trends have previously been identified through research. For example, seasonal fluctuations in emissions of NOx (Figure 2). Oxides of nitrogen are highly concentrated during the brick making season particularly around urban environments, but there is a broader spread of higher concentrations in the off-season as the drivers of pollution ebb annually[5]. Further, PM2.5 concentration levels have been identified around key Indian urban centres, with increases in these emissions having increased over time as the number of kilns have also increased[6].

[3] https://www.oecd.org/environment/indicators-modelling-outlooks/Policy-Highlights-Economic-consequences-of-outdoor-air-pollution-web.pdf

[4] https://energyandcleanair.org/wp/wp-content/uploads/2020/02/Cost-of-fossil-fuels-briefing.pdf

[5] Jackson, B. (2020). Slavery from Space: An analysis of the modern slavery-environmental degradation nexus using remote sensing data. University of Nottingham.

[6] 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: 111. https://doi.org/10.1057/s41599-021-00792-z

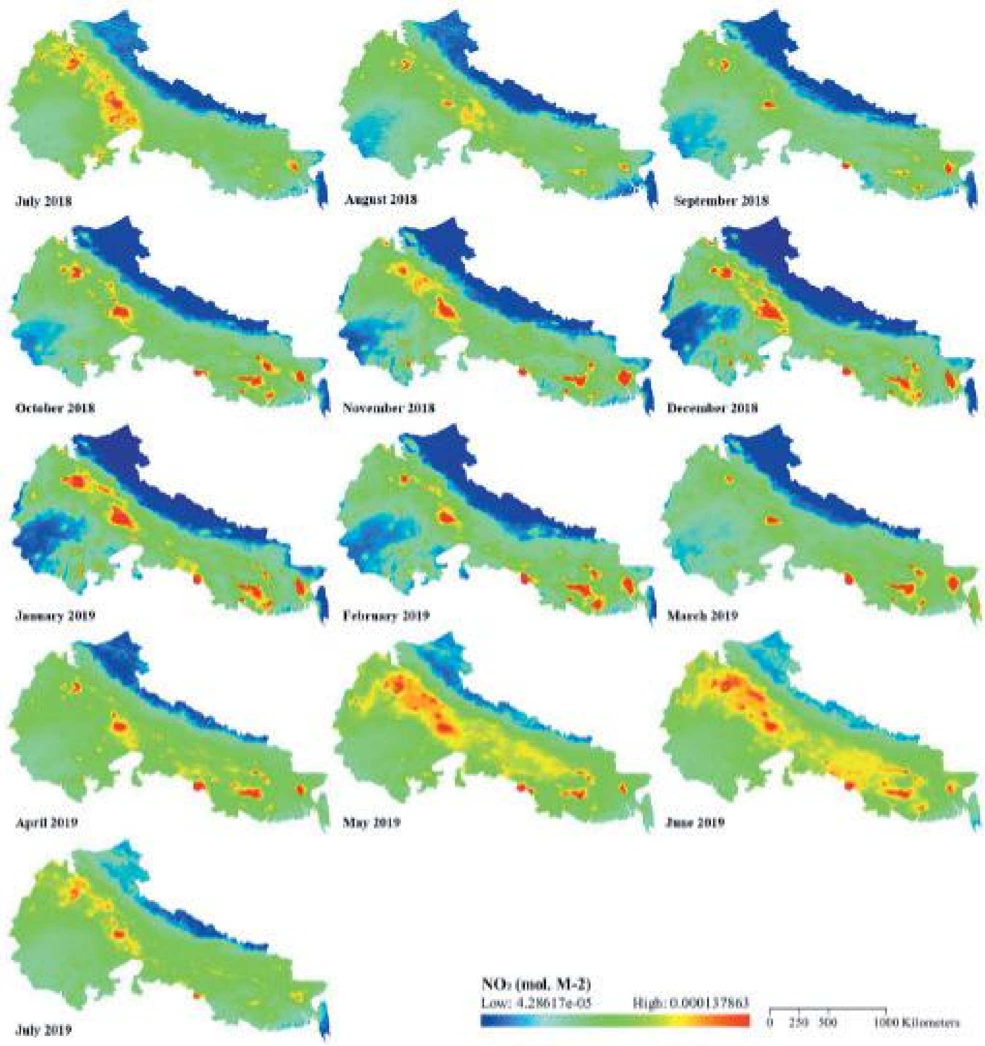


Figure 1.2: Monthly mean average NO2 pollutant concentrations (mol. M-2) over the 'Brick Belt' (data measured by the Sentinel-5p TROPOMI sensor; data processed in Google Earth Engine). Minimum and maximum pollutant concentration averages were 4.28617e-05 and 0.00013

Various attempts have been made by the government at the national and state level to improve energy efficiency and reduce the amount of coal required to operate brick kilns. The apex body on air pollution in India, Central Pollution Control Board, Govt. of India, via various notifications has suggested brick kilns across the country to adopt new innovations, improve production efficiency and reduce air pollution.

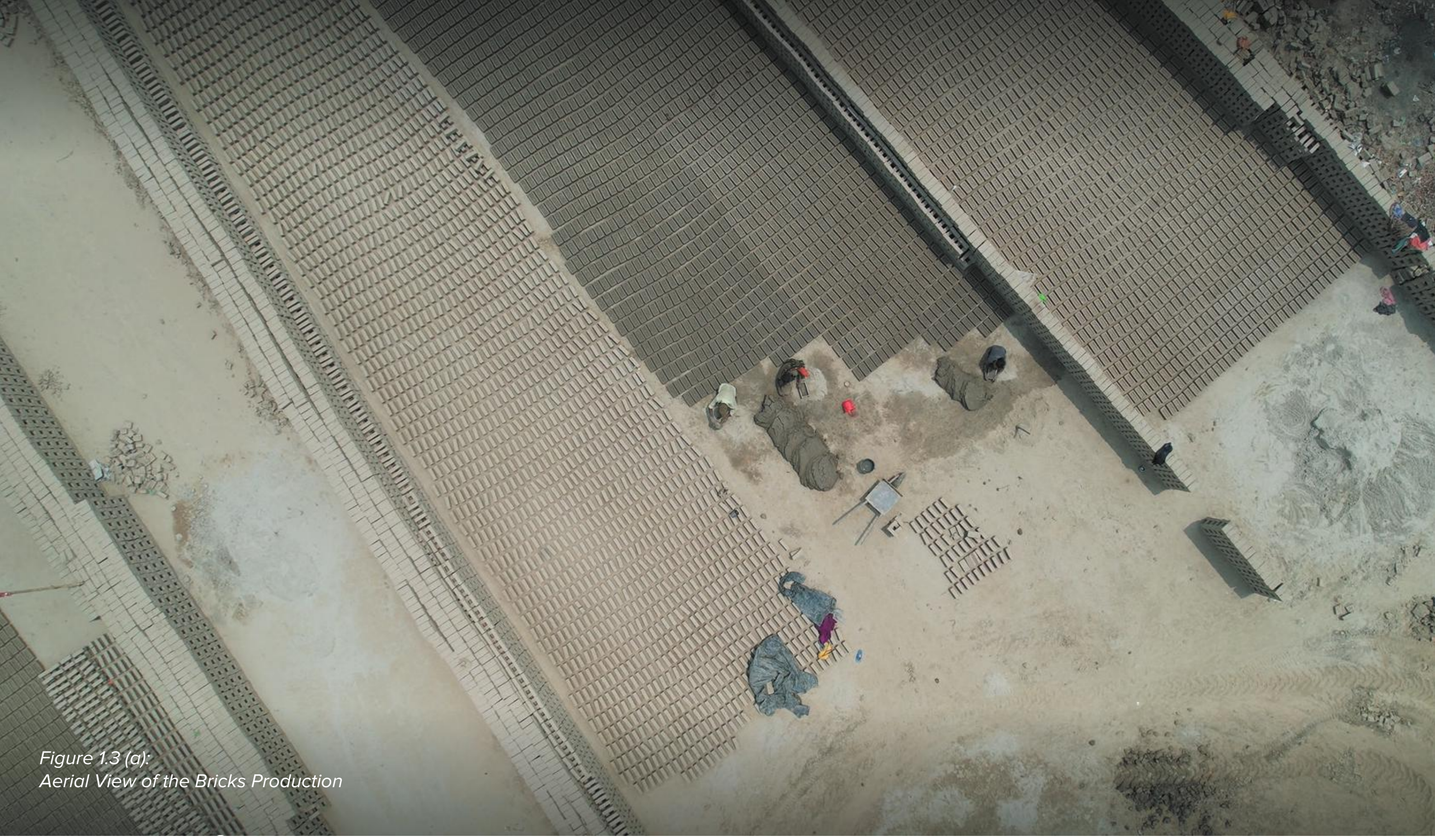
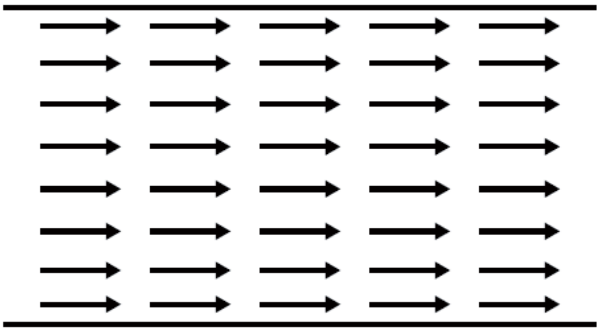


Figure 1.3 (a):
Aerial View of the Bricks Production

Figure 1.3 (b):
Images of Bricks Production in India



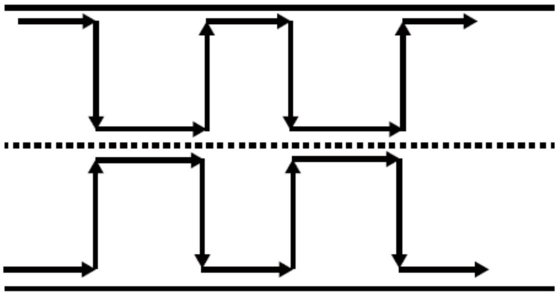


Figure 1.4 (a): Air Flow in FCBTK and Figure 1.4 (b): Air Flow in Zig-Zag Kiln

Some examples of this include the improvements in fuel efficiency by Development Alternatives in a pilot project in Bihar where mixing coal waste with soil increased energy efficiency by 9% and reduced the cost of external fuel by 30% while improving the compressive strength of the brick. Similarly, as an alternate to crop burning, which is a major cause for pollution in Northern India, Punjab State Council for Science & Technology (PSCST) initiated trials to establish use of paddy straw pellets as partial replacement of coal in induced draft brick kilns with zigzag firing resulting in reduction of particulate emission by 30% besides economic savings. After the success of the trials, the state government has mandated use of paddy straw pellets by replacing 20% coal in brick kilns.

Other improvements have been seen in the evolution of brick kiln technology, like the transition from the traditional Fixed Chimney Bull Trench Kiln (FCBTK) to zig-zag technology has resulted in significant reduction of coal consumption by 20%, black carbon emission and SPM reduction by 75%, and specific energy consumption reduced by 20%. However, there are still many kilns in India that haven't made this shift due to operational costs involved in the transition, increasing demands for bricks and the absence of government monitoring from a real-time perspective.

While the world is working towards accelerating progress for achieving the Sustainable Development Goals (SDGs), targeting air pollution and ensuring clean air intersects multiple goals. It affects the three dimensions of sustainable development: the economic, social and environmental. Though not standalone in achieving multiple SDGs, ensuring clean air can, at the very least, play an enabling role in accelerating progress towards them. Clean air has a direct correlation with human health (SDG 3); healthy people and healthy working conditions are also more likely to be more productive, which helps overall economic growth (SDG 8); Air pollution exacerbates climate change affecting agricultural productivity and linked with it is significant crop loss, nutritional insecurity, and deteriorating quality of life in cities (SDGs 2, 4 and 11). All these factors compound to affect vulnerable populations the most, especially women, children and the elderly.

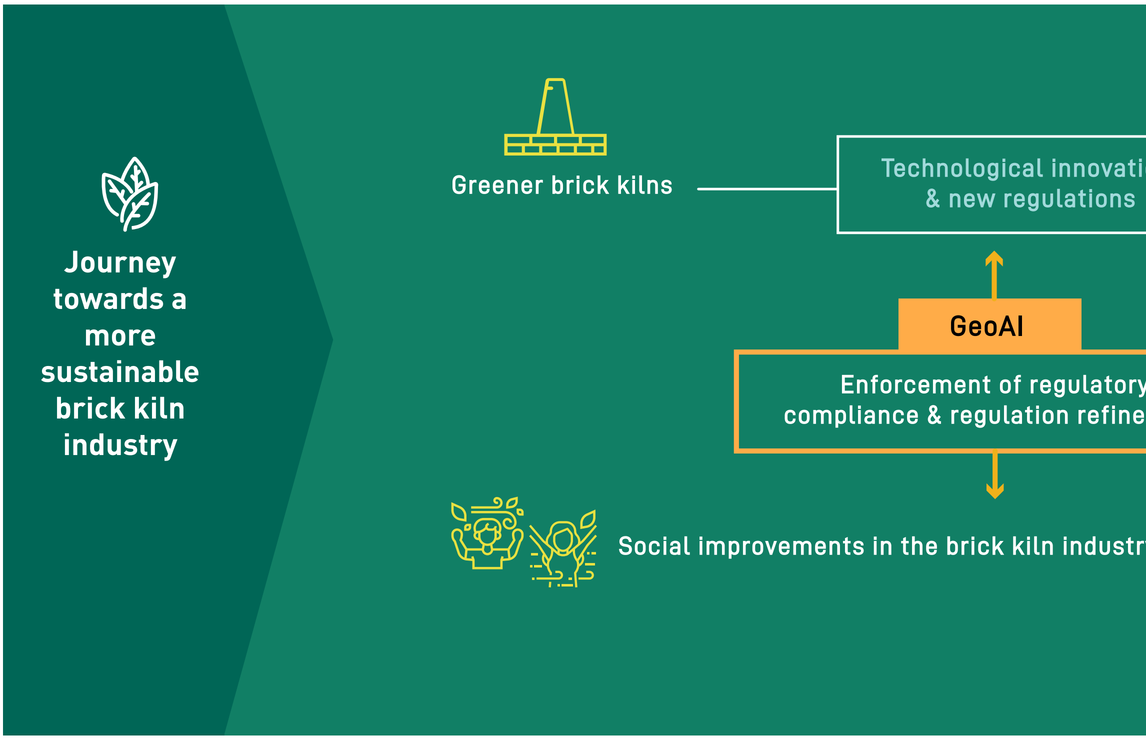
Also affected from consequences of air pollution are the ultra-poor, who face multiple hurdles to transition out of poverty and depend on insecure and informal sources of livelihood[7]. These include seasonal migrant workers, akin to workers in the brick manufacturing sector, who don't have agency in choosing a safe space to work, don't have money to afford education for their children and are continuously subject to newer forms of bonded labour[8].

The Indian brick sector creates employment for around 8 million people, in various forms of unorganized labour. Each season, it produces over 170 million bricks in 150,000 units and uses around 350 million tonnes of fertile topsoil and 24 million tonnes of coal, emitting 42 million tonnes CO_2 in the process[9]. On the flipside, economic losses induced by air pollution that lead to lower labour productivity and health, account for an estimated \$2.9 trillion cost, equating to 3.3 percent of the world's GDP[10].

Considering this scale, the brick manufacturing sector not only holds immense potential for adoption of cleaner technologies in production and process modifications, but also in meeting basic human rights and needs of the unorganized labour involved. This workforce primarily comprises of the ultra-poor, bonded/forced migrant seasonal labour, who are often accompanied with their children and wives at work and are exposed to high working temperatures, dust, a multitude of toxic chemicals and concentrated localised air pollution – making respiratory diseases like asthma and tuberculosis common. With the large number of kilns in India and fewer resources in identifying unregulated kilns, regulating this sector, towards green transition and a safer work environment, needs new approaches.

[7] https://www.povertyactionlab.org/case-study/targeting-ultra-poor-improve-livelihoods
[8] https://www.cec-india.org/brick-kiln-workers.php
[9] http://www.perspectives.devalt.org/2020/11/01/greening-the-brick-sector-in-india-bihar-leading-the-way/#:~:text=Despite%20being%20unorganised%2C%20the%20Indian,tonnes%20CO2%20in%20the%20process.
[10] https://energyandcleanair.org/wp/wp-content/uploads/2020/02/Cost-of-fossil-fuels-briefing.pdf

*Figure 1.5 (a) and (b):
Worker in Zig-Zag Brick Kiln*



Recent amendments in environmental regulation endorse cleaner technologies in the brick manufacturing sector. In 2022, the Ministry of Environment, Forest & Climate Change (MoEF&CC) released the Environmental (Protection) Amendment Rules, which only allow zig-zag technology, vertical shaft and use of Piped Natural Gas as fuel in brick making. However, it becomes a challenging task to implement such rules given the sheer number and scale at which brick kilns operate in Northern India. This coupled with the "hidden" nature in which unregulated brick kilns operate, often in the outskirts of villages or small towns, make them hard for regulators to locate on ground.

To address some of these issues and bring in novel technology to provide real-time data to the government for effective decision making, UNDP partnered with the Bihar Pollution State Control Board, Development Alternatives and the University of Nottingham (United Kingdom), to use earth observations in developing new knowledge and practices. This partnership showcases new ways of understanding the dynamics of under-the-radar brick manufacturing and to improve working conditions of thousands of people involved in it. While University of Nottingham leads the research on Earth observation and Artificial Intelligence (AI) in identifying such kilns, UNDP adds digital means to make the

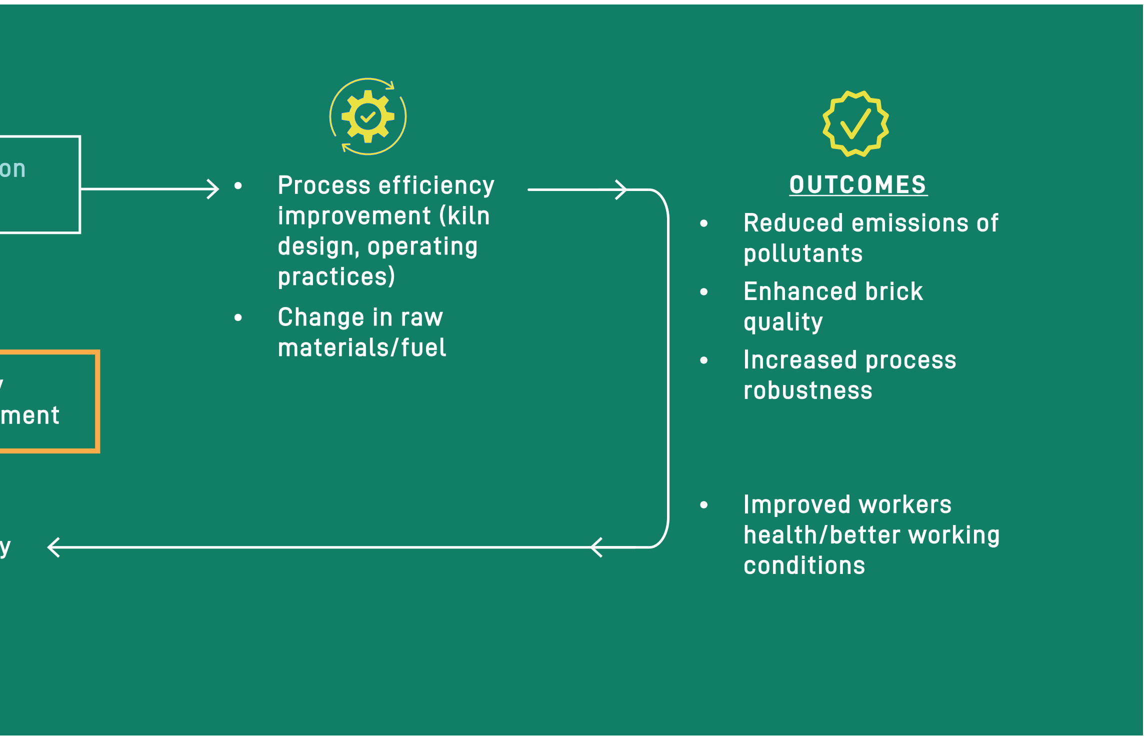


Figure 1.6: GeoAI Overview

complex AI technology easily accessible to diverse stakeholders for collaboration and collective action for this project, Development Alternatives contributes to the ground level research with their decades of experience in working with the brick manufacturing industry. This research culminates in action taken by the Bihar State Pollution Control Board in regulating brick kilns that are non-compliant to the latest environmental rules, labour laws and in supporting kilns for transition to cleaner technology.

The partnership led to the development of a Geo AI platform. This digital platform provides real-time information of brick kilns across North India, with their geolocations, technology used and various other parameters that support the decision-making at the state and national level on brick kiln compliance. This innovation is powered by artificial intelligence, citizen science, satellite imagery, and mobile technology, providing intelligence on the location and compliance of the brick kiln sector. It aims to improve the environmental compliance of the brick manufacturing industry in the country.

GeoAI has accurately mapped more than 47,000 brick kilns across 12 states of India in the Indo-Gangetic plains that are hotspots of air pollution.

02

SECTION 2:

GeoAI Architecture and Technology

02

GeoAI Architecture and Technology

2.1 About GeoAI

Geospatial artificial intelligence, often known as GeoAI, is an emerging scientific discipline that combines innovations in spatial science, AI methods such as Machine learning (ML), and Deep Learning (DL), data mining, and high-performance computing [source]. According to Gartner, GeoAI is the use of AI methods, including ML and DL, to produce knowledge through the analysis of spatial data and imagery.

GeoAI can be used for diverse applications involving pattern detection in spatial imagery such as Segmentation, Object Detection, Feature Extraction, Image Classification, Change detection and many more analyses that can be applied to inform a wide range of sustainable development challenges.

Figure 2.1: GEO AI Specifications

▼

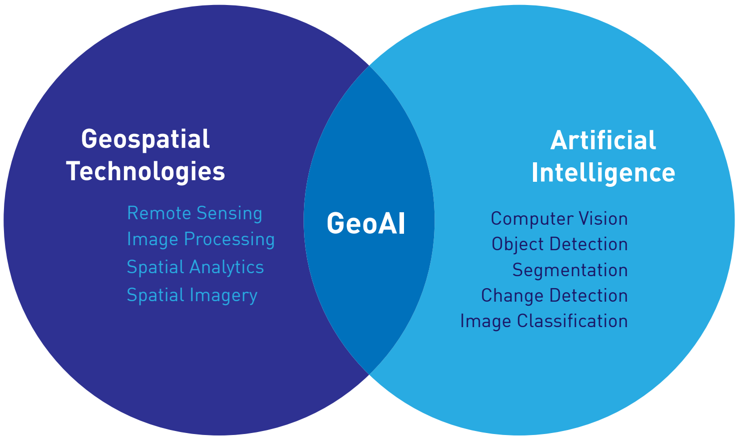


*Figure 2.2:
GeoAI Platform for Brick Kilns*

2.2 GeoAI platform for Brick Kilns

The Geo AI platform for Brick Kilns has been co-created by UNDP and University of Nottingham by leveraging various technologies such as Artificial Intelligence, Spatial Sciences, Citizen Science, and Digital Development. Partnerships at every stage were fundamental to building this platform. Our problem statement was to “Provide data and evidence on brick kilns for development policies and programs to reach them in a targeted and accelerated manner”

▲

Figure 2.3: Satellite Imagery of Brick Kilns

Satellite Imagery:

Very High Resolution (VHR) satellite imagery was procured from Airbus through a data partnership between University of Nottingham and Airbus. The dataset included Airbus Pléiades optical imagery which is distributed at a resolution of 50 cm per pixel, across four spectral wavebands (blue, green, red and near-infrared) within a 20 km swath[11]. The data offered full contiguous coverage of the 'Brick Belt', extending ~ 1,550,000 km^2 across multiple countries (India, Pakistan, Nepal and Bangladesh). The use of very high resolution data is a key requirement as brick kiln installations will be readily visible at the detail level offered by the imagery, thus simplifying the detection task in both visual assessment and any automated detection.

In addition, the freely available Google Earth satellite basemap imagery from 2014-2016 was used as a source of VHR data for visually identifying and crowdsource labelling of brick kilns, producing the first rigorous estimates of the number of kilns across the 'Brick Belt' and an annotated sample dataset. The basemap, which incorporated imagery from Maxar's WorldView-2 and Airbus' Pléiades at an average of 50 cm per pixel, was further exploited to generate an input dataset for AI detection and classification.

Spatial Analytics:

Image processing and spatial analysis methods were used to obtain a dataset compliant with the requirements of Machine Learning or Deep Learning algorithms.
In the initial stage[12], very high resolution imagery from Google Earth's basemap was used to

[11] Airbus Pleiades Product Description accessible at: Pléiades (intelligence-airbusds.com)
[12] Boyd, D., Jackson, B., Wardlaw, J., Foody, G.M., Marsh, S., Bales, K., Slavery from Space: 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, Volume 142, 2018, Pages 380-388, ISSN 0924-2716,
DOI: 10.1016/j.isprsjprs.2018.02.012.

identify and map brick kilns via visual interpretation and spatial statistics with the goal of providing a statistically credible estimate of the expected number of kilns. The entire 'Brick Belt' area was divided using a grid composed of 100 km^2 cells. By applying probabilistic and statistical sampling theory it was determined that with only a number of 320 randomly selected cells, a 95% level of confidence in the yield estimate would be achieved across the entire 'Brick Belt'. Image extracts for each selected grid cell were interpreted and brick kilns locations were marked. The initial estimate indicated the number of brick kilns to be between 44,542 and 66,270 units, pointing at the uneven density distribution of brick kilns across the 'Brick Belt' landscape. To validate this estimate, a subset area of 250 km^2 in the region of Rajasthan was selected for volunteers to analyse image extracts and mark the presence of brick kilns. A verified and enhanced version of this resulting dataset has served as an original 'labelled dataset' for subsequent AI training along with a curated dataset of Airbus Pléiades imagery covering the 'Brick Belt' [13].

Citizen Science:
Processed imagery from the 250 km^2 in the region of Rajasthan was uploaded on the online Zooniverse[14] citizen science platform for digital volunteers to help with the visual detection of brick kilns. This allowed for 120 international volunteers to visualise and confirm the presence of kilns. Repeated markings of a single kiln on the same image were spatially clustered and confirmed and annotated by an expert interpreter, hence aiding in building an initial 'AI labelled' dataset containing 263 brick kilns.

Further, in a separate effort, 13 digital volunteers in India were engaged to classify the detected more than 2500 brick kilns as FCBTK and Zigzag based on their spatial layout, which fed into training data of an image classification AI algorithm.

Citizen involvemment allowed widespread engagement and information dissemination on the issues linking modern slavery and environmental issues at brick kilns, proving that citizen participation has considerable potential to support large-scale mapping and rapid action when individuals are motivated by serving a public good purpose.

Artificial Intelligence:
Algorithms built on contemporary deep learning architectures such as a Convolutional Neural Networks (CNNs) were applied for detection of brick kilns over the large geographies of the 'Brick Belt' and India. A state-of-the-art CNN architecture, capable of handling large scale VHR satellite data and providing a good trade-off between the speed and the accuracy of the detection, was chosen for performing the tasks of object detection and prediction. For effectively processing the large scale volume of VHR imagery, a three-step iterative method has been designed for training the CNN. Starting from

[13] Boyd, D.S., Perrat, B., Li, X. et al. Informing action for United Nations SDG target 8.7 and interdependent SDGs: Examining modern slavery from space. Humanit Soc Sci Commun 8, 111 (2021). https://doi.org/10.1057/s41599-021-00792-z
[14] Projects — Zooniverse

the initial crowd-annotated dataset, the CNN was fed a twice enhanced training set in order to learn the features associated with a brick kiln. Last, the trained model was finally applied on image subsets of 50 km^2 for detection and kiln probability prediction. 47,000 brick kilns were detected with 96% accuracy along the indo-gangetic plains and across 12 states of India.

Digital User Interface:
A user-friendly mobile application and web platform were developed to facilitate field inspection and field action by various stakeholders; and generate various analytical reports. As early adopters of this unique technology, BSPCB in partnership with DA implemented this technology in 5 districts of Bihar.

Partnerships:
Data partnerships between Airbus and UoN; UNDP and UoN; and then between UNDP-BSPCB-DA helped in co-creating and implementing the GeoAI platform to tackle the problem of detection of brick kilns from space and provide value added insights.

How does Object Detection Work?

The object detection task involves the accurate recognition of brick-kiln objects in satellite imagery in an automated manner, moving forward from the initial visual and statistical assessment. Brick kilns display a characteristic appearance in shape (oval, rectangular and circular) with a central chimney. Their size is variable with shape, with an average radius of 33 m being considered a standard[15]. Due to their shape and size, brick kilns are distinctly recognizable on VHR imagery, as the region of pixels occupied by the brick kiln is sufficiently large to accommodate details of the object. This eliminated the need of exploiting the spectral information associated with the kiln, a method which has been traditionally used in conventional classification algorithms and move instead towards a contemporary object detection approach.

These contemporary methods for automated image analysis were based on a set of machine learning architectures, deployed in a multi-iterative sequence involving CNN-based algorithms. Convolutional Neural Networks (CNNs) are a specialised type of neural network architecture that have been proven to be very effective for object detection and classification of satellite imagery. A CNN architecture is inherently built to recognise the presence of certain patterns and features, such as edges and textures associated with the kiln shape and position within the image, by repeatedly scanning (convolving) over a sample image and applying image filters to extract meaningful features.

Object detection within the GeoAI platform was performed using a specialised type of CNN architecture, the YOLOv3 (You Only Look Once, Version 3), a state-of-the-art deep

[15] Foody GM, Ling F, Boyd DS, Li X, Wardlaw J. Earth Observation and Machine Learning to Meet Sustainable Development Goal 8.7: Mapping Sites Associated with Slavery from Space. Remote Sensing. 2019; 11(3):266. https://doi.org/10.3390/rs11030266

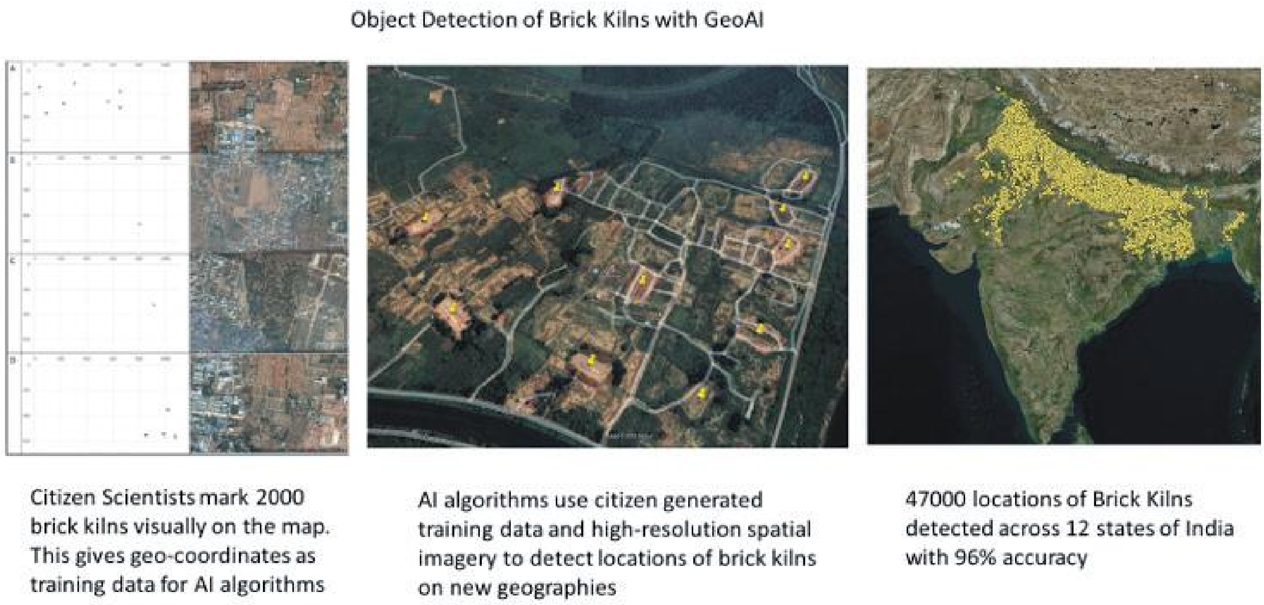


Figure 2.4: Object Detection of Brick Kilns with GeoAI

learning model that has been pre-trained for object detection. The known advantage of YOLO is that due to its architecture, it provides a good trade off between the speed and the accuracy of detection, making it a popular choice for large-scale analysis of satellite data.

An iterative three step method was designed for training the CNN model. In the initial step, a set of a thousand examples of annotated brick kilns representations was used to train the model in learning the visual cues associated with a kiln. The data used for training was obtained by sampling the previously crowd-annotated dataset for a high density region of just 120 km2 in Rajasthan and apply data augmentation techniques to enhance the total number of representations. The small scale dataset proved to be sufficient for the network to learn and generate a general detection map across the 'Brick Belt'. Secondly, 3000 random kiln detections were selected from these total predictions and manually reviewed by an expert for false interpretation. The resulted 2709 correct predictions, ensuring enough representation of brick kiln structure and locational context (urban vs rural), were collected for retraining the CNN in the third step.

In order to process the entire 'Brick Belt', the area was divided into a grid of 50 km2. Satellite data from each of the 893 cells of the grid were iteratively passed through the pre-trained CNN for object detection. For predicting the likelihood of an object to be a brick kiln, each cell was further divided into 1 km2 patches. A total of 66, 455 kilns were identified across the 'Brick Belt' with an accuracy of 98%. Applying this methodology across the 12 Indian states, resulted in 47, 000 possible locations were mapped with a 96% accuracy.

Advance analytics on Brick Kilns

Calibration of Distances as regulatory criteria

Every brick kiln operating in India is bound to comply with the Government rules. Each state has set specific distance criteria for the operation of brick kilns w.r.t nearest roads, railway, water bodies etc.. The GeoAI helps the regulators to find out about the distance of each brick kiln from these features, thereby giving indication of kilns which are not complying with the government regulations.

For this, the spatial dataset of existing road and railway network, water bodies etc. are gathered from the open data source. Then the distance from each brick kiln location to the nearest roads, railway line and water bodies are calculated in the geographic information system (GIS) environment. The distance between two adjacent brick kilns are also calculated in a similar way. All these distance information are populated for each of the 47000+ brick kilns in the GeoAI platform.

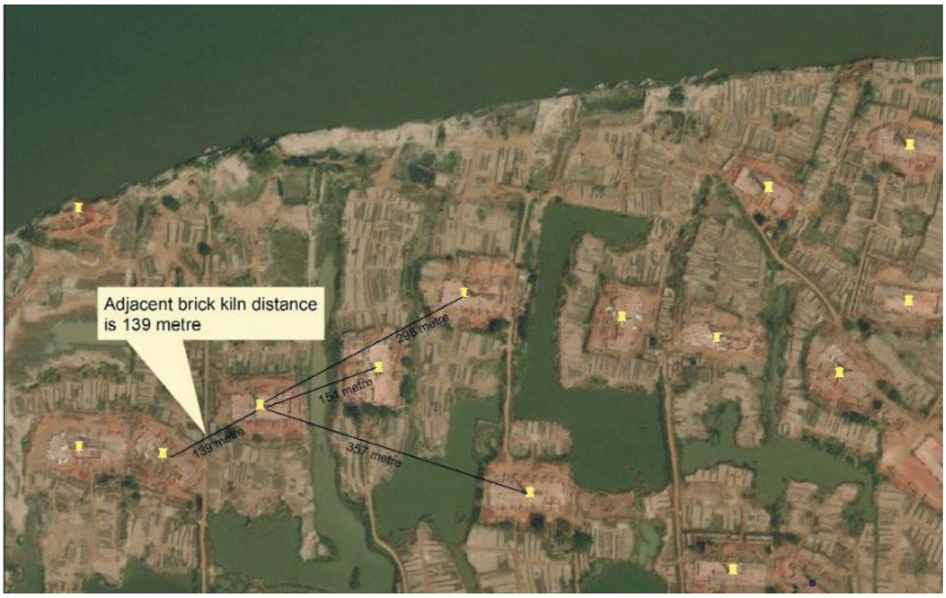
The information on the regulatory distance criteria for brick kilns operating in Bihar state was collected from BSPCB and cross checked with the above-mentioned features. Above 500+ brick kilns out of 7500+ brick kilns in Bihar state were found to have non-compliant w.r.t distance criteria.

To provide further information regarding each brick kiln, the spatial data regarding the administrative boundaries (District and State), nearest health facilities, nearest post office were gathered. All this information is tabulated to each brick kiln data using the GIS environment.

The GeoAI helps the regulators to find out about the distance of each brick kiln from these features, thereby giving indication of kilns which are not complying with the government regulations.

◀ *Figure 2.5: Distance of Each Brick Kiln to the nearest waterbody*

◀ *Figure 2.6: Distance of each brick kiln to the nearest road feature*



◀ *Figure 2.6: Distance of Each Brick Kiln to its Adjacent Brick Kiln*

Image Classification based on Brick kiln type.

The type of the brick kilns is recognised using the visualisation of brick kilns from the satellite images. Usually, the brick kilns which use the old bull-trench will be having an oval shape for the outer wall of kilns. Similarly, the brick kilns using new technology called Zig-Zag kilns will have rectangle outer walls for the kiln.

This specific shape difference of oval and rectangular is used to classify the brick kilns. The brick kilns with oval shape will be classified as Bull-Trench and the brick kilns with rectangular shape will be classified as Zig-Zag kilns. For the automatic identification of brick kilns type, a training sample of 5000 small satellite patches of brick kiln locations were visually interpreted and classified into categories of Bull Trench, Zig-Zag or doubtful area (places where it is doubtful to identify from space). Using these sample images the algorithm was trained and entire brick kilns locations in India were classified into any of these categories based on the specific shape of the kilns.

NOx correlations with brick kiln density.

Figure 2.8: Bull Trench (FCBTK) Klins

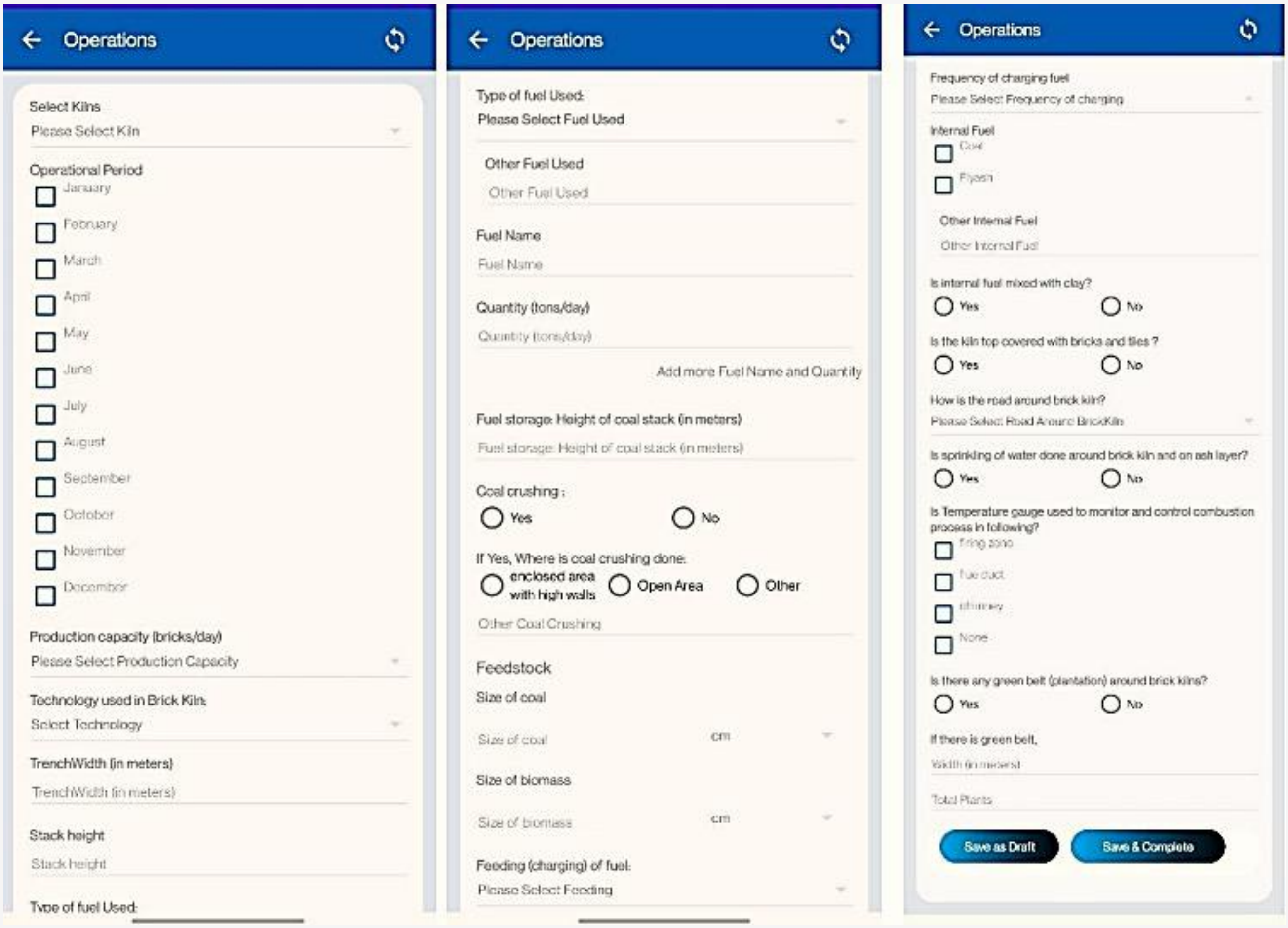
Figure 2.9: Zig Zag Kilns

Figure 2.10: GeoAI Mobile App

2.3 GeoAI Mobile App

The Geo AI Brick Kiln Monitoring System Mobile App is designed to assist field functionaries in managing kilns, environmental details, and labor information. The application aims to capture both physical and material specifications of the kilns.

This application is intended for use by various field officers to collect details about kilns and labor working at the kiln sites. Field functionaries can use the mobile application to gather information such as kiln environment details and site-specific questions. Admins, on the web portal, can access reports, approve or delete field functionary access, and manage user permissions.



▲
Figure 2.11: Operations Details

In the Kiln Registration process, field functionaries register new kilns by providing essential details, including the kiln supervisor and other pertinent information related to the kiln site. This step is a prerequisite before conducting any surveys on the assigned kilns.

The Environment Module is subdivided into two key sections: Operation and Consent to Operate. In the Operation section, field functionaries input details about the kiln's operational practices, covering aspects like operation period, technology used, production capacity, fuel utilization, and coal crushing practices. The Consent to Operate section further delves into seven sub-categories, addressing specific citing criteria such as air emission, flu gas emission, water consumption, waste water, solid waste, raw material, and product details.

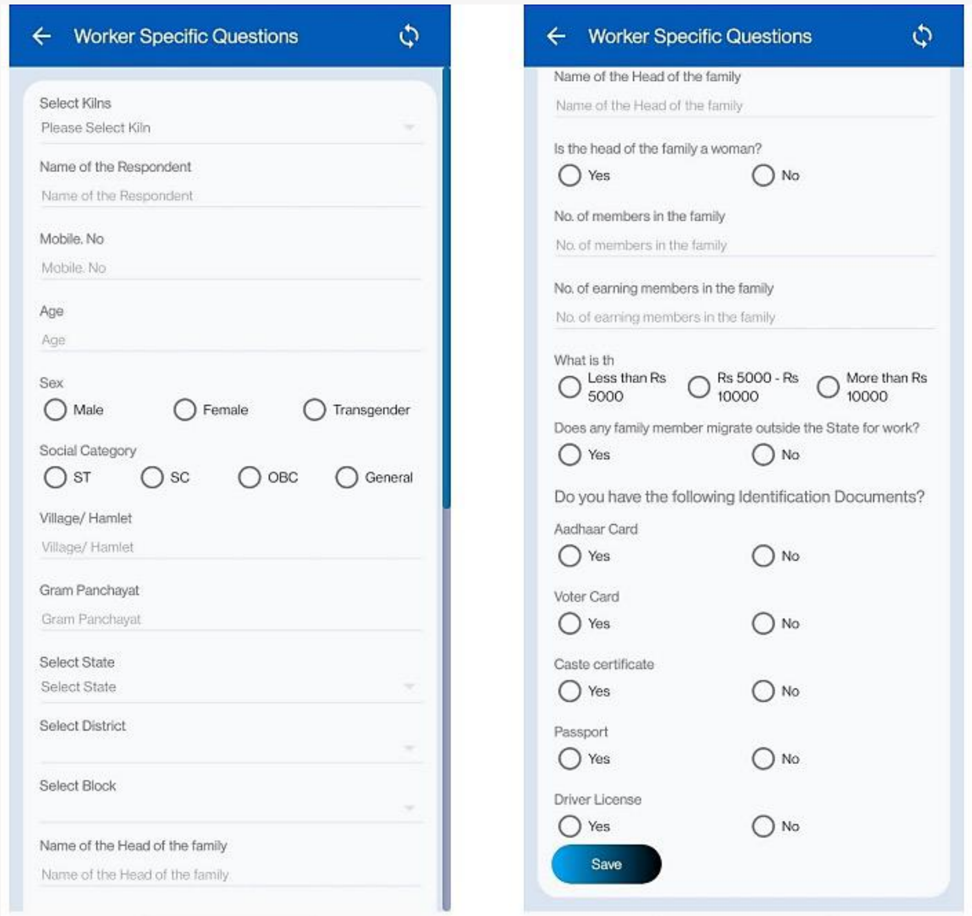
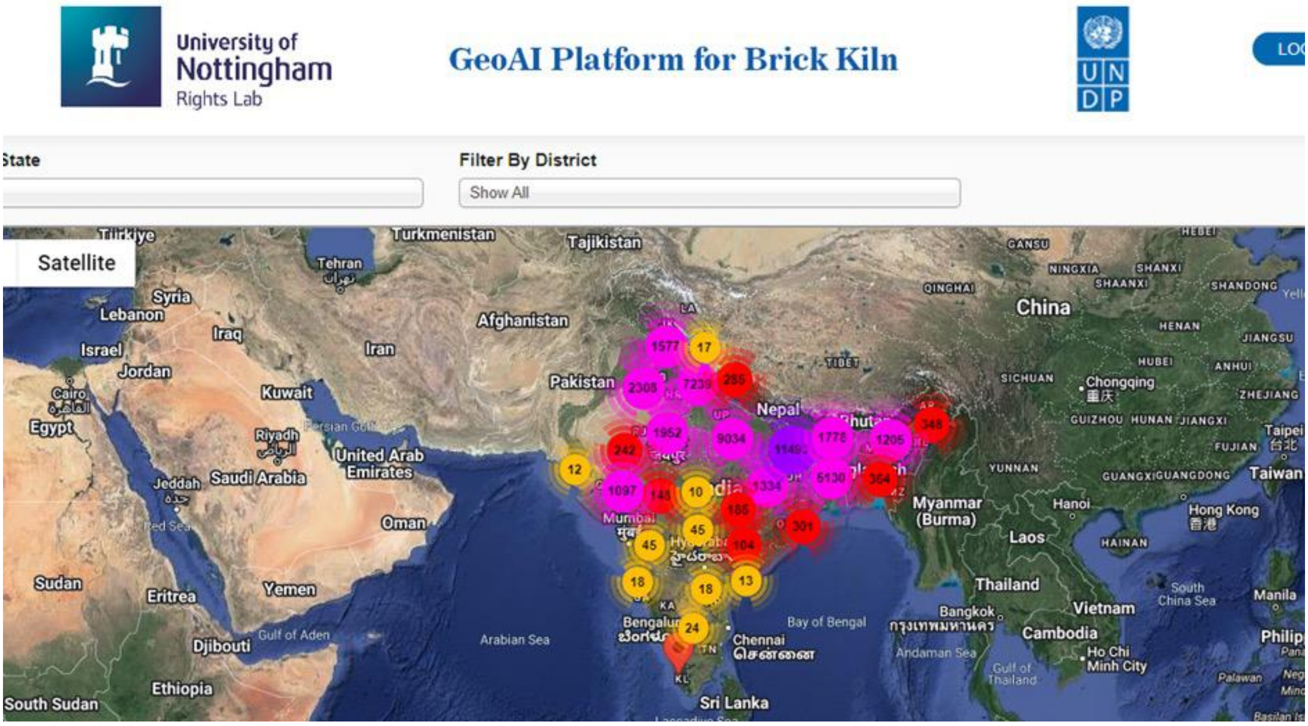


Figure 2.12: Worker Specific Questions

In the Upload Kiln Photos section, field functionaries can upload photos of the kiln site by selecting the kiln name, choosing photos, previewing them, and uploading. This section also enables users to view previously uploaded photos. The View function allows users to see reports of all data captured against their assigned kilns, with the option to edit until the data is saved as a draft. Finally, the Sync function is crucial for storing and uploading data in low or no connectivity areas, ensuring seamless data transfer between the user's device and the live server.

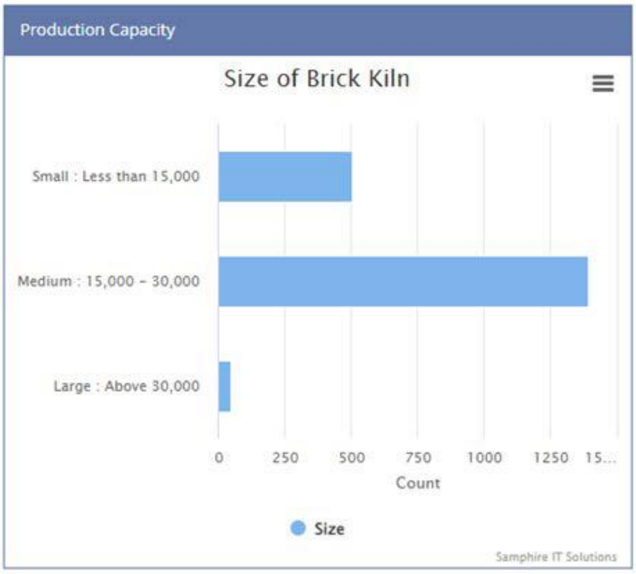


▲
Figure 2.13: GeoAI Platform for Brick Kiln

2.4 GeoAI Web platform

Dashboard

Upon entering admin credentials and signing in, the user is directed to the Geo AI Web portal dashboard. This dashboard provides a comprehensive overview of kiln records, field functionary assignments, and details related to kiln and kiln sites through graphical representations. The dashboard allows filtering of kiln data by state, district, and block, with kiln locations displayed on a map. Clicking on a kiln indicator reveals its exact location, represented by a red marker, along with details such as name and year of establishment. The map supports zooming in and out.



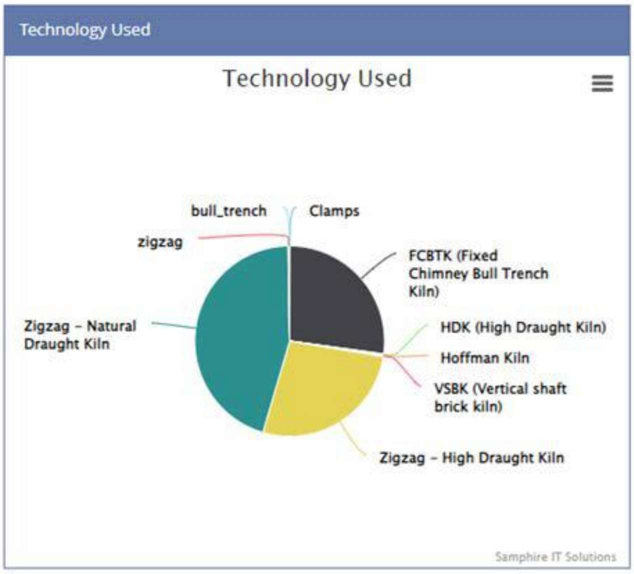


Figure 2.14 Charts showing size of Brick Kiln and Technology used

The dashboard features a chart illustrating the year-wise establishment report of kilns, with hover-over information on the number of kilns established in a given year. Kiln size is categorized as large, middle, or small, and the technology used in brick kilns is specified. The operation period chart indicates the number of active kilns in each month. Additionally, the dashboard provides insights into fuel types used in the kilns and whether they follow coal crushing practices. The Admin section of the Geo AI Platform has two main parts: Module & Rights, and Masters. In Module & Rights, administrators handle web modules, permissions, and application access. Masters deals with foundational settings like roles, states, districts, and more, allowing admins to add, modify, or delete information in table forms.

In Manage Users, admins can easily handle user tasks, such as adding, modifying, and deleting users, assigning roles, and approving or rejecting user requests. This section also includes functions like importing kilns, setting criteria, updating technology, and assigning kilns.

The “Report” section gives a comprehensive view, covering kiln details, operations, environmental data, labour information, and actions against non-compliant kilns. It includes “Registration Reports” for basic kiln details and Environmental Module for operations and environmental aspects. The Labour Module has site-specific and scheme details, with separate reports for various schemes. Non-comply Kilns track actions against non-compliant kilns, and Field Worker and Volunteer Reports offer insights into performance and data updates.

ADVANTAGES OF GEOAI PLATFORM FOR BRICK KILN

With SpaceTech	With Ground Survey	Possibilities SpaceTech + Ground Survey
→ Detect location of Brick Kilns accurately from space → Brick Kiln Census → Year of Establishment of Brick Kilns → Verify Regulatory Criteria: Distance from Road, Distance from water bodies, Distance from Hospitals, Intra-distance between brick kilns, presence of tree line etc. → To understand more about the link between brick kilns and air pollution	→ Assess production capacity of brick kilns → Categories and Fuel utilization in brick kilns → Record the ownership and registration details of brick kilns → Workers working at brick kilns → Measure Emissions from individual brick kilns → Regulatory Compliance on CTE and CTO → Detect and document Fly Ash Bricks facilities → Quantify Carbon Emissions from Brick Kilns	→ Need more ground truthing data for AI to: → Classify brick kilns as Operational vs Non-Operational → Classify types of brick kilns as FCBTK vs ZigZag → Worker welfare through better management of kilns and improved air quality

▲
Table 1 Advantages of GeoAI Platform for Brick Kiln

Possible limitations of identification of brick kilns from space are

The accurate capture of the Brick kiln location from space needs very high-resolution satellite images which are commercial and expensive. Various attempts are being made to capture the same from open-source satellite data which obviously have only lesser spatial resolution.

Over the period brick kiln's location changes and periodic updating (every one to two years) of brick kiln locations from the satellite data are required.

Some of the existing brick kilns are non-operational and many of these can be identified from space (by looking at the colour, tone, and texture). But still there will be limitations in identifying all of these from space. Ground survey is required to check the operational status of these uncertain brick kilns.

The details like brick kiln name, ownership details, worker information etc cannot be captured from space. This information has to come through the combination of field surveys.

ROLES & RESPONSIBILITIES IN GEOAI PLATFORM FOR BRICK KILN

Function	UoN	UNDP	BSPCB	Development Alternatives
Research & Development on detecting brick kilns with AI using high resolution AirBus imagery	(✓)			
Co-create Digital User Interface and development of modules for field inspection and action		(✓)	(✓)	
Defining Use Case and Problem Statements for further R&D			(✓)	
Research & Development on AI experimentation for value added data insights to support regulatory action	(✓)	(✓)		
Nominate field inspectors/field functionaries for using GeoAI platform			(✓)	
Capacity Building of field functionaries on using digital user interface (Mobile App & Web Platform)		(✓)	(✓)	(✓)
Conduct field Inspection in select five districts with high-probability of non-compliance			(✓)	(✓)
Multi-stakeholder coordination for reporting results of field survey				(✓)
Follow up on Action taken on non-compliant brick kilns			(✓)	(✓)
Consultation with brick kiln association on survey findings			(✓)	(✓)
Co-design market incentives and capacity building strategies for brick kilns switch to green tech		(✓)	(✓)	(✓)
Scale up GeoAI to more states of India - Resource Mobilization & Implementation	(✓)	(✓)	(✓)	(✓)
Deepen technology to have Open Digital Stack on Air Pollution - Resource Mobilization & Implementation	(✓)	(✓)	(✓)	(✓)
Develop Knowledge Publication & Policy Recommendations	(✓)	(✓)	(✓)	(✓)

▲ *Table 2 Roles & Responsibilities in GeoAI Platform for Brick Kiln*

03

SECTION 3:

Analysis on Field Inspection

03

Analysis on Field Inspection

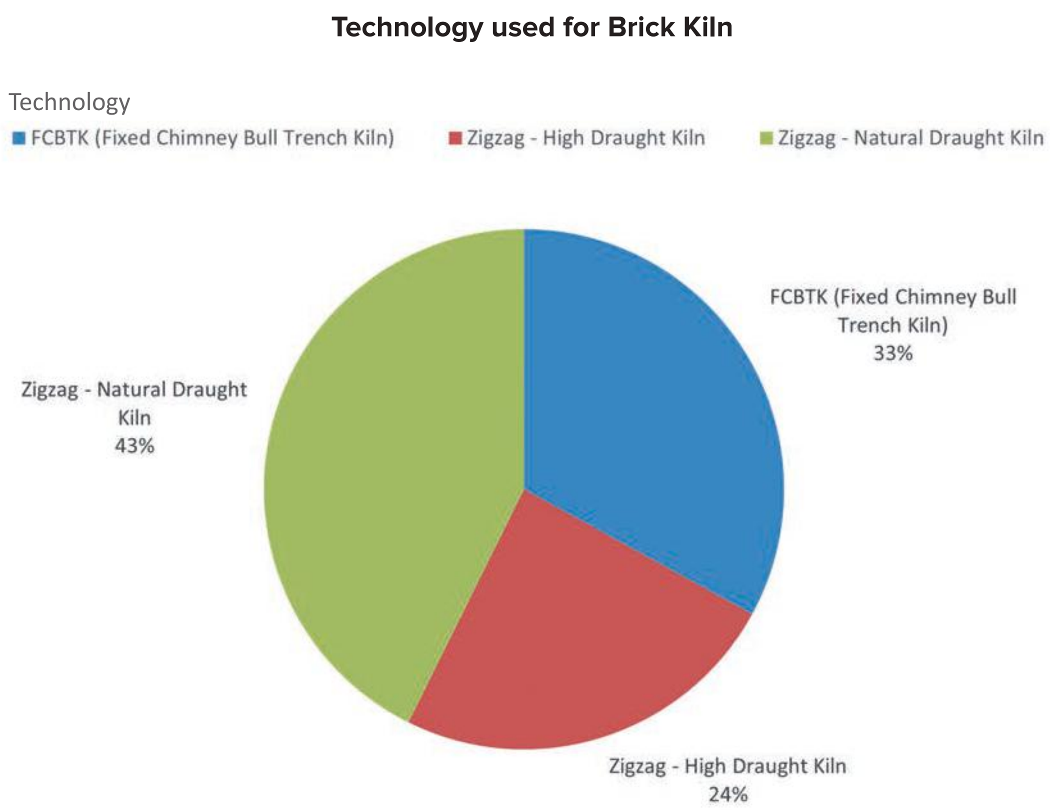
This section of the report examines the ground inspection conducted by Development Alternatives using GeoAI platform for 1680 brick kilns in five different districts in the state of Bihar. The primary focus of this analysis encompasses several key aspects, each of which has undergone in-depth analysis.

First and foremost, we present a comprehensive exploration of the brick kilns themselves, categorizing and delineating their various types and classifications. This entails a detailed examination of the specific features and characteristics that distinguish one kiln from another, including but not limited to their structural designs and operational practices. The aim is to provide a clear and comprehensive understanding of the diverse landscape of brick kilns within the studied regions. Subsequently, the report delves into an in-depth investigation of the fuels employed in these brick kilns. This aspect of the analysis delves into the types of fuels used, their sources and efficiency. The intent is to offer a comprehensive overview of the fuelling practices within the brick kiln industry, shedding light on the environmental impact and sustainability factors associated with these energy sources.

Furthermore, the report extends its scrutiny to encompass an analysis of the social conditions of the workers employed in these brick kilns. This component of the analysis seeks to provide insights into the socio-economic status and well-being of the labour force that is integral to the functioning of the kilns. It encompasses various facets, such as living conditions, wage structures, healthcare, and overall quality of life for brick kiln workers.

Figure 3.1(a): Brick Production in Kiln

Figure 3.1 (b): Brick Kiln Worker



▲

Chart 1 Technology used for Brick Kilns

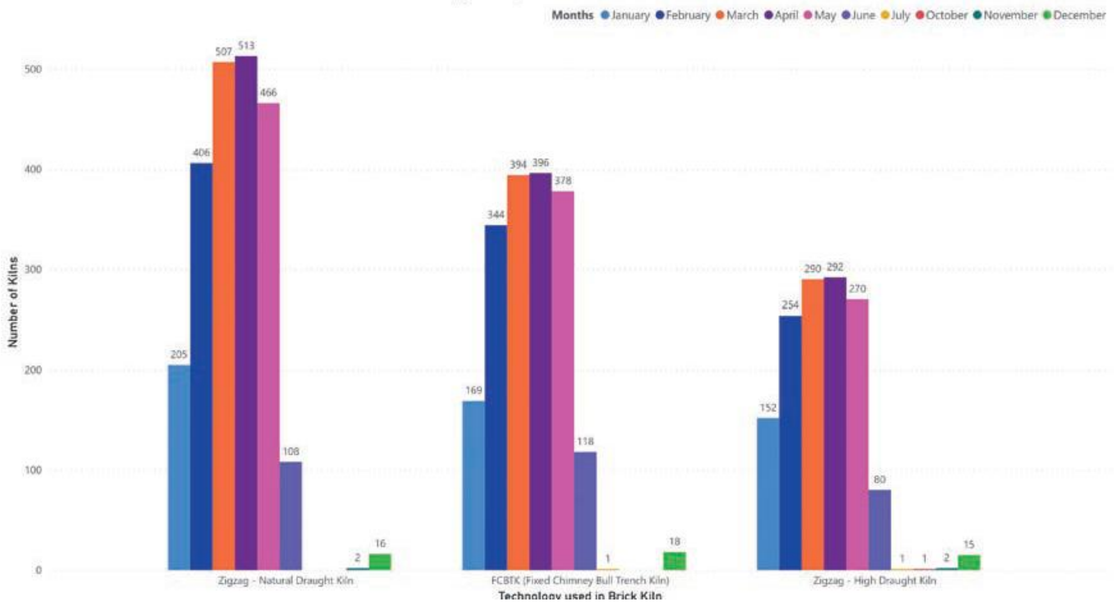
3.1 Distribution of Technology

The distribution of technology used for brick kilns underscores a noticeable shift towards more environment friendly options and greater energy efficiency in the brick production industry.

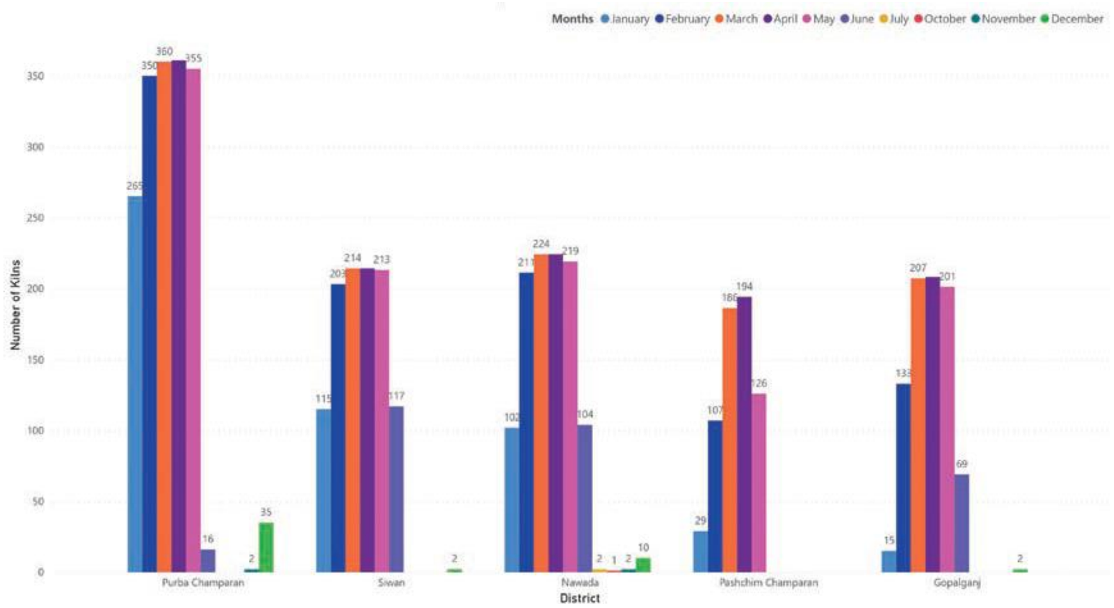
- Zigzag - Natural Draught Kiln, representing 42.67% of the technology used, signifies a transition from traditional methods (e.g., FCBTK) towards improved designs that enhance combustion efficiency and reduce environmental impact.
- Zigzag - High Draught Kiln, at 24.36%, represents an even more advanced and environment friendly option. These kilns further enhance combustion efficiency, making them one of the preferred choices for reducing emissions and improving energy efficiency in brick production.
- FCBTK (Fixed Chimney Bull Trench Kiln), while still significant at 32.97%, shows a decreasing trend in usage. This traditional kiln type has been associated with environmental concerns due to energy inefficiency and emissions.

This data suggests that the brick industry is making strides in adopting more eco-friendly and energy-efficient technologies, with Zigzag kilns, especially those with high draught, leading the way. This shift is indicative of the industry's commitment to sustainability and reducing its environmental footprint.

Technology wise Operational Months of Brick Kilns



District Wise Operational Months of Brick Kilns



▲ *Chart 2 Technology wise Operational Months of Brick Kilns and Chart 3 District Wise Operational Months of Brick Kilns*

3.2 Operational Season

In Bihar, brick kilns typically operate during the dry season, which generally falls between October end and June. During this period, the weather conditions are more favorable for brick production, as the absence of heavy rainfall reduces the risk of damage to the bricks and facilitates the drying and firing processes. Brick kilns are usually less active or may shut down during the monsoon season, which typically spans from July to September due to the challenges posed by wet and humid conditions. This operational cycle is adapted to take advantage of the region's climate patterns, ensuring efficient and effective brick production.

Cost of Production Capacity (bricks/day)

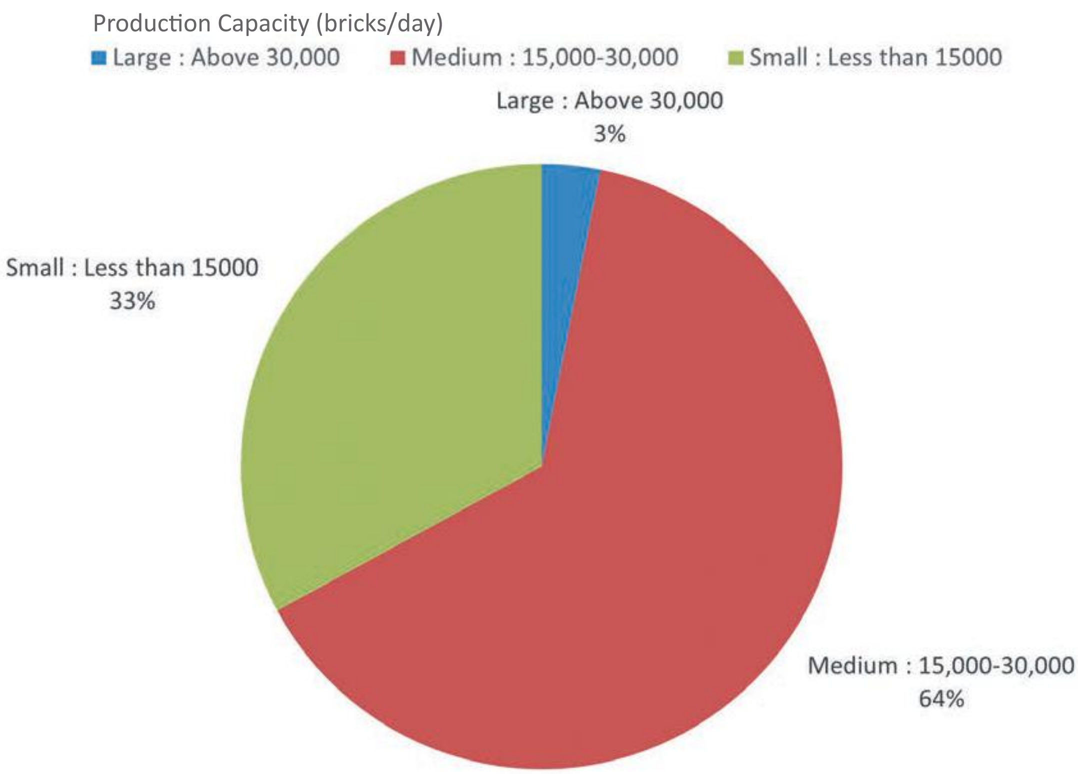


Chart 4 Production Capacity (Bricks/Day)

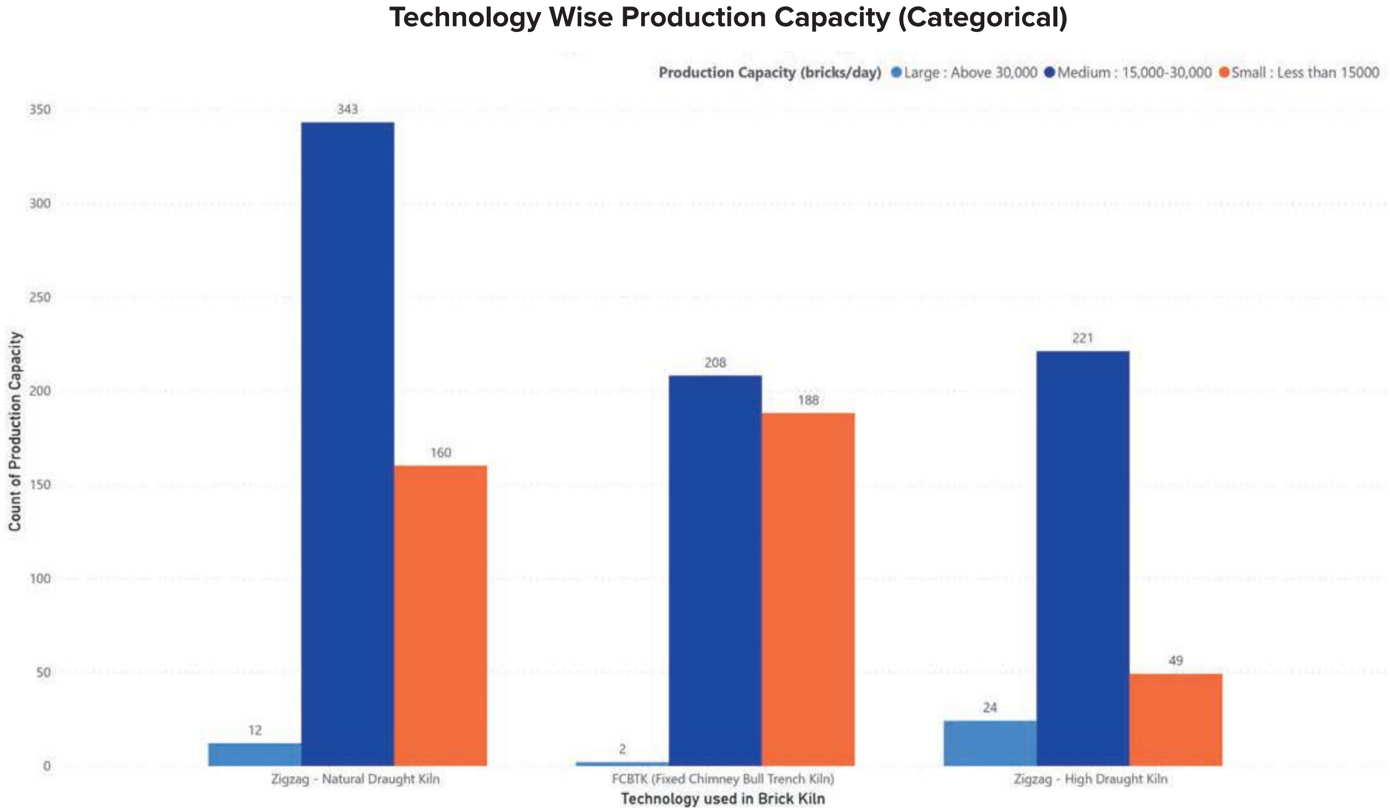
3.3 Production Capacity

As per the field inspection conducted in five districts of Bihar, the production capacity of brick kilns is distributed as follows:

- Large Brick Kilns (Above 30,000 bricks/day): These represent approximately 3.15% of the total production capacity.
- Medium Brick Kilns (15,000 to 30,000 bricks/day): A significant majority, constituting around 63.96%, falls into this category.
- Small Brick Kilns (Less than 15,000 bricks/day): About 32.89% of the brick kilns have a production capacity of less than 15,000 bricks per day.

This distribution provides an overview of the size and scale of brick production facilities in these districts, with medium-sized kilns dominating the sector, followed by smaller and a limited number of larger facilities.

The data reveals that different types of brick kiln technologies are being used, with a predominant presence of "Zigzag - Natural Draught Kiln" and "Zigzag - High Draught Kiln" in the Medium (15,000-30,000 bricks/day) production capacity category. There is also a notable usage of "FCBTK (Fixed Chimney Bull Trench Kiln)" in the same production capacity range. In contrast, "FCBTK"



▲ *Chart 5 Technology Wise Production Capacity (Categorical)*

is also found in the Small (Less than 15,000 bricks/day) category, along with "Zigzag - Natural Draught Kiln" and "Zigzag - High Draught Kiln". Interestingly, "Zigzag - High Draught Kiln" and "Zigzag - Natural Draught Kiln" are the technologies with the highest production capacities, reaching the Large (Above 30,000 bricks/day) category.

The data suggests a varied usage of brick kiln technologies across different production capacity ranges, with a prevalence of medium-scale kilns using zigzag technology. There's also a limited presence of large-scale kilns employing both zigzag and FCBTK technologies.

Upon analysis, it becomes evident that the efficiency of coal is optimized in brick kilns, leading to a classification of "medium-scale" production capacity. However, a few kilns exhibit a "large-scale" production capacity, signifying greater coal efficiency in these instances. The preference for newer technology, specifically zigzag technology, is notable due to its advantages, including reduced carbon emissions, a 20% savings in coal combustion, and a decrease in the number of PM particles. Despite similar productivity levels, the adoption of newer technology reflects a commitment to environmental sustainability and resource conservation.

District Wise Brick Production (in lakhs)

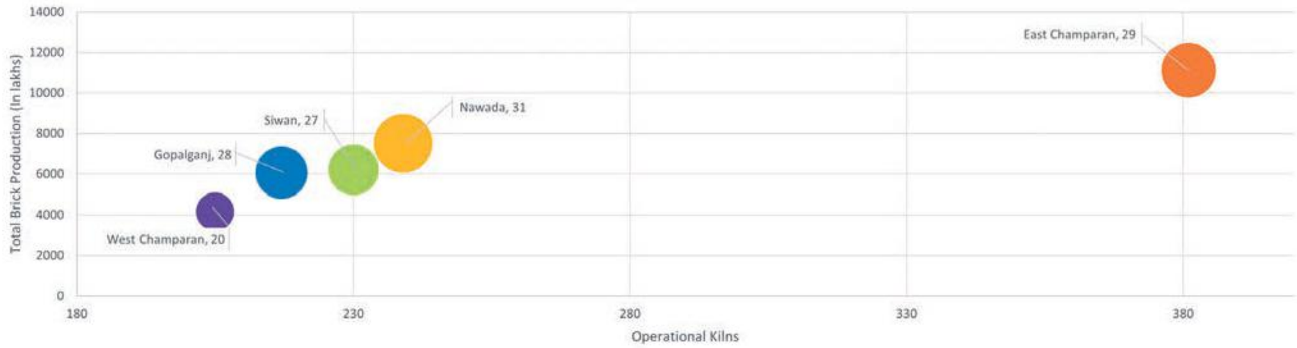


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Chart 6 District Wise Brick Production/ Kiln (in lakhs)

The data provides insights into the brick production in several districts, including the number of operational brick kilns, the total brick production (in lakhs), and the mean brick production per kiln (in lakhs) for each district. With 205 operational brick kilns, the district produces a total of 4162 lakh bricks, averaging 20 lakh bricks per kiln. This district exhibits a significant brick production capacity relative to the number of operational kilns. East Champaran has 381 operational brick kilns, producing a total of 11123 lakh bricks, resulting in an impressive mean of 29 lakh bricks per kiln. This district shows a robust brick production industry. Siwan, with 230 operational kilns, contributes to a total production of 6207 lakh bricks, averaging 27 lakh bricks per kiln. The district demonstrates efficient brick production. Gopalganj, with 217 operational brick kilns, yields a total production of 6075 lakh bricks, averaging 28 lakh bricks per kiln. This district reflects a commendable mean brick production per kiln. In Nawada, there are 239 operational kilns that produce a total of 7520 lakh bricks, resulting in a mean of 31 lakh bricks per kiln. This district showcases a high mean brick production, indicating strong output per kiln.

3.4 Types of Roads Around Brick Kiln

The data regarding the types of roads around brick kilns indicates a diverse infrastructure landscape in the vicinity of these facilities. Notably, there is a nearly equal distribution between two primary road categories, with kutcha earthen roads representing 44.74% and pucca roads also at 44.74%. Kutcha - gravel/paved roads account for the remaining 17.32%.

This distribution suggests a balanced mix of road types. The prevalence of kutcha earthen roads, which are generally less developed and constructed from natural materials, indicates that many of these areas might still lack advanced infrastructure. On the other hand, the significant presence of pucca roads, which are well-constructed and often paved, reflects the existence of modernized transportation routes in some regions.

The coexistence of these road types signifies the diverse and evolving nature of infrastructure surrounding brick kilns, with some areas having undergone development while others remain less developed, relying on traditional earthen roads. This data can be valuable for planning and improving transportation networks in and around these brick kiln areas to enhance accessibility and logistics.

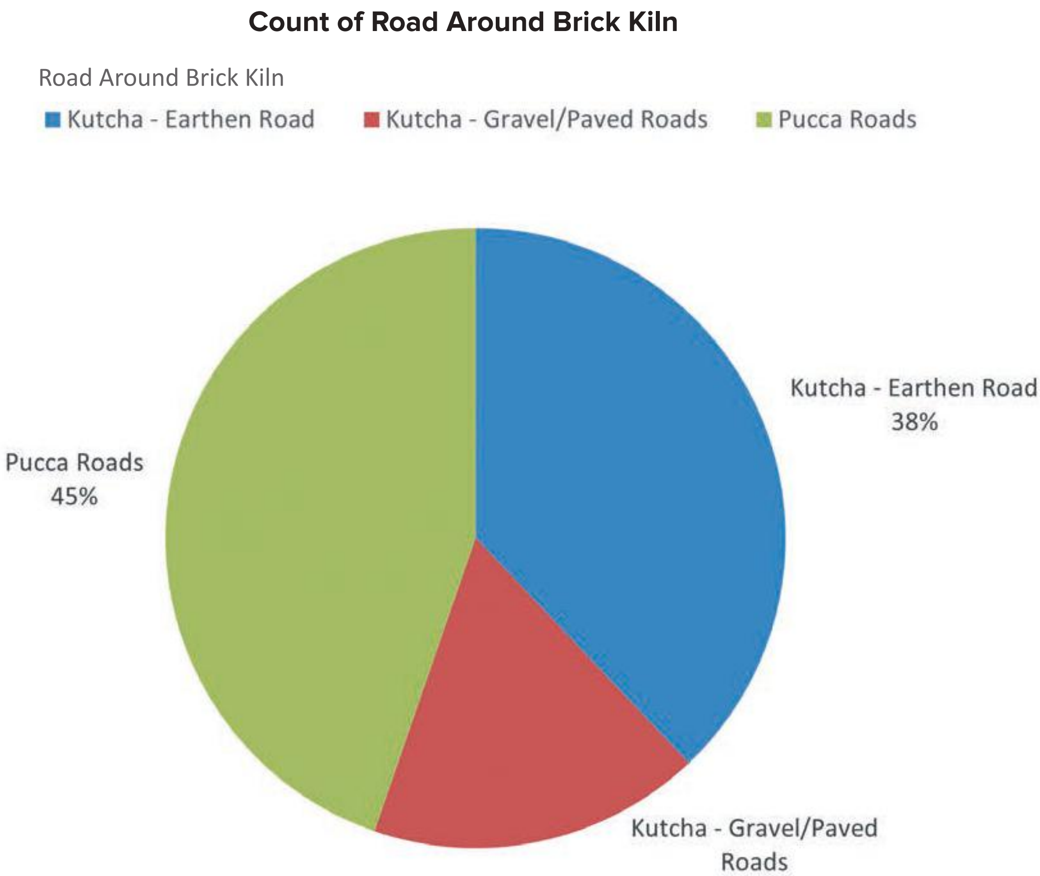


Chart 7 Type of Road around Kiln

3.5 Operational Practices - Sprinkling Water

The analysis of the data on the sprinkling of water around brick kilns and on the ash layer reveals a nearly equal split in practices within brick kiln operations.A significant portion of brick kilns employ the practice of sprinkling water around the kiln and on the ash layer. This is a positive environmental measure aimed at mitigating dust and controlling air pollution. Sprinkling water helps to settle dust particles and ash, reducing their dispersion into the surrounding environment. While slightly more than half of the brick kilns do not engage in this practice, it's important to note that the absence of water sprinkling might lead to increased dust and ash emissions. This choice could be due to resource constraints, operational considerations, or varying levels of awareness regarding environmental impacts.

The data underscores the need for continued awareness and adoption of environmentally responsible practices within the brick kiln industry. Implementing measures like water sprinkling can significantly contribute to reducing air pollution and its associated environmental and health impacts.

Sprinkling of Water done around Brick Kiln and on Ash Layer

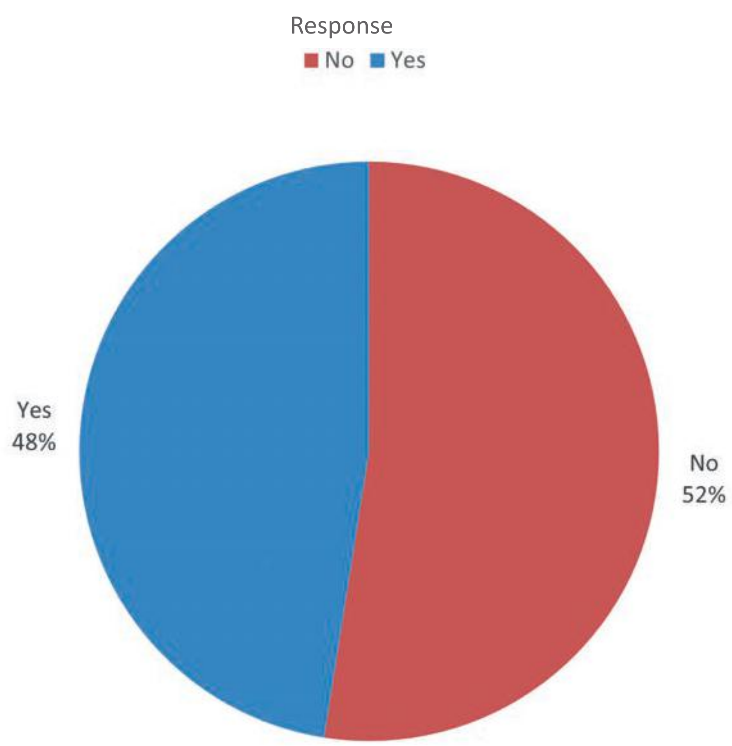


Chart 8 Sprinkling of Water done around Brick Kiln and on Ash Layer

3.6 Types of Fuels

The data on the types of fuel used in brick kilns indicates a varied fuel landscape within the industry.

- Coal is a significant source of fuel for brick kilns, representing a substantial portion of the industry. However, it's important to note that coal combustion can have environmental and air quality implications due to emissions of particulate matter and greenhouse gases.
- Biomass, includes organic materials like wood or crop residues, is used in a smaller percentage of brick kilns. While biomass can be considered a renewable fuel source, its sustainability depends on responsible harvesting and management.

It's noteworthy that all kilns use coal, while 15% of them initially utilize biomass for firing. However, at a later stage, these kilns shift to using coal exclusively for combustion.

The sub-categories of fuel used in brick kilns offer a detailed breakdown of the sources of energy within the industry.

- Raniganj Coal: This category represents the use of coal from the Raniganj coalfield, a significant source of thermal coal in India.
- Jharia Coal: From the Jharia coalfield, is another prevalent choice. Both Raniganj and Jharia coal are known for their energy content.
- Assam Coal: This sub-category denotes the use of coal sourced from Assam.
- Rice Husk: Rice husk is a biomass fuel derived from rice processing.
- Sawdust: Sawdust represents another biomass option, which can be obtained from wood processing.
- Coal Rejects of Thermal Power: These are rejects or waste coal from thermal power plants, sometimes repurposed as fuel.
- Karia Coal Dust: This represents the use of coal dust from the Karia region.

The sub-categories illustrate the wide array of fuel sources used in brick kilns, with a mix of conventional coal, various biomass materials, and even recycled materials from thermal power plants. The choice of fuel is based on the purpose of its use, whether it has been used for firing the brick kiln or for regular combustion.

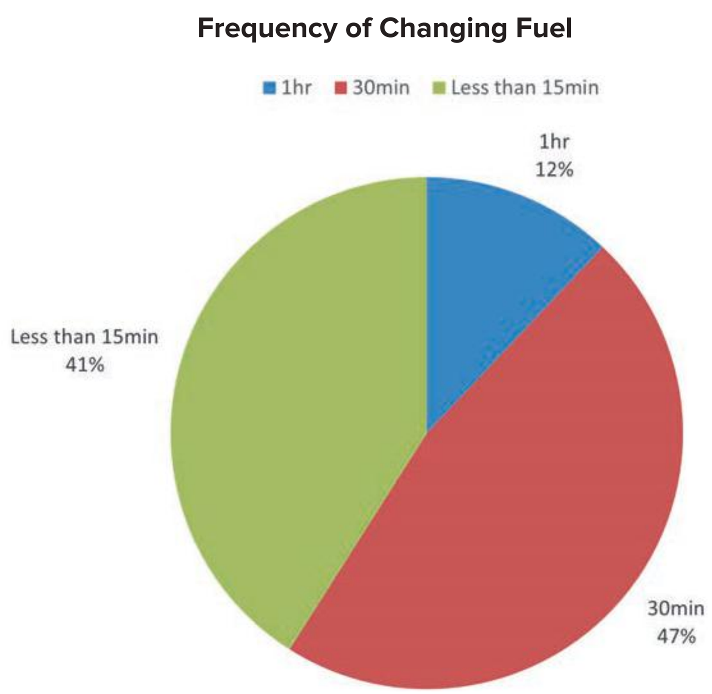
3.7 Frequency of Charging of Fuel

The choice of charging frequency can impact energy consumption and production efficiency within brick kilns. The data suggests a diverse range of practices, with various kilns adopting strategies that align with their specific operational requirements and infrastructure.

A significant portion of brick kilns adopt a charging frequency of less than 15 minutes. This suggests a rapid and frequent loading of fuels into the kilns, which may be associated with smaller kilns or a desire to maintain a consistent and efficient temperature during the brick firing process. Nearly half of the brick kilns opt for a more extended charging interval, loading fuels into the kilns approximately once every hour. This practice might be related to larger kilns or kilns with advanced insulation that can retain heat over more extended periods. A smaller percentage of kilns employ a charging frequency of 30 minutes. This approach falls between the more frequent and less frequent loading strategies, potentially reflecting a balance between operational efficiency and energy conservation.

The data provides insights into the charging frequency of fuels in various brick kiln technologies, revealing distinct patterns across different kiln types. “Zigzag - Natural Draught Kiln” exhibits a range of charging frequencies. A significant number of kilns charge fuel less frequently, with “less than 15 minutes” being the dominant choice. However, there is also notable usage of “30 minutes” and “1 hour” charging intervals, indicating a variety of operational practices.

Chart 9 ▶ Frequency of Charging Fuel



"FCBTKs" primarily employ "30 minutes" as their charging frequency, representing an approach between the more frequent and less frequent charging strategies. There are also instances of "1 hour" and "less than 15 minutes" charging, albeit in smaller numbers. "Zigzag - High Draught Kilns" predominantly adopt a "less than 15 minutes" charging frequency. While "30 minutes" charging is also observed, it is less common. Charging every "1 hour" is the least favored option in this kiln type.

Coal is the predominant fuel choice, with a significant majority of kilns employing a "30 minutes" charging interval. A substantial number of kilns also opt for "less than 15 minutes" charging, emphasizing the desire for frequent and consistent fuel loading. However, there are some kilns that follow a less frequent "1-hour" charging schedule.

Biomass is another fuel type, though less common than coal. Kilns using biomass predominantly adopt a "30 minutes" charging frequency, indicative of the need to maintain a regular supply of biomass to sustain the firing process. "Less than 15 minutes" charging is also employed but less frequently. "1-hour" charging is the least favored option for biomass.

Kilns utilizing internal fuel exhibit a pattern similar to coal kilns. "30 minutes" charging is the preferred choice, reflecting the necessity for a consistent fuel supply. "Less than 15 minutes" charging is also employed by a substantial number of kilns. "1-hour" charging is less common in this category.

Technology wise Frequency of Charging of Fue

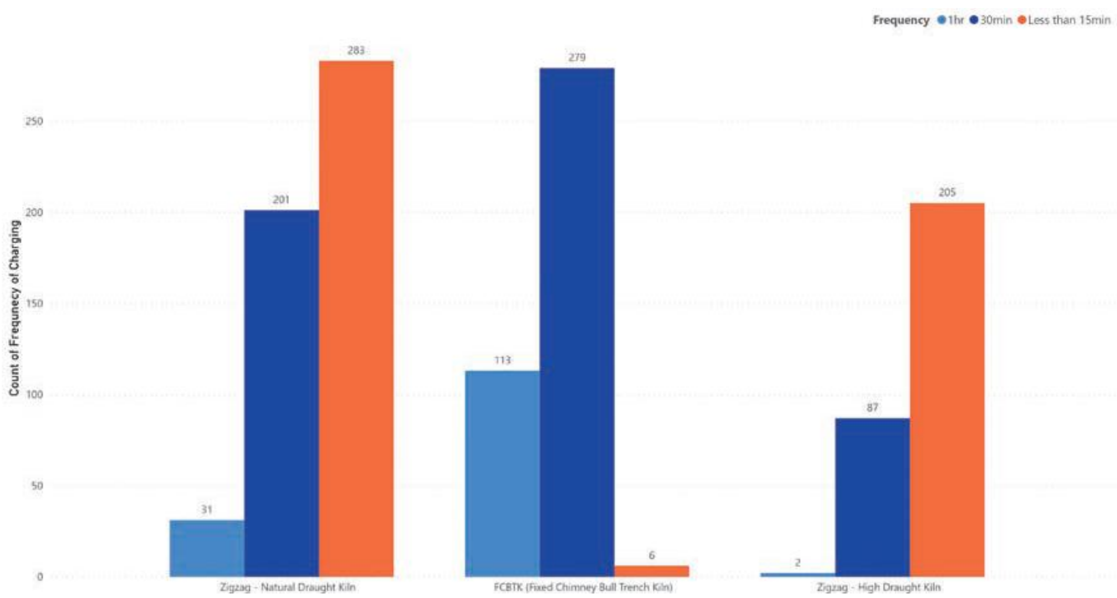


Chart 10 Technology wise Frequency of Charging of Fuel

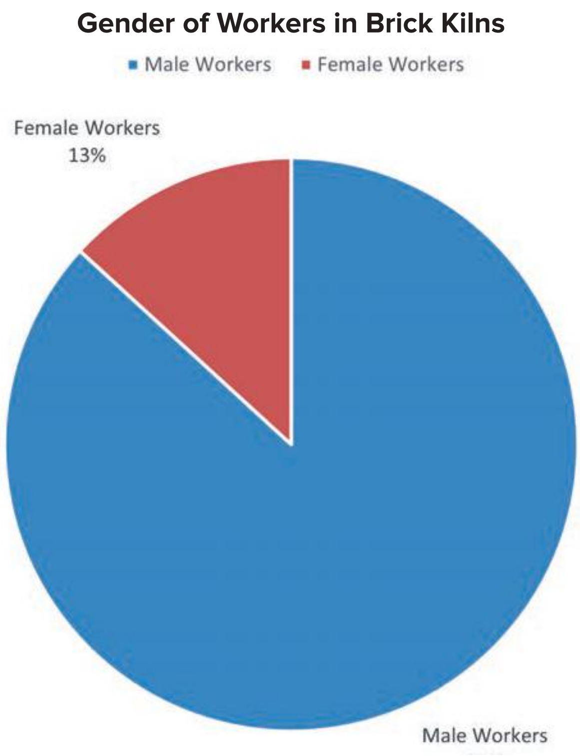
3.8 Workers Information

The majority of the workforce in brick kilns is male (86.8%), representing a substantial portion of the labor force. This could be due to the physically demanding nature of brick-making work. Female workers make up a much smaller fraction of the workforce (13.2%). Their representation is notably limited, possibly due to various factors, including cultural norms, safety concerns, or the demanding and often hazardous working conditions in brick kilns.

This tells us about the need for addressing gender disparities and promoting more inclusive and equitable employment opportunities within the brick kiln sector. Efforts to create safer and more accommodating working conditions could help increase female participation in the industry and improve overall gender balance.

The data on the category of workers in brick kilns underscores a significant representation of historically marginalized and disadvantaged groups in the industry. The general category represents a relatively small percentage of the workforce within brick kilns (2.59%), indicating limited participation from non-marginalized groups. OBC workers also make up a minority of the workforce (1.62%), suggesting that historically disadvantaged groups are more prevalent in brick kilns. The Schedule Caste category accounts for a substantial portion of the workforce (42.05%),

Chart 11 ▶ Gender of Workers in Brick Kilns



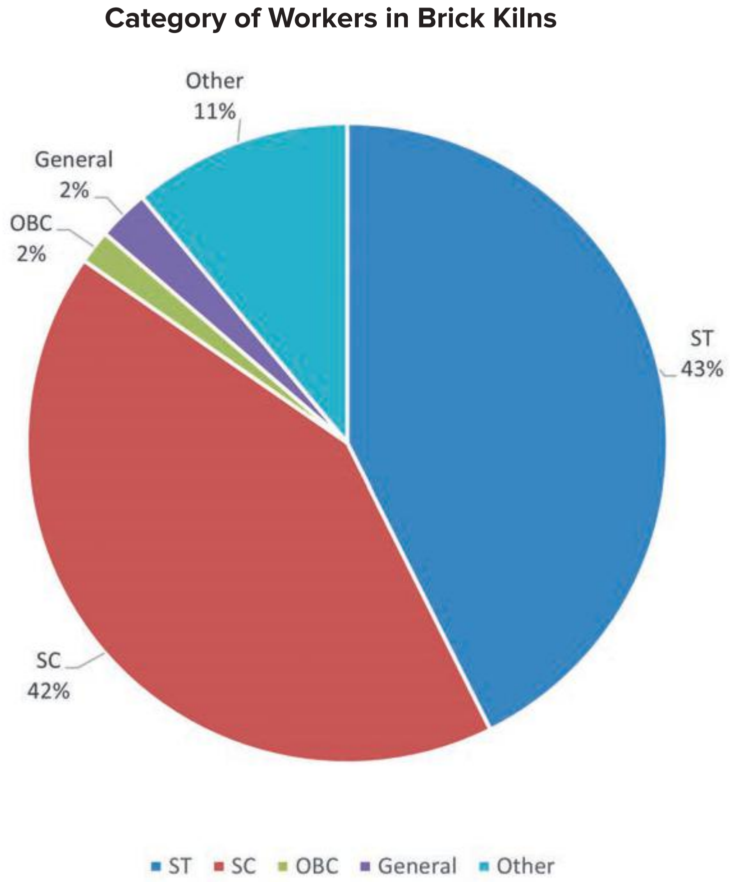


Chart 12 Category of Workers in Brick Kilns

highlighting the significant representation of individuals from historically disadvantaged backgrounds within the industry. Schedule Tribe workers also make up a considerable percentage of the labor force (42.66%), indicating a strong presence of individuals from tribal communities in brick kilns. "Others" category, which likely includes a diverse range of worker backgrounds, represents a noteworthy fraction of the workforce (11.08%).

The data illustrates the brick kiln industry's reliance on labor from historically marginalized and disadvantaged communities, particularly from Schedule Caste and Scheduled Tribe backgrounds. These communities often face socio-economic challenges and have limited access to alternative employment opportunities. Efforts to improve working conditions, provide equitable wages, and address social disparities are essential to enhance the well-being of these workers and promote inclusivity within the industry.

The majority of brick kilns have first-aid facilities available, indicating a strong emphasis on worker safety and health within the industry.

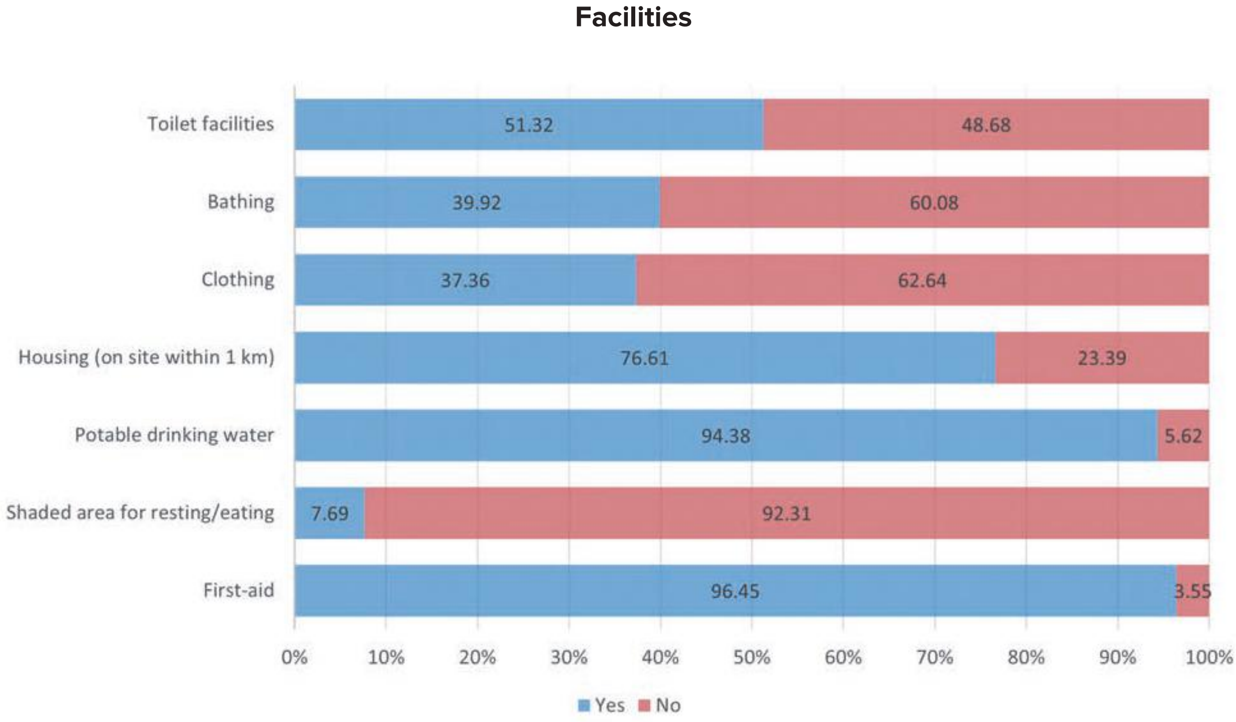


Chart 13
Facilities

Conversely, the provision of shaded areas for resting or eating is limited, with only a small percentage of kilns offering this amenity. This suggests that a significant portion of workers may lack comfortable spaces for breaks. The availability of potable drinking water is widespread, showcasing a commitment to ensuring a basic necessity for the workforce. A considerable percentage of brick kilns provide on-site housing within a 1 km radius, indicating that a significant portion of workers may have accommodation conveniently located. The availability of clothing for workers is limited, with a substantial percentage lacking this facility. This highlights a potential area for improvement in providing basic necessities to workers. The provision of bathing facilities is also less common, with a significant portion of workers lacking access. This underscores the need to enhance basic amenities for the workforce. The availability of toilet facilities is roughly balanced, with slightly over half of the brick kilns offering this essential amenity. However, nearly half still lack proper toilet facilities, indicating a need for improvement.

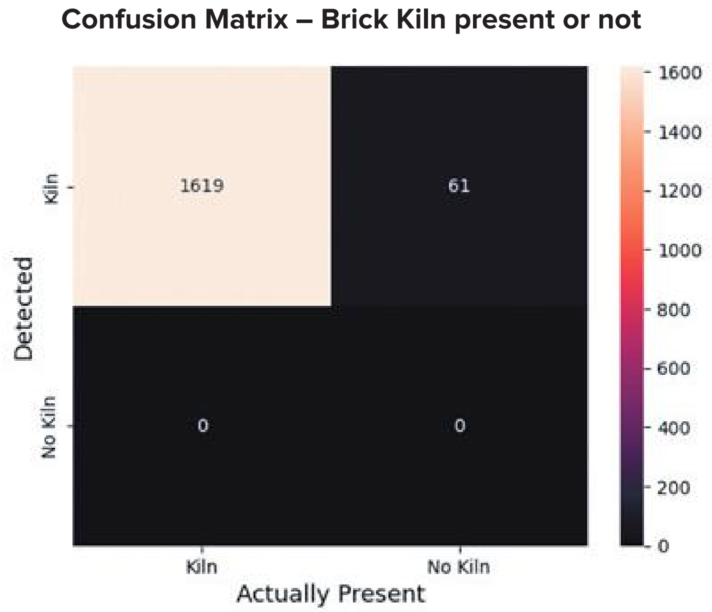


Chart 14 Confusion Matrix- Brick Kiln present or not

3.9 Satellite Insights vs Ground Truthing Insights:

The dataset consists of 1680 kilns identified in GeoAI across various locations. However, it's noteworthy that at 61 locations, the kilns were not detected by the AI model. Interestingly, evidences have been found on the ground that most of these inaccurately detected kilns were there before but have been completely removed from those locations since then.

Precision is a measure of the accuracy of the positive predictions made by the model. In this case, the model's precision is 96.37%, indicating that out of all the kilns predicted by the model, 96.37% were true positives, and only 3.63% were false positives.

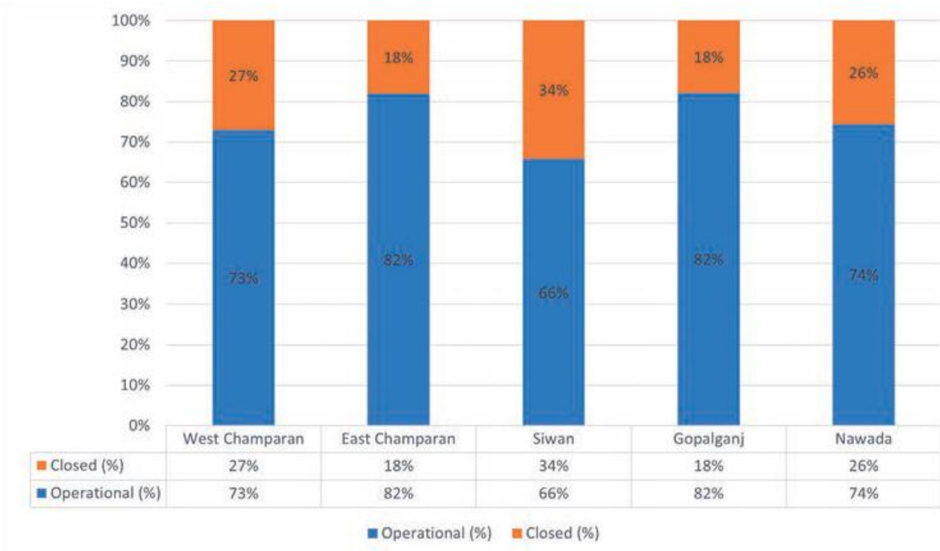
Accuracy represents the overall correctness of the model's predictions. The accuracy of 96.37% suggests that the model correctly identified both positive and negative instances, considering true positives (TP), true negatives (TN), false positives (FP), false negatives (FN), positive samples (P), and negative samples (N).

The F1 score is the harmonic mean of precision and recall. In this case, the F1 score of 98.15% indicates a balanced performance between precision and recall. It considers both false positives and false negatives, providing a comprehensive measure of the model's accuracy.

Measure	Value	Derivation
Precision	0.9637	PPV = TP / (TP + FP)
Accuracy	0.9637	ACC = (TP + TN) / (P + N)
F1 Score	0.9815	2TP / (2TP + FP + FN)

Table 3 Precision, Accuracy and F1 Score

Operational and Closed Brick Kilns



	West Champaran	East Champaran	Siwan	Gopalganj	Nawada
Closed (%)	27%	18%	34%	18%	26%
Operational (%)	73%	82%	66%	82%	74%

Chart 15 ▶ Operational and Closed Brick Kilns

3.10 Operational vs Non-Operational

The majority of brick kilns in the dataset are marked as operational. This signifies that they are currently active and engaged in brick production, reflecting the ongoing nature of this industry. A smaller subset of brick kilns is classified as non-operational, implying that they are temporarily or permanently not in production. This could be due to various factors, such as seasonal closures, maintenance, or economic considerations. The category of closed kilns represents a limited number of facilities that have ceased their operations, potentially due to various reasons, including economic challenges, regulatory issues, or other factors.

In West Champaran, there are 205 operational brick kilns, signifying the ongoing production of bricks, while 76 brick kilns are reported as closed, indicating either temporary non-operational status or their complete removal from the location. East Champaran shows a similar trend with 381 operational brick kilns and 84 closed brick kilns. This district reflects a significant number of active brick kilns. Siwan reports 230 operational brick kilns and 119 closed ones. This district, like the previous two, has a substantial presence of brick kilns but also indicates a significant number of non-operational or removed kilns. Gopalganj reveals 217 operational

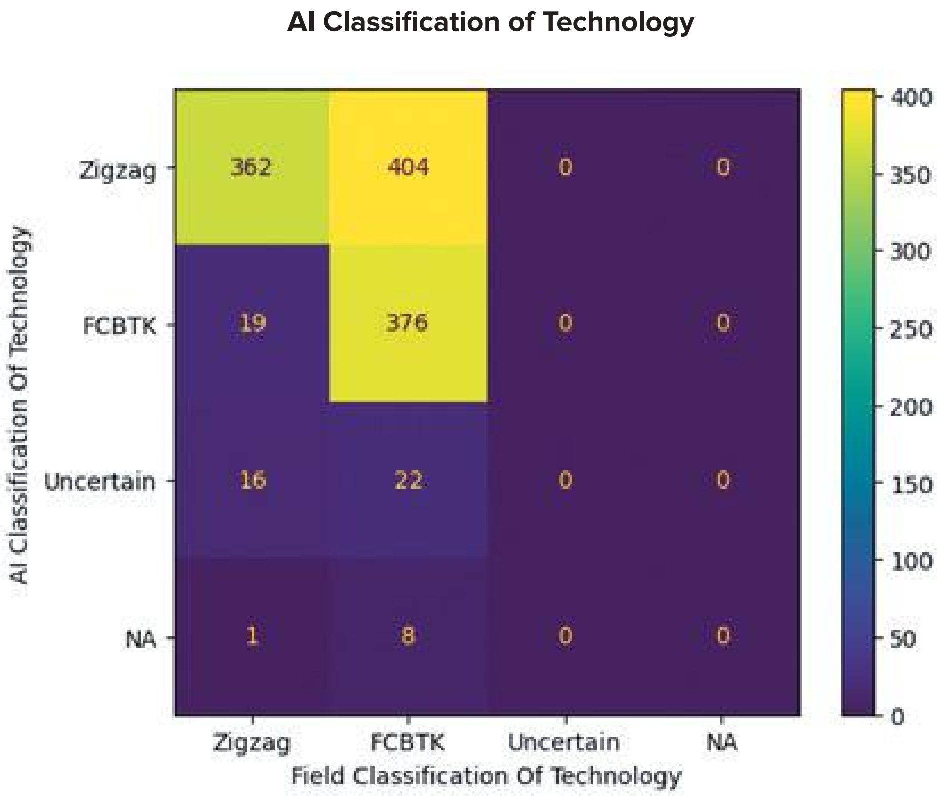


Chart 16
AI Classification of Technology

brick kilns and 47 closed ones. It shows a relatively lower number of closed kilns, potentially indicating better continuity in brick production. Nawada has 239 operational brick kilns and 82 closed ones. This district also exhibits a significant number of closed kilns, which could be due to seasonal or operational factors.

The GeoAI has proven to be effective in correctly identifying whether a kiln uses Zigzag or FCBTK technology. It achieves an accuracy of about 65%, showing that the model used in GeoAI is quite good at distinguishing between these two types of kiln technologies.

3.11 Actions Taken by BSPCB

Following an extensive field survey conducted by Development Alternatives, subsequent discussions took place with the chairman of the Brick Association and brick kiln owners. During these interactions, detailed briefings were provided regarding the relevant regulations. Stakeholders were informed about the imperative need to adhere to compliance criteria. Owners were further advised to transition from Fixed Chimney Bull's Trench Kiln (FCBTK) to Zigzag technology, either through retrofitting existing FCBTKs or by constructing entirely new kilns. Additionally, a strict directive was issued to curb the operation of illegal brick kilns. Kiln owners were given a deadline until December 2023 for the registration process to ensure compliance with the specified regulations. This strategic approach aims to improve environmental sustainability and encourage responsible practices within the brick kiln industry.

The decision tree appears to prioritize compliance with environmental criteria, encouraging the adoption of Zigzag technology for its environmental benefits. The process emphasizes the importance of not only opening new kilns but also ensuring they meet compliance standards. The option to restructure old kilns and retrofit technology aligns with sustainable practices and encourages the adoption of more environment friendly technologies. The deadline for completing the registration process suggests a time-sensitive aspect to comply with regulations.

Decision Tree for Opening New Kiln

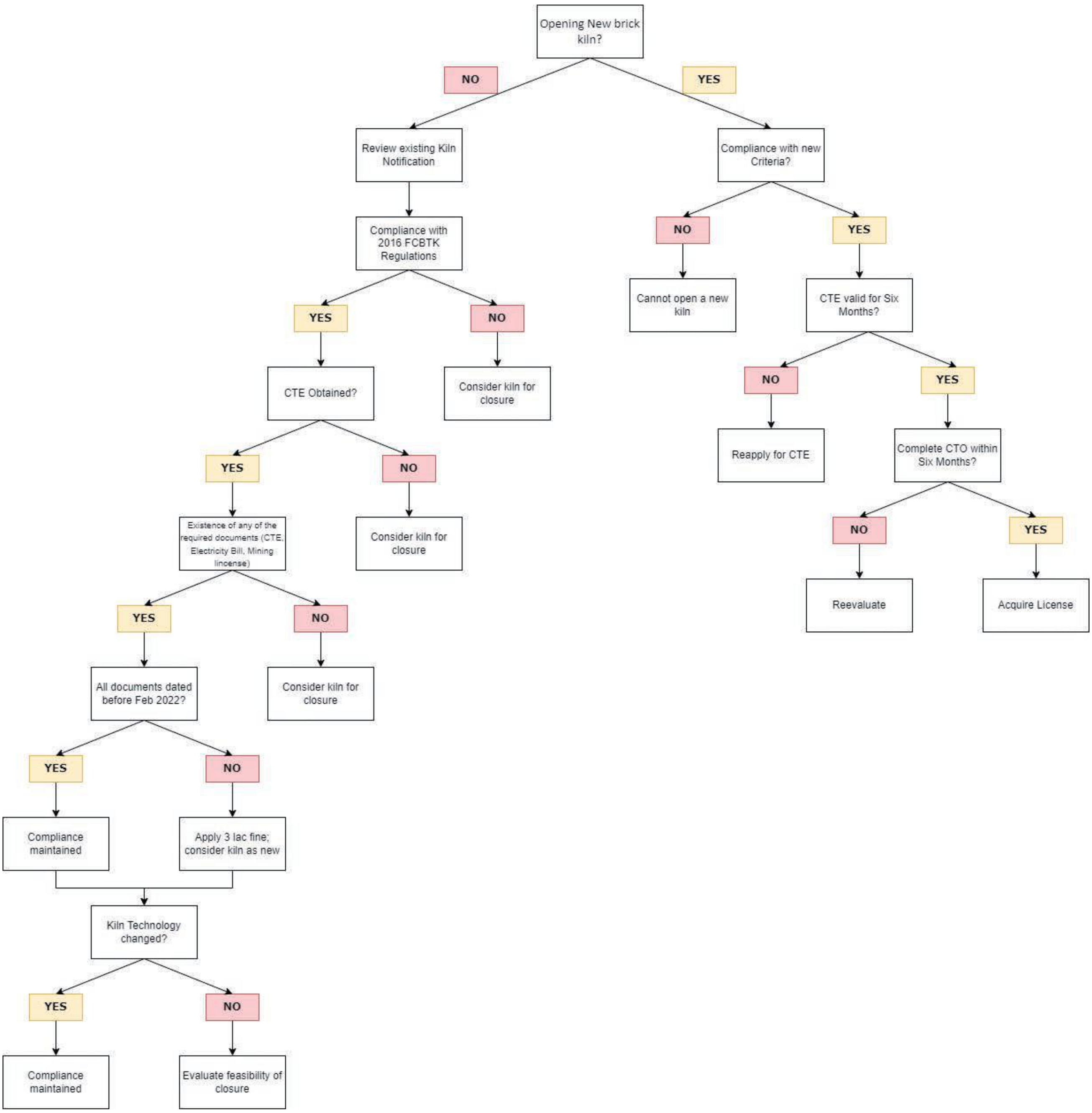


Figure 3.2:
Decision Tree for Opening New Kiln

Revised Compliance Criteria as of February 22, 2022:

1. Distance between two Brick Kiln units: Minimum of 1 kilometer.
2. Proximity to Essential Facilities:
   – Schools, Hospitals, Courts, Government Offices, Habitation, Orchards: Not less than 800 meters.
3. Distance from Infrastructure:
   – State & National Highways and Railway Lines: Not less than 200 meters.
   – National Highways with more than 4 lanes: Not less than 300 meters.
   – River, Natural Water Resources, Dams, Ailetland: Not less than 500 meters.
4. Environmental Restrictions:
   – New Brick Kiln units are prohibited in areas declared as Over Exploited or Semi-Critical (OCS) by CGWA.
   – Brick kiln activity is not allowed within the eco-sensitive zone.

The brick kiln shall be allowed consent-to-operate only with ZIG-ZAG cleaner technology or Vertical shaft technology or related cleaner technologies

Action Plan

I. Existing Kiln Compliance:

a. Review the existing kiln's overall notification published in 2016 with a deadline until December 31, 2019, for FCBTK compliance.
b. Verify the Consent to Establishment (CTE) status; ensure that CTE has been obtained.
c. Confirm the existence of either of the following documentation:
   – CTE
   – ever applied for CTE
   – Electricity bill
   – mining license.
d. Ensure that all relevant documents are dated before February 2022.
e. Establish a fine of 3 lac as compensation for any missing documents; non-compliance may result in considering the kiln as new, rendering old compliance criteria invalid.
f. Evaluate the feasibility of closure if the kiln technology remains unchanged.

II. Opening a New Kiln

1. Ensure compliance with all new criteria for opening a new kiln.
2. Upon meeting criteria, obtain Consent to Establishment (CTE), valid for six months.
3. Complete the Consent to Operate (CTO) verification within six months to acquire the license.
4. Mining License: Define soil mining criteria, ensuring compliance after obtaining Consent to Operate (CTO).

▲
Box 1
Revised Compliance Criteria as of February 22, 2022

3.12 Carbon Emissions

Bihar's brick industry causes 14% of the state's air pollution. Dominated by traditional techniques, limited mechanization, and small-scale operations, this industry produces 23 billion bricks annually, stripping 65 million tons of fertile topsoil. It is the second largest consumer of coal, significantly impacting climate change through greenhouse gases (GHG) and pollutants like Black Carbon, Sulfur Dioxide, and Nitrogen Oxide.

Bihar's brick-making industry, comprising around 7,865 burnt clay brick units, is undergoing a significant transformation. About two-thirds of these units have embraced more environment-friendly technologies, notably the Zig-Zag kilns and fly ash bricks. However, despite these advancements, the industry remains a substantial emitter of greenhouse gases (GHGs), releasing about 12.6 million tons of CO2 annually (estimates by Development Alternatives, 2023).

Despite the adoption of environment friendly burnt brick kiln technology e.g. Zig-Zag kilns, the extensive emissions are primarily attributed to the use of low-grade coal, coupled with a lack of technical expertise and suboptimal production processes prevalent in the majority of the improved brick kilns. Analysis of coal samples collected from different brick kilns across various regions in the State confirms the lower calorific value and poor grade of the coal being used, which does not contribute to reduction of energy consumption. On the contrary, it directly contributes to greenhouse gas emissions, black carbon, and increased energy consumption within the sector. To mitigate these environmental impacts and align with broader climate goals, it is imperative for the brick industry to accelerate its transition towards cleaner technologies and adopt more efficient practices.


MALA

04

SECTION 4:

Policy Recommendations

04

Policy Recommendations

Findings from the Geo AI project provide insights into three major policy points – Technology upgradation, regulatory frameworks and capacity building. While technology upgradation stems directly from the analysis presented in this report, the other two policy points emerge from the operational experience of the project, a series of consultations with regulatory authorities like the BSPCB and the project's on-ground partner organizations like Development Alternatives. This section sheds light on key policy recommendations to advance the on-going efforts of the Govt of Bihar by scaling up to use novel technologies in other geographies, scaling deep in enhancing the technology itself and scaling out by using such novel approaches in other polluting sectors as well.

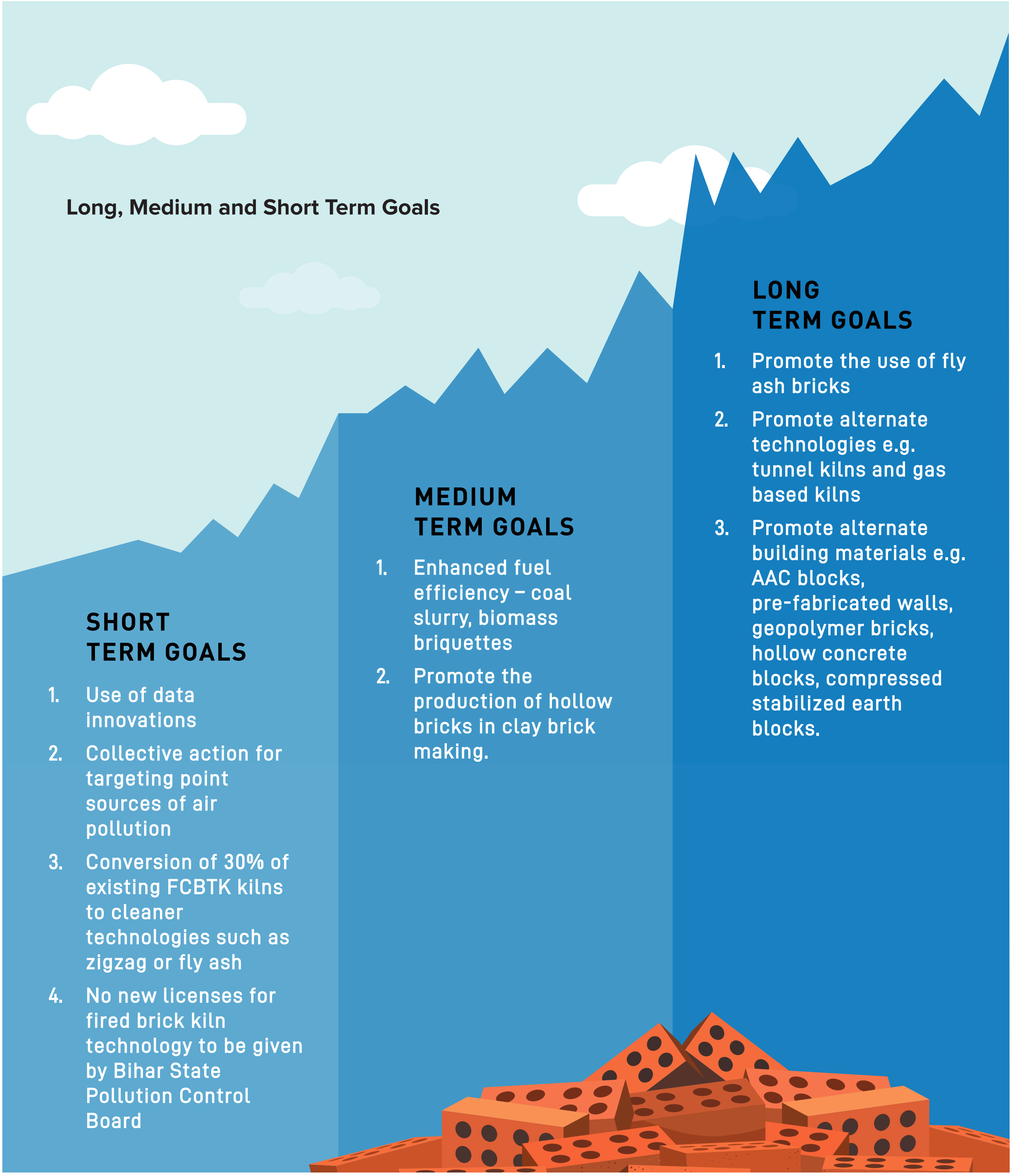


Figure 4.1: Long, Medium, and Short Term Goals

A. Adoption of Data Innovations for evidence-based decision making

The GeoAI initiative in Bihar highlights a practical approach to bridge the evidence gap on brick kiln census and the informal economy. By leveraging Artificial Intelligence and Remote Sensing, coupled with collaborative digital platforms, we could efficiently address the evidence gap. Unlike time-consuming large-scale surveys, this method, as evidenced by mapping of more than 47,000 brick kilns in the Indo-Gangetic belt, proves scalability for widespread adoption.

Building on this success, the collaboration in Bihar will further deepen the GeoAI platform to map other sources of air pollution. We will demonstrate the combined power of IoT, citizen science, and AI in creating hyperlocal maps of air pollution by targeting the point sources of air pollution within Patna city.

Data innovations with frontier technologies such as AI/ML have tremendous potential to unlock complexity and promote collective action across stakeholders. As evidenced by GeoAI, efficiency and scalability are key advantages offered by frontier technologies that can be taken to pan-India scale. To expedite progress, national agencies like CPCB and MoEFCC can create an innovation platform with suitable investments to foster innovative solutions and experimentation at an accelerated pace.

▲
Figure 4.2:
Brick Kiln Worker

B. Technology upgradation of Brick Kilns

B.1
Standardizing kiln design protocols

The first piece of this policy puzzle involves a deep dive into standardizing protocols for brick kiln design. In India, Fixed Chimney Bull's Trench Kiln (FCBTK) is the most common kiln for firing green soil bricks, which is energy inefficient and generates a very high amount of CO2 along with black carbon and suspended particulate matter (SPM). It is in response to this practice, that innovations in brick kiln design have resulted in better resource efficiency and lower pollution levels with the new High Draught Kiln (Zigzag kiln) and Vertical Shaft Brick Kilns (VSBK). Thus, a major need was recognized to shift from FCBTK to Zigzag kilns. This led to the ban on FCBTK by MoEFCC in 2022, which are now only allowed to operate on Piped Natural Gas (PNG).

B.2
Skilling of brick kiln labour

To support this large-scale transition from FCBTK to Zig-Zag technology, there is a need to standardize the many protocols involved in construction, operationalization and maintenance of kilns. Starting with making kiln designs and drawings available to brick kiln makers and contractors, our experience of Patna showcases how developing a manual for standardizing natural draught zigzag kilns, making it available in Hindi and distributing It widely helped masons and contractors better understand the process of building zig zag kilns.

Moving to masonry, large scale trainings and capacity building of masons is recommended to help them better understand the nuances involved in kiln construction and the various quality parameters involved in it. This is a crucial step as we begin to construct 40,000 kilns over a short period of time of 1-2 years. Once zig-zag kilns are constructed, the next step involves developing capacities for operationalization of brick manufacturing processes. This requires large scale- formal trainings for workers, as seen in Patna, for a minimum of two weeks to ensure the success of this initiative.

▲
Figure 4.3:
Brick Kiln Firing

▲
Figure 4.4:
Fly Ash

B.3
Fly ash and use of ponded and fly ash in brick making

Fly ash, a byproduct of coal fired at thermal power plants, is a material that is of major interest to the brick production industry. When compressed and processed, this waste material turns into valuable bricks, in turn replacing the need for precious topsoil and polluting coal for making traditional bricks. Use of fly ash in brick making is a low carbon and resource efficient technique that does not require large scale firing processes as was seen in FCBTK kilns. Thus, the report suggests conversion of at least 30% of FCBTK kilns to cleaner technology like fly ash and zig-zag kilns.

Alternate low carbon technology like tunnel kilns and gas based kilns may be promoted. These should be coupled with promoting alternate building materials as well e.g. AAC blocks, pre-fabricated walls, geopolymer bricks, hollow concrete blocks, compressed stabilized earth blocks. For this to be achieved in the long run, the government must make it mandatory for burnt brick producers to make hollow bricks, mandate the use of fly ash in construction and thermal power plants should be able to provide fly ash free of cost to brick units. Further, compensation money from thermal power plants to be used to provide subsidy to fly ash brick making. Some ways in which this may be done is via systematic auctioning of fly ash from thermal power plants and inclusion of fly ash in state's industrial policy through recognition and promotion of fly ash brick with financial incentives for manufacturers, provision of land and availability of fly ash at competitive prices.

C. Regulatory Support

C.1

As per Bihar State Pollution Control Board (BSPCB) via notification number 23 dated 31.08.23 that consent order for operationalizing brick kilns will not be provided to those who have not shifted to cleaner technology. Further the notification also states that brick kilns, which have not shifted to cleaner technology latest by 31 December 2023 will be considered illegal and action would be initiated against them. The neighbouring state of Odisha has implemented the same for the last decade and no new licenses are being issued for burnt clay brick production. This has helped them to substantially reduce emissions from the brick industry.

C.2

Cancelling the mining lease of FCBTK kilns

This will discourage the uptake and continued operations of the existing polluting technology and will promote the adoption of cleaner technology, consequently reducing CO_2 emissions by an estimated 30%.

D. Fuel Efficiency

D.1

Semi mechanization of fuel feeding process

It is an important process in providing fuel to the kiln in a way that protects the firemen, who would otherwise have to manually feed fuel to the kiln in extreme heat. The surface temperature of the top of the kiln, from where firemen feed fuel goes over 100 degrees Celsius. This method is not only unsafe for workers but also an inefficient way for feeding fuel. Thus, the project recommends research and deployment of semi mechanized fuel feeding through trickle feeders. These feeders also prove to help save more fuel or use lesser fuel than manual feeding. Thus, this process not only protects firemen but also focuses on resource efficiency.

D.2

Enhanced Fuel Efficiency

Ban on the use of plastic waste in burnt brick making as an external fuel and use coal slurry as internal fuel. Promote and disseminate use of good quality coal from Jharkhand, West Bengal, Assam, Meghalaya. There has been no benefit in energy consumption even by adopting newer and efficient technologies e.g. Zig-Zag kilns. Due to the use of inferior coal in the form of slurry, the total energy consumption is high.

D.3

Biomass Briquette - Fuel Policy

Implement a policy for using at least 25% biomass briquette as an alternative fuel. A mix of coal and biomass will decrease reliance on fossil fuels, leading to a 25% reduction in emissions. Punjab's policy, which mandates a 25% usage of biomass briquette fuel, can be a reference.

E. Promote the production of hollow bricks in clay brick making

Hollow bricks use less soil and require less baking time, decreasing coal usage by up to 15% and conserving fertile topsoil.

E.1

Policy for Hollow Bricks:
The state may incentivize the production of hollow bricks and introduce a policy for the production and uptake in a phased approach, starting from 15% hollow volume to achieving 50% hollow bricks. This graded approach ensures a gradual transition, allowing manufacturers to adjust and ensuring market acceptance. The Bureau of Indian Standards also published a specification for hollow bricks via IS 3592: 2013. This standard covers the requirements for general quality, dimensions and physical requirements of hollow bricks and blocks made from burnt clay and having perforations through and at right angle to the bearing surface..

Figure 4.5: Hollow Bricks

F. Worker Welfare

Many of India's kiln workers are migrants and many are from the scheduled castes. Workers carry heavy loads and are exposed to high radiant heat from the kilns, in addition to extreme outdoor temperatures. By filling the evidence gap on the informal economy of brick kilns and transforming the industry to ensure green standards, stakeholders will change the current harsh conditions where workers are made more vulnerable by environmental and health damage from air pollution, exacerbated by climate change. As kilns become more environmentally sustainable, monitored and regulated, labour and health conditions are likely to improve.

Additionally, the worker module in the GeoAI platform collects data that can reveal the status of the workers in the kiln. It provides a wealth of data for more targeted action to ensure decent working conditions and help access to social security schemes. This component of the worker module of the GeoAI platform will fill a large evidence gap on the demographics of workers and the drivers for entering poor labour conditions in kilns, enabling stakeholders to target efforts to register workers with key welfare schemes, support them to claim

▶
Figure 4.6: Workers loading Brick Kilns

health and maternity benefits, and support them to access education for their children.

Stakeholders should encourage civil society and volunteer organisations to use the GeoAI platform to prioritise and target their development initiatives to organize kiln labourers to secure minimum wages, enhance working conditions and assure access to social security schemes to all brick kiln workers in India.

This piece rate system of payment limits workers' ability to earn statutory minimum wages and incentivises long working hours.

A time-based wage would be in accordance with minimum wage and overtime requirements. There would be improved economic security, less need to take an advance and increased ability to change employment. As stakeholders transform the industry with new, greener technologies they should regulate the sector in terms of labour, classify all kilns as factories and introduce time-based wages.

Workers carry heavy loads and are exposed to high radiant heat from the kilns, in addition to extreme outdoor temperatures. By filling the evidence gap on the informal economy of brick kilns and transforming the industry to ensure green standards, stakeholders will change the current harsh conditions.

Figure 4.7:
Male Worker at Brick Kiln

G. Stakeholders and Their Roles:

G.1

Bihar State Pollution Control Board and Department of Environment, Forest & Climate Change

Bihar State Pollution Control Board (BSPCB) and the Department of Environment, Forest & Climate Change (DoEF&CC) play a critical role in steering the state towards a sustainable future, especially in areas like cleaner brick production technology. The BSPCB, in conjunction with the DoEF&CC, are pivotal regulatory authorities in Bihar. Tasked with formulating policy guidelines, they drive the state's vision of sustainable brick production. These bodies ensure that industries adhere to green standards, penalizing non-compliance and rewarding eco-centric practices. They also play an instrumental role in promoting the transition to cleaner technologies. By organizing awareness campaigns, providing technical support, and ensuring the availability of resources, they propel the brick industry's shift to environment friendly methods, contributing to a greener Bihar. BSPCB does not give consent to brick kilns that use FCBTK technology to operate. As per notification no. 23 dated 31.08.23, the board will demolish brick kilns that are found to be operational and have not shifted to cleaner technology after 21 December 2023.

G.2 Mines & Geology Department

The Mines & Geology Department of Bihar manages material provisions and regulates mining for the brick kiln industry. By enforcing green standards, they ensure sustainability. Crucially, by withholding licenses from non-compliant brick kilns, the department can promote eco-friendly practices and steer Bihar towards an environmentally conscious trajectory.

G.3 Labour Resource Department

The Labour Resource Department (LRD) should spearhead a comprehensive needs assessment for kiln workers. Based on the identified skill gaps, develop training modules focused on safety protocols, operational efficiency, and new kiln technologies. Prioritize hands-on, on-site training supplemented by digital learning platforms. Introduce certification post-training to boost morale and professional growth. Collaborate with kiln operators and NGOs to ensure effective implementation and awareness. Regular feedback and program updates will ensure relevancy, catering to evolving industry standards and technological advancements, ultimately enhancing kiln operations' safety, efficiency, and sustainability.

▲
Figure 4.8:
Female Worker at Brick Kiln

G.4 Department of Industries

The Department of Industries plays a pivotal role in bolstering the growth of fly-ash brick production. Tasked with streamlining industrial processes, it ensures the timely provision of essential resources such as land, finance, and raw materials. It is a backbone for entrepreneurs and manufacturers to thrive in the sustainable brick industry.

G.5 National Thermal Power Corporation

The role of the National Thermal Power Corporation (NTPC) is key in the transition to sustainable brick production, given its status as a leading fly ash producer. Recognizing the transformative potential of fly ash bricks in mitigating environmental impact, NTPC's role extends beyond mere power generation. By ensuring a streamlined and consistent supply of fly ash to brick manufacturers within the state, NTPC can directly influence the scale and speed of adopting eco-friendly brick production methods.

◄
Figure 4.9:
Bricks at Kiln

G.6 Department of Power

As the authority overseeing power plants generating fly ash, it can be pivotal in ensuring and monitoring fly ash availability to manufacturers. By standardizing processes and ensuring transparent distribution, the department can help accelerate the uptake of eco-friendly brick manufacturing, showcasing the benefits of cross-sectoral collaboration in achieving environmental objectives and furthering the state's commitment to green practices.

G.7 Department of Finance, Construction Departments & Municipal Corporation Department

The Department of Finance, Construction Departments, and the Municipal Corporation Department are instrumental in steering eco-friendly construction practices. By allocating funds, setting construction standards, and implementing municipal regulations, they can champion the use of green building products. Their collective influence can mandate eco-friendly standards, incentivize sustainable practices, and foster a culture of environmental responsibility in urban planning and infrastructure development. Their joint efforts can significantly drive the transition towards sustainable construction in their respective domains.

G.8 Entrepreneurs & Contractors

Entrepreneurs & Contractors are central stakeholders in transitioning to cleaner brick production technology. They bear the upfront costs of adopting new methods but stand to gain from long-term efficiency and market demand for eco-friendly bricks. Their commitment and adaptability are vital to actualizing a greener brick industry.

It's essential to continuously monitor the progress and adjust strategies based on real-world data, outcomes, emerging trends, and technological advancements. Whether transitioning from Fired Red Clay Bricks or advancing towards fly-ash bricks, iterative evaluation, and adaptation are critical. The collaboration of all stakeholders, encompassing regulatory bodies, industry participants, and supporting departments, is paramount to ensure the successful transformation of the brick industry, aligning it with sustainable and eco-friendly practices.

H. Collective Action

To address the multifaceted challenges posed by brick kilns, we propose a comprehensive approach centered around "Collective Action." The regulation and operation of brick kilns involve numerous stakeholders, including government bodies, labor, consumers, fuel suppliers, and technology providers. Recognizing the interconnectedness of environmental, social, and economic issues surrounding brick kilns, fostering collaboration among these diverse actors is crucial.

Leveraging innovative platforms such as GeoAI to facilitate collective action is highly recommended. These digital solutions can break down data siloes, bridge evidence gaps, and provide an integrated outlook for all stakeholders involved. To enhance the efficacy of such platforms, we suggest expanding their scope and making them open to encourage active participation from all relevant parties.

By fostering collaboration and information sharing, we can develop a unified strategy to mitigate emissions from brick kilns. This approach will not only enhance regulatory compliance but also promote sustainable practices, ultimately leading to a more environment friendly, socially responsible, and economically viable brick industry.

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Figure 4.10
Interactive Map Visualization
and
Figure 4.11:
UNDP at Brick Kiln

Moving Forward

Recognizing the inadequacy of business as usual in addressing India's air pollution crisis, there is a pressing need for innovative approaches, transformative practices, and collaborative strategies across diverse agencies to undertake collective and coordinated action for achieving clean air.

Drawing inspiration from the insights gained from the GeoAI experiment conducted in Bihar, the collaborative in Bihar led by BSPCB, UNDP and partners are poised to amplify their commitment to advancing data innovations through the hyperlocal mapping of air pollution sources, with the overarching goal of establishing an 'open digital stack' for shared understanding.

The GeoAI experiment in Bihar served as a pivotal learning experience, and the upcoming phase will witness a strategic expansion of these data innovations. The focus will be on the integration of the combined power of the Internet of Things (IoT), citizen science, and artificial intelligence (AI) to curate hyperlocal maps pinpointing air pollution sources within the urban landscape of Patna. Spearheaded by the Bihar State Pollution Control Board (BSPCB) and bolstered by the support of the GIZ's Lacuna Fund, this initiative is poised to unveil an open digital stack tailored specifically for addressing air pollution. The primary aim is to foster collective action among the myriad stakeholders constituting the ecosystem, ensuring a more inclusive and participatory approach.

The collaborative effort in Bihar represents a beacon of innovation and a paradigm shift towards leveraging cutting-edge technologies for the betterment of air quality. The strategic integration of IoT, citizen science, and AI not only enhances the precision of mapping air pollution but also democratizes the process, encouraging active involvement from the citizens of Patna. This initiative, bolstered by the Lacuna Fund, not only addresses the immediate concern of air pollution but also serves as a model for sustainable, technology-driven solutions that can be replicated in other regions grappling with similar challenges.

As we move forward, the commitment to fostering collaborative efforts by BSPCB, UNDP and partners remain at the forefront of the agenda. This involves a continuous exploration of ways to integrate innovations into policy frameworks, thereby ensuring effective policy coherence and anticipatory action against air pollution. Simultaneously, there is a recognition of the need to understand and address capacity gaps within agencies to adopt innovations and other best practices effectively.

The forward-looking strategy encompasses identifying emerging strategies, solutions, and best practices aimed at safeguarding the health of citizens. This proactive approach recognizes the dynamic nature of the challenges posed by air pollution, emphasizing the importance of adaptability and innovation. By combining the power of technology, collaborative partnerships, and a commitment to addressing capacity gaps, the goal is to create a comprehensive and sustainable framework that goes beyond mitigating immediate concerns, setting the stage for long-term resilience against the air pollution crisis in India.This collaboration envisions collective action, innovation, and adaptability as the cornerstones for achieving a future with clean and breathable air for all.

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