AJG

Article

Assessment of Brick Kilns Induced Air Pollution: A Micro-Regional Approach

Kaniz Fatema, Md. Rahedul Islam* and Mis. Shukhi Khatun

Geospatial Lab. of Environment and Disaster, Department of Geography and Environment, Pabna University of Science and Technology, Rajapur, Pabna-6600, Bangladesh

*Corresponding author: Prof. Md. R. Islam, Email: <rahe_ge@pust.ac.bd>

Received: September 12, 2025; Accepted: January 12, 2026; Published: January 29, 2026

ABSTRACT

Brick kilns in Bangladesh significantly contribute to poor air quality due to their hazardous emissions, resulting in severe health impacts on local communities, contributing to climate change, and adversely affecting agricultural productivity. The primary aim of this research was to identify areas with high brick kiln density and assess variations in pollution concentrations in and around these kilns. The methodology adopted both primary and secondary data collection, analysis, and representation. For data collection, the MCD19A2 MODIS product was utilized to calculate the mean density of Aerosol Optical Depth (AOD), in addition to direct field observations using an instrument called the Intelligent Air Detector and conducting Key Informant Interviews (KII) in March 2024. The results indicated that the average AOD in the study area ranged from 0.4590 to 0.8723. Higher values were observed in the central and northeastern regions, suggesting a significant presence of aerosols, particularly in areas with a high density of brick kilns. Pollutant levels were found to be high within 50 meters of all the kilns, decreasing as the distance from the kilns increased. A moderate to strong positive correlation ($PM_{2.5}$ with PM_{10}: $r=0.935$, $p<0.01$; $PM_{1.0}$ with $PM_{2.5}$: $r=0.815$, $p<0.01$; $PM_{1.0}$ with PM_{10}: $r=0.675$, $p<0.05$) indicated that the kilns were hotspots for pollutants. Yearly emission estimates for various pollutants were calculated using local emission factors, revealing high emissions from these kilns owing to their use of outdated technology. The findings of this study are expected to help reinforce regulations and policy-making based on the data provided regarding serious pollution scenarios in the study area.

Keywords: Air Pollutants, Polluted Areas, High Brick Kilns Density, AOD, Emission

1. INTRODUCTION

1.1 Background

Brick is an indispensable building material in Bangladesh, and the demand for bricks is soaring day by day for rapid urbanization. Bangladesh has secured its position as the fourth-largest brick-producing country in the world (Rahman, 2022). There are around 7,000 to 7,200 brick kilns nationwide, employing approximately one million people directly or indirectly. Every year, approximately 23 to 32.4 billion bricks are produced in Bangladesh, contributing to about 1% of the national gross domestic product (Siddik et al., 2021). Despite contributing an important role in the country's economy, the brick manufacturing industry is not totally recognized as a formal industry in Bangladesh.

This is primarily due to its seasonal operation, which typically occurs from November to April, during the dry season when there is less rainfall (Chowdhury et al., 2022). However, among small-scale industries, the brick kiln industry is booming as the demand for bricks is increasing almost universally owing to rapid economic growth, urbanization, and prosperity (Skinder, 2014).

Most of the brick kiln plants in Bangladesh use low-quality coal, wood, or other solid waste/raw materials such as rubber tires, plastic bags, used footwear, dried animal waste like dung and thus resulting in the production of SOx, NOx, COx, and PM along with many other organic pollutants due to burning of substandard waste material (Bhat et al., 2014). As those fuels used in brick kilns are the sources of greenhouse gases, a report published by the World Bank mentioned that about 9.8 million tons of greenhouse gases are emitted annually by brick kilns in Bangladesh (World Bank, 2014). A research report illustrated that the total of released gases and particulate matter from the brick kilns in the Dhaka region of Bangladesh for yearly 3.5 billion bricks production was 302,000 tons of CO, 23,300 tons of $PM_{2.5}$, 6000 tons of BC, 15,500 tons of SO_2 and 1.8 million tons of CO_2 (Guttikunda et al., 2013). According to a World Bank report, only 5% of bricks produced come from kilns that emit low levels of pollution in Bangladesh (Saju et al., 2020).

It takes approximately two weeks to complete the brick production cycle, starting from mixing the soil to unloading the fired bricks. During this cycle mentioned in Fig. 1, various air pollutants are produced, with PM, CO_2, CO, SO_2, and NO_2 being the most notable. Brick kilns consume about 2.2 million tons of coal yearly, most of which is imported by land from the Indian states of Meghalaya and Assam (World Bank, 2012). The use of these low-quality coals in brick firing leads to elevated emissions of these air pollutants, which are often referred to as “silent killers” due to their serious health risks.

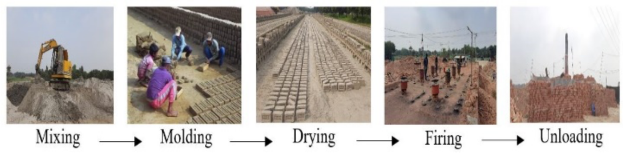


Fig. 1: Brick production process.

A report by Health Effect Institute (HEI) states that air pollution results in 6.67 million deaths globally each year (Health Effects Institute, 2021). Bangladesh is no exception to this trend. Recently, the country has encountered greater challenges from air pollution than from other forms of environmental pollution. Air pollution become third leading risk factor for mortality in the country, responsible for almost 14% of all deaths (Fuller et al., 2022). Additionally, Bangladesh incurs annual losses of approximately $6.5 billion, equivalent to 3.4% of its Gross Domestic Product (GDP) in 2015, due to pollution and environmental degradation (World Bank, 2018).

Emissions from brick kilns pose health risks to local communities, hinder agricultural productivity, and contribute to the degradation of nearby ecosystems. Therefore, it is essential to measure ambient air quality in brick kiln areas to implement effective measures for reducing air pollution levels. This study aimed to determine the concentration of air pollutants in and around the brick kilns within the study area, as well as to estimate the air pollution caused by brick kilns. The findings are expected to provide valuable insights for planners and policymakers in promoting cleaner and more sustainable brick-making practices, ultimately reducing environmental and health impacts.

Numerous studies have shown that brick kilns contribute to air pollution through various techniques in different regions. A study in the Marmara region of Turkey used satellite-based observations to monitor air quality. MODIS Level 2 aerosol products from Terra (MOD04) and Aqua (MYD04) with a spatial resolution of 10 km at nadir were collected for 2015. The operational product "Optical-Depth-Land–and-Ocean" AOD at 0.55 μm band for ocean and land was used in that study. The aerosol profile covering the Marmara region was generated for each day of the year 2015 and monthly aerosol profiles were created by averaging the daily AOD data to study the spatial and temporal patterns. The result showed that high aerosol loadings (AOD > 0.4) appear in regions with intensive industrial and urban activities while low values (AOD < 0.2) are usually observed in areas covered with vegetation (Ettehadi et al., 2019).

The spatial and temporal aerosol optical depth in six major cities in Bangladesh was analyzed in-depth, including seasonal variations of aerosol optical depth (AOD), pattern analysis of aerosol optical characteristics (PM2.5 and PM10), and source characterization. They compared satellite data from MODIS Terra and Aqua with ground measurements from AERONET and examined their relationship with particulate matter to ensure data verification. High AOD values (0.70) were obtained in most of the western regions in all seasons, and anthropogenic and biomass-burning aerosols dominated in all seasons (Zaman et al., 2021).

Researchers analyzed the chemical composition and examined the effects of air pollution from brick kilns on public health in Mardan District of Khyber Pakhtunkhwa in the northern Pakistan. A field-based investigation was conducted to measure air pollutants including PM_1, $PM_{2.5}$, and PM_{10}, CO_2, CO, NO, NO_2, H_2S, and NH_3 using mobile scientific instruments in selected study area locations. The mean values of different parameters were measured by EPAM-5000PM for PM, USA Nova 600, Canada for NO_2, CO_2, CO, NO, NH_3, and H_2S. The data were presented using bar graphs in GraphPad version 8.0, while maps were designed using ArcGIS version 10.5. The results showed that the concentrations of PM_1, $PM_{2.5}$, and PM_{10} were higher than the normal range prescribed by Pakistan's NEQS (Bhat et al., 2014).

A study was conducted in Panzan village of Budgam district in Jammu and Kashmir State of India, between April and September, 2012 to monitor brick kiln emissions. This study estimated the levels of pollution, including SOx, NOx, RSPM, and NRSPM, on an 8-hourly basis during both the operational and non-operational phases of the brick kilns. To evaluate the air quality in and around the brick kiln area, a high-volume EnvironTech Air Sampler was used. The association between pollutants was assessed using Pearson correlation. The entire analysis was conducted on log10-transformed data. A two-tailed probability with a significance level of $p < 0.01$ was considered statistically significant. The analysis was performed using SPSS (Statistical Product and Service Solutions). The results showed that all pollutants, including SOx, NOx, RSPM, NRSPM, and SPM (the sum of RSPM and NRSPM), exceeded the limits set by the National Ambient Air Quality Standards (NAAQS) during the operational phase of brick kilns (Skinder, 2014).

The study conducted in Trishal Upazila of Mymensingh district from March 12-15, 2022, aimed to estimate the levels of CO_2 and other pollutants from brick kilns as well as their effects on human health and the environment. Different methodologies were employed for data collection and measurement including interviewing the local people, and portable instruments named Airveda (Air Quality Monitor) and Testo 317-3 (Ambient CO Meter). Data were collected through direct field observations in the study area, including interviews with brick workers, local residents, and managers. This approach aimed to gather information about the types of fuels used and the total annual fuel consumption in the brick kilns, as well as the effects and challenges faced by the community in the area. The average value of each pollutant from brick kilns in different unions acquired from field data was shown in the graph and chart. The air pollutants in the study area exceeded national standards, leading to poor air quality in many unions (Akhi et al., 2023).

The quantification of various air pollutants, including SOx, NOx, COx, and particulate matter (PM), was conducted around brick kilns in Gujrat city. The study utilized a Gaussian dispersion model to analyze the distribution of these pollutants in the atmosphere. It was found that as the distance from the brick kiln increased, the concentration of pollutants gradually decreased (Hassan et al., 2012). Both mapping the kiln clusters and modeling the particulate pollution for the Greater Dhaka region were completed. In that study, the Atmospheric Transport Modeling System dispersion model was used to estimate the impact of brick kiln emissions on the Dhaka Metropolitan Area from October to March. Monthly average $PM_{2.5}$ concentration data from monitoring stations, along with Google Earth imagery, were used to identify brick kiln clusters in the Greater Dhaka Region (Guttikunda et al., 2013).

Previous studies have mapped the density of brick kilns and induced air pollution using in situ measurements and statistical techniques. Geospatial techniques are potential and efficient tools for such analysis, but they have been overlooked in some earlier studies. In this context, our study aimed to monitor the current pollution scenario caused by brick kilns in the study area using both geospatial techniques and in situ measurements.

1.2 Objectives

This study aimed to address previously overlooked areas in understanding brick kiln pollution. By focusing on these issues, the research ensured that its outcome would be effective and meaningful. First, the research intended to map the density of brick kilns and identify polluted areas with a high concentration of these kilns. This helped in understanding their contribution to regional pollution. Second, the study sought to analyze the variation in the concentration of air pollutants in and around brick kilns to determine whether they were the primary sources of air pollution hotspots. Finally, the study aimed to estimate the extent of air pollution caused by brick kilns, emphasizing the urgency of implementing effective measures to combat pollution. The specific objectives of this research were as follows:

1. To map brick kiln density and to identify polluted areas with high brick kiln density,
2. To analyze the variation in concentration of air pollutants in and around brick kilns,
3. To estimate air pollution induced by brick kilns.

1.3 Study Area

For fulfilling this study, Lalpur Upazila, located in the Natore district of the Rajshahi division has been chosen, which is situated between the latitudes of 24°07' and 24°18' north and the longitudes of 88°52' and 89°08' east., with an area of 327.92 sq. km and a total 274405 populations. Bagatipara and Baraigram upazila are located to the north, Ishwardi, Bheramara, and Daulatpur (Kushtia) upazila to the south, Baraigram upazila to the east, Bagha upazila on the west (Banglapedia, 2023).

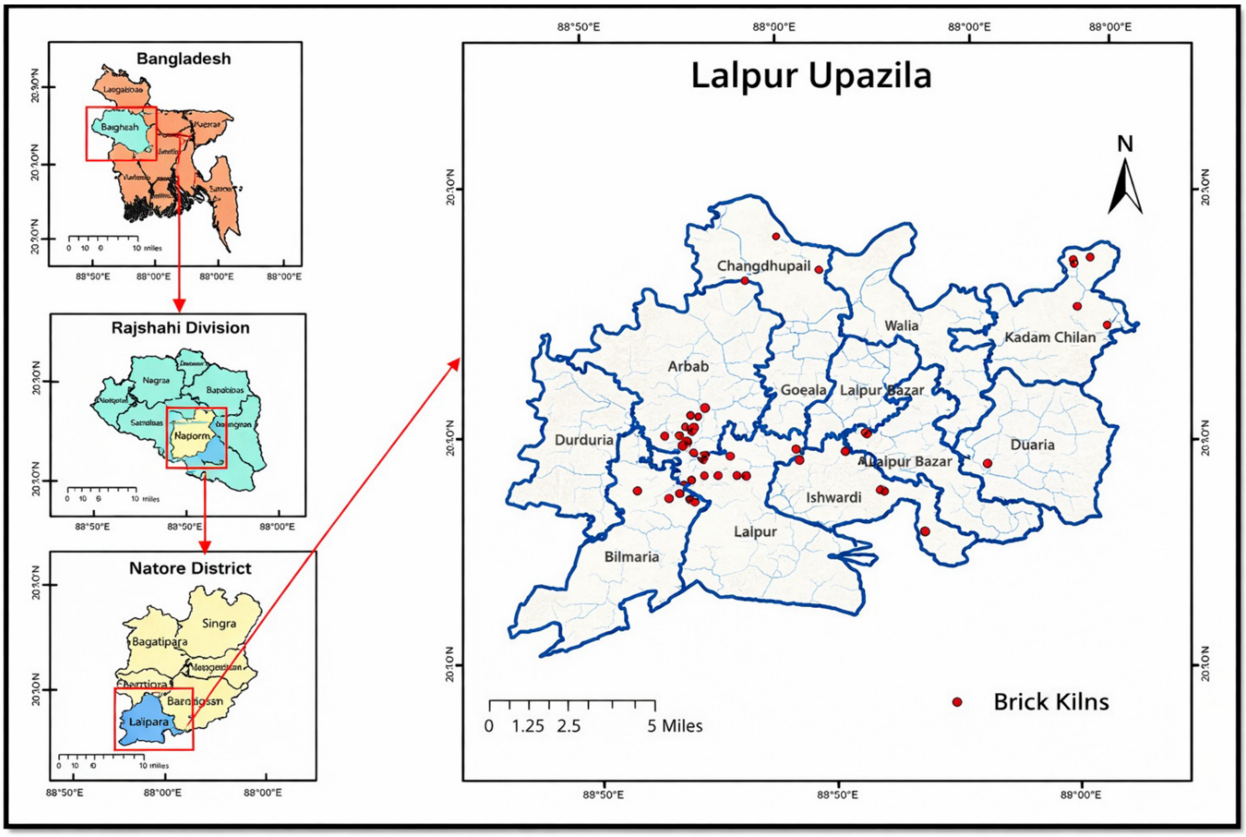


Fig. 2: Map of the study area with the locations of brick kilns (source: Google Earth Pro)

This upazila contains nearly 50 brick kilns. As most of the kilns run on low quality coal, they emit continuous and profuse streams of unhealthy smoke, causing significant pollution to the surrounding area. Without maintaining proper guidance, the mushrooming of brick kilns in the upazila threatens the environment and public health. The land use and land cover map of Lalpur upazila in Fig. 3 shows that most of the kilns are located along the banks of the Padma River, particularly concentrated in the Lalpur, Bilmaria, and Arbab unions. Each kiln occupies a large area, typically ranging from 3-4 acres, especially for drying and production purposes. Because these kilns occupy substantial agricultural land, they restrict food production and hinder crop growth in the surrounding areas. Despite the high density of kilns, few studies have assessed the overall air pollution scenario induced by brick kilns in this area. To address this limitation, Lalpur upazila was selected as the study area.

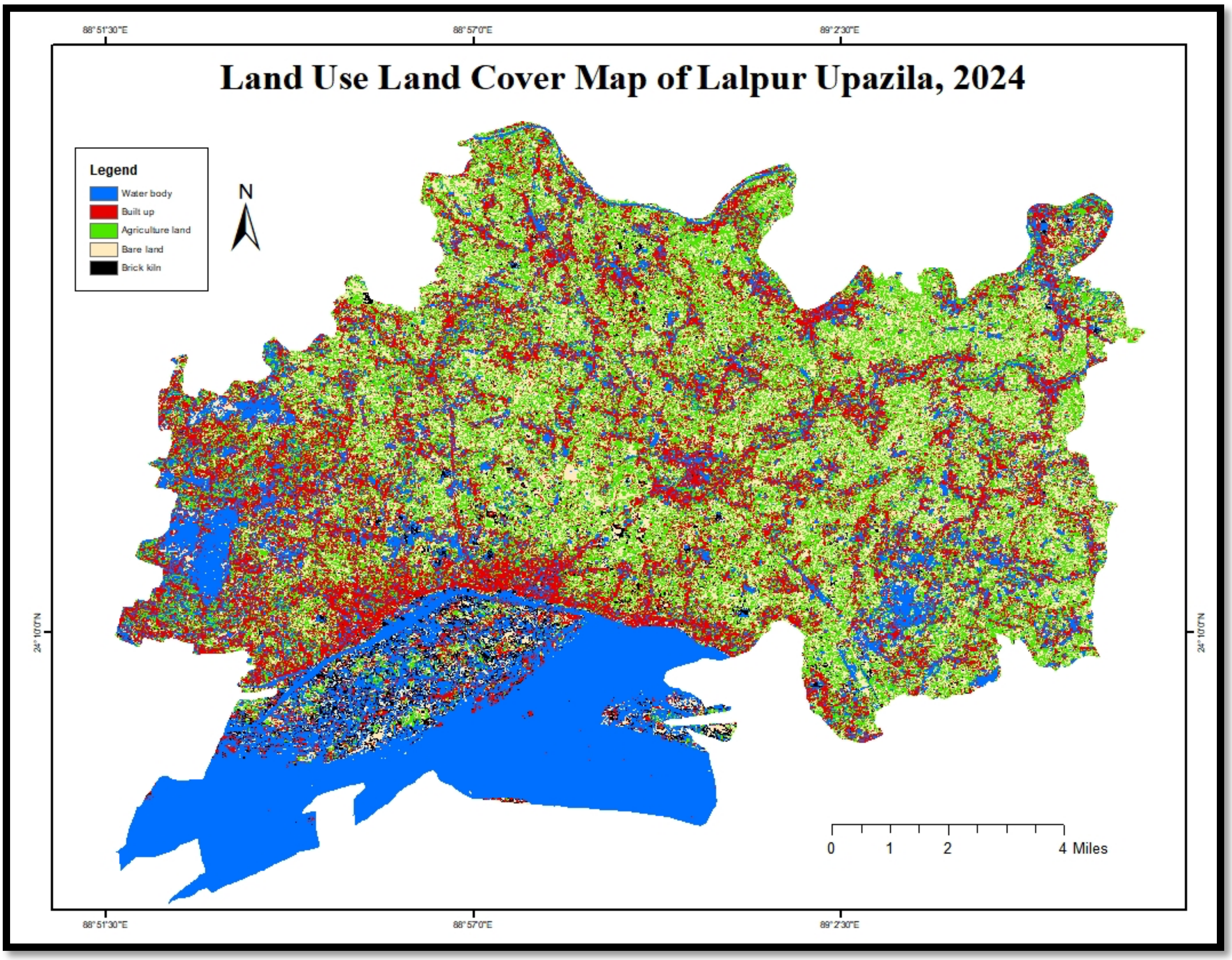


Fig. 3: Land use and land cover map of Lalpur Upazila in the year of 2024.

Table 1: Characteristics of MCD19A2 images (source: NASA LP DAAC, USGS EROS EROS, 2024)

Satellite	Sensor	Product	Parameter	Band	Spatial Resolution	Temporal Resolution
Terra	MODIS	MCD19A2.061	AOD	Blue (0.47 µm)	1 km	24 hours

2. DATA COLLECTION AND METHODOLOGY

2.1 Data collection

For the completion of this study, we used both spatial and field data.

Sources of primary data

1. Emission analyzer

An Intelligent Air Detector was employed to measure air pollutants levels, specifically $PM_{1.0}$, $PM_{2.5}$, and PM_{10}, emitted from brick kilns during a field survey conducted in March 2024. Multiple readings were taken to ensure accuracy. This portable device is capable of detecting particulate matter and other gases, with a measurement range of 0 to 999 μg/m³. In this study, it was used to assess the levels of various particulate matters at the selected sites.

2. Key informant interview (KII)

Data were collected through direct field observations at the study sites by interviewing key informants in the brick kiln industry, including kiln owners, managers, and workers. This approach facilitated the gathering of information on fuel types and total fuel consumption for each season, annual brick production, land acquisitions, and other relevant details.

Sources of secondary data

1 Geospatial data sources

Remote sensing methods, especially Terra satellite imageries, which have a sensor namely MODIS (Moderate Resolution Imaging Spectroradiometer), were used for monitoring air quality in the study area. AOD data from MODIS in March, 2024 were used to identify polluted sites with high brick kiln density in the selected study area. The characteristics of the dataset are summarized in Table 1.

2 Additional secondary sources

Previous relevant research papers, various organizational reports such as the U.S. Environmental Protection Agency (EPA), World Bank (WB), World Health Organization (WHO), U.S. National Oceanic and Atmospheric Administration (NOAA), India's National Programme on technology Enhanced Learning (NPTEL) etc., government reports like Department of Environment (DoE), and other online resources were utilized to ensure accuracy and support the research finding.

2.2 Methodology

Various methods were employed to achieve the ultimate goal of this research. The study was conducted in a hybrid mode, incorporating field data collection, satellite data collection, data analysis, and desktop reviews. The methodological framework for completing this research is illustrated in Fig. 4.

2.2.1 Identification of polluted areas with high brick kiln density

Aerosol Optical Depth (AOD) is an essential parameter for evaluating aerosol content and assessing air pollution levels. It measures the vertical columnar aerosols levels and has no unit. AOD data are effective for assessing air quality, particularly in local areas where ground-based air quality monitoring instruments are not available. It can be used as proxy to surface $PM_{2.5}$ (Scott Lindstrom, 2018). In this study, we used the MCD19A2 product from MODIS to create a mean density map of AOD for March 2024 in the study area. The AOD map was then overlaid with the brick kiln density map generated using Google Earth Pro, enabling identification of regions with high brick kiln density and elevated pollution levels. We conducted further research on selected sites in the most polluted areas with high brick kiln density.

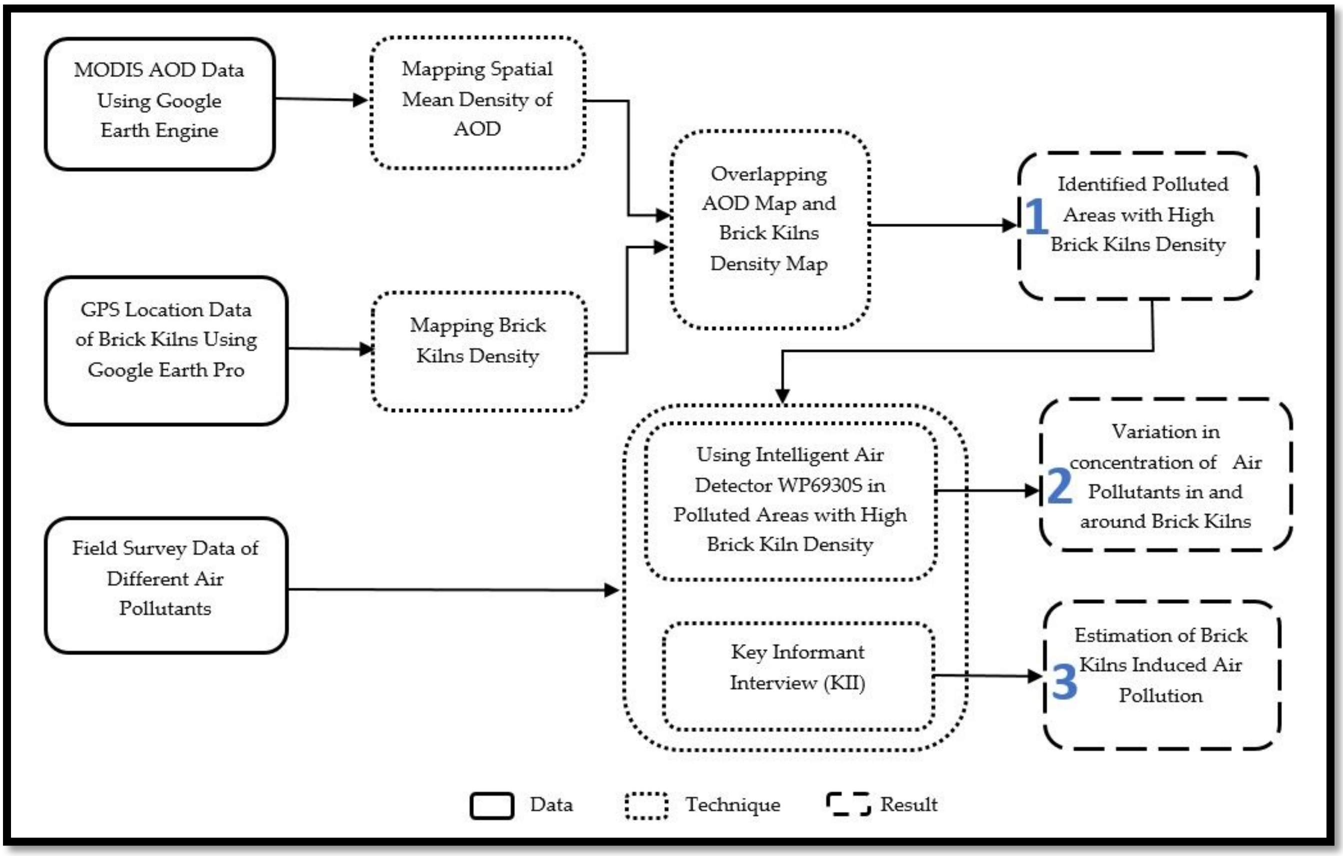


Fig.4: The data, data processing, analysis and finding shows as the methodological framework for this study.

To validate this overlapping map, we created a wind speed map for the same period. This wind speed map visually represents the factors contributing to variations in AOD within the region. We conducted regression analyses to explore the relationships between AOD and wind speed, and between AOD and $PM_{2.5}$ levels. It is important to note that $PM_{2.5}$ data were collected on specific days using the aforementioned portable device. After averaging the total data, we used the monthly mean values for $PM_{2.5}$ in the analysis. Based on average $PM_{2.5}$ data, we evaluated the air quality in the region of interest according to national standards, ensuring a comprehensive assessment of environmental health.

2.2.2 Analyzing variation in concentration of air pollutants in and around brick kilns

An Intelligent Air Detector was used to assess the variation in the concentration of air pollutants around brick kilns. This assessment aimed to show the extent of air pollution levels in and near the kilns. Data were recorded at various distances from the brick kilns. To determine whether different air pollutants in the study area were generated from the same source (brick kiln), Pearson's Correlation of Coefficient analysis between different air pollutants was conducted using IBM SPSS Software.

2.2.3 Estimation of air pollution induced by brick kilns

Yearly coal consumption and brick production data from selected brick kiln sites were collected by KII. Based on this information, yearly emissions of various air pollutants were calculated using different emission factors.

Emission estimation CO_2 (IPCC Reference Manual, 2007)

CO_2 emission from the brick kiln was calculated by the following equation.

$$CO_2 = \mathrm{FC} \times \mathrm{CEF} \times \mathrm{f_0} \times 44/12 \quad (1)$$

Where, FC= total coal consumption in energy conservation unit of brick kiln during a year (TJ)

CEF= carbon emission factor of coal (tC TJ-1)

f_0= carbon fraction of coal that has been oxidized during the combustion process

44/12= stoichiometric factor, i.e. mass conservation factor of mass carbon to mass CO_2 generated during combustion processes

Firstly, the quantities of coal consumption were converted into energy units (TJ) using the appropriate conservation factor (heating value for coal 20.93 GJ t^{-1}, source: BCAS, 2005), and then transformed into carbon emissions based on the carbon emission factor (CEF). As an approximation, Intergovernmental Panel on Climate Change (IPCC) provides CEF value of coal of 26.4 tC TJ^{-1} (the average value of anthracite, cooking coal, other bituminous coal, sub-bituminous coal, and lignite). The Fraction-oxidized value is used to account the carbon compound of coal that does not oxidize during the combustion. As an approximation, the fraction-oxidized value of 0.980 was used for coal (Saadat et al., 2008).

Emission estimation SO_2 (IPCC, 1996)

According to NPTEL, Indian coal typically contains 1% Sulphur (S). During combustion of coal, Sulphur combines with Oxygen to form Sulfur dioxide (SO_2).

$S+O_2=SO_2$

$(32/32)S+ (16 \times 2) /32\ O_2 = (32+16 \times 2)/32\ SO_2 = 2\ SO_2$

Therefore, 1 unit Sulfur + 1 unit Oxygen = 2 unit Sulfur dioxide.

Generally, 100 kg of wood contains 1 kg of Sulfur. So, X kg coal contains = (X ×1%) kg Sulfur

Here, X = Total Coal

So, 1 kg Sulfur = 2 kg SO_2

(X ×1%) kg sulfur= (2 ×X×1%) kg SO_2 (Akhi et al., 2023).

Emission estimation NO_2 (IPCC, 1996)

According to NPTEL, Indian coal typically contains 0.7% Nitrogen (N). During combustion of coal, Nitrogen combines with Oxygen to form Sulfur dioxide (NO_2).

N+O2=NO2

$(14/14)N+ (16 \times 2)/14\ O_2 = (14+16 \times 2)/14\ NO_2 = 3.29\ NO_2$

Therefore, 1 unit Nitrogen + 2.29 unit Oxygen =3.29 unit Sulfur dioxide.

Generally, 100 kg of wood contains 0.7 kg of Nitrogen. So, X kg coal contains = (X × 0.7%) kg N.

Here, X = Total Coal

So, 1 kg Nitrogen = 3.29 kg NO_2

(X × 0.7%) kg Nitrogen= (3.29 ×X ×0.7%) kg NO_2 (Akhi et al., 2023).

Emission estimation PM and CO

Local emission factors for $PM_{2.5}$, PM_{10}, and CO estimation have been used to assess the maximum impact of brick kiln emission. For, $PM_{2.5}$, PM_{10}, and CO, local emission rates of 7.33, 24.43, and 2.05 kg ton-1 brick production, respectively, were used in this research. It is important to note that the weight of each brick was considered as 2.8 kg (Ahmed & Hossain, 2008).

3. RESULTS

3.1 Polluted areas with high brick kilns density

The observed average Aerosol Optical Depth (AOD) value for March 2024 in the study area ranged from a low of 0.4590 to a high of 0.8723. High AOD values have been recorded in the central and northeastern regions, indicating a significant presence of aerosols in the atmosphere. Conversely, lower AOD values were found in the southern area, which suggests a reduced aerosol content. Notably, in this southern region the Padma River is located. This AOD distribution indicated that areas with high brick kiln density had the most aerosol load, while areas that are comparatively far away, such as in the south and north, had relatively low aerosol load.

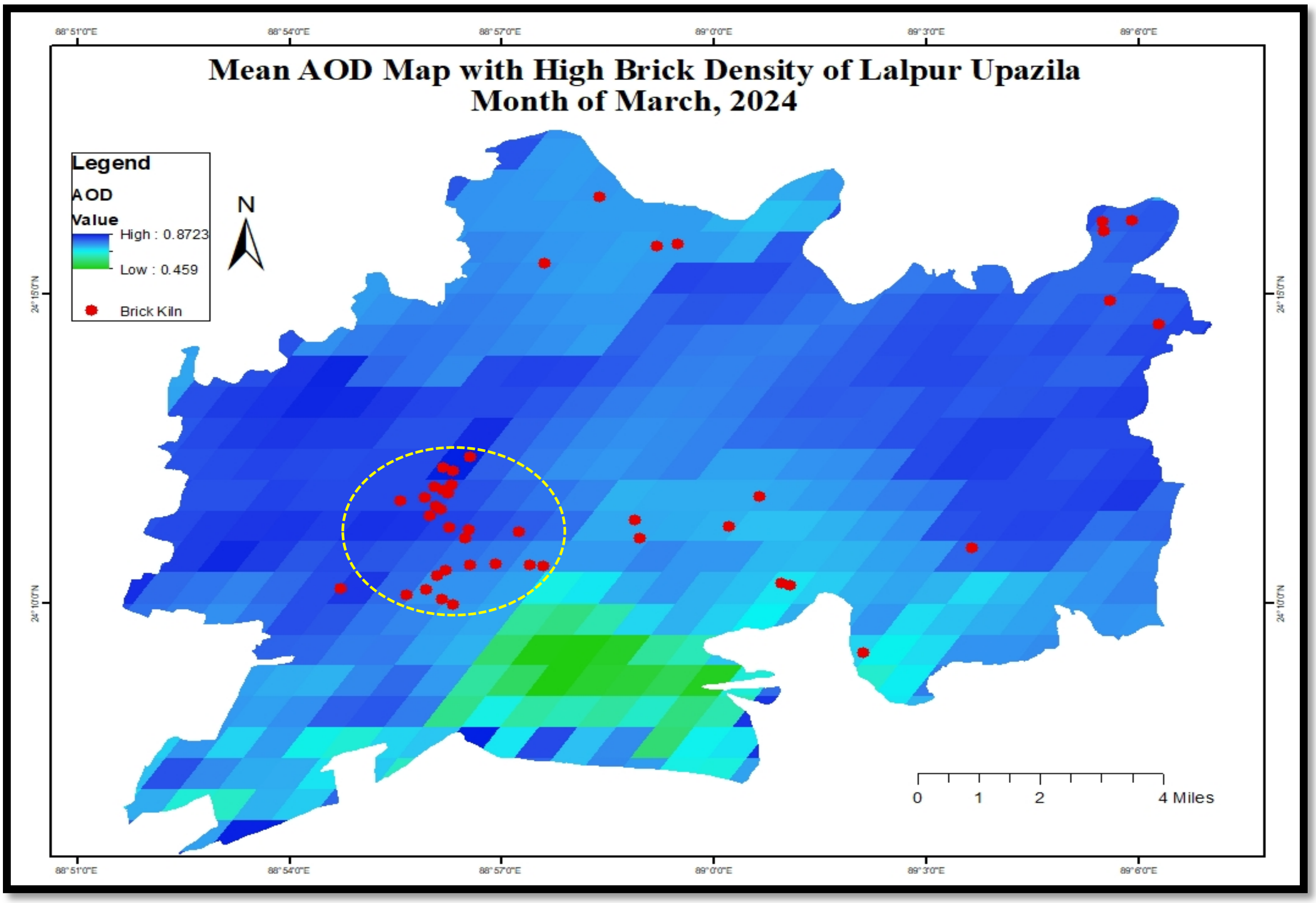


Fig. 5: Mean AOD map with the locations of brick kiln of Lalpur Upazila, March 2024.

Within a radius of approximately 2.3 kilometers, there are around 25 brick kilns, making it the area with the highest density of brick kilns in Lalpur Upazila. Fig. 5 highlights this region (marked with a yellow dotted circle) as a polluted area characterized by a high AOD value. The intelligent air quality device used to collect the $PM_{2.5}$, PM_{10} and CO data around the brick kilns area (Table S1).

Table 2: Correlation between pollutants in ambient air of the selected brick kiln sites

Parameters	$PM_{1.0}$	$PM_{2.5}$	PM_{10}
$PM_{1.0}$	1		
$PM_{2.5}$	0.815** ($p>0.01$)	1	
PM_{10}	0.935** ($p>0.01$)	0.675* ($p>0.05$)	1

To facilitate further investigation, three brick kiln sites were chosen in the high-density area of brick kilns, specifically within the polluted zone. The sites were MHA, MRP, and MKM, as illustrated in Fig. 6.

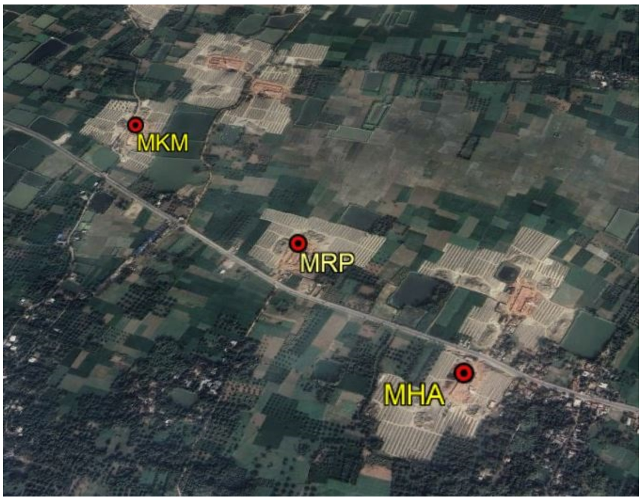
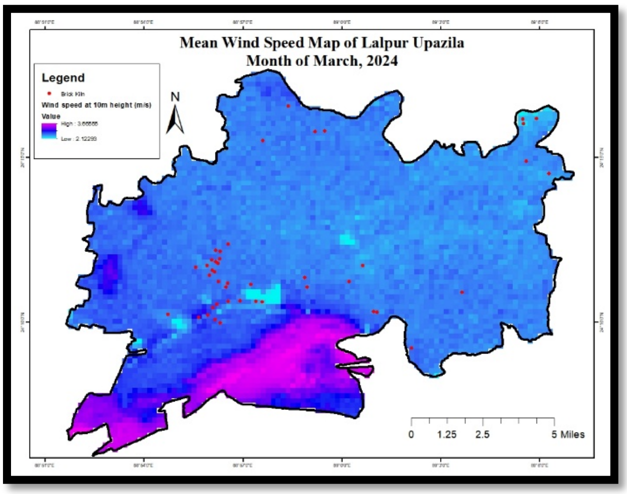


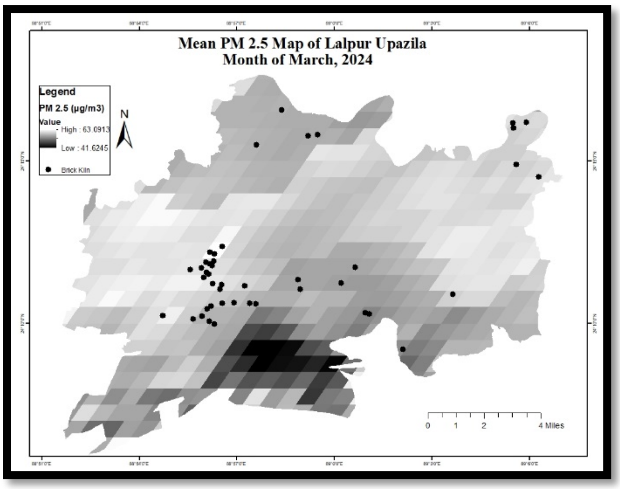
Fig. 6: Satellite image of selected brick kiln sites (Source: Google Earth Pro).

Fig. 7(a) shows a mean wind speed map for Lalpur Upazila in March, indicating winds blowing from the southwest to the northeast. This resulted in the dispersal of aerosol optical depth (AOD) in the northeastern direction, despite few brick kilns in that area. A linear regression analysis between wind speed and AOD revealed a negative relationship, with a significant value of $R^2 = 0.689$ as illustrated in Fig. 8 (a). That meant to 68.9% variation of AOD can be attributed to wind speed, and the remaining portion is unexplained.

$PM_{2.5}$ levels was observed to be high in areas where with elevated aerosol optical depth (AOD) and low wind speeds, as illustrated in Fig. 7(b). Additionally, a strong positive relationship was found between $PM_{2.5}$ and AOD, with a significant value of $R^2 = 0.843$ illustrated in Fig. 8(b). This indicates that 84.3% of the variation in ground-level $PM_{2.5}$ can be explained by AOD, leaving the remaining portion unexplained.

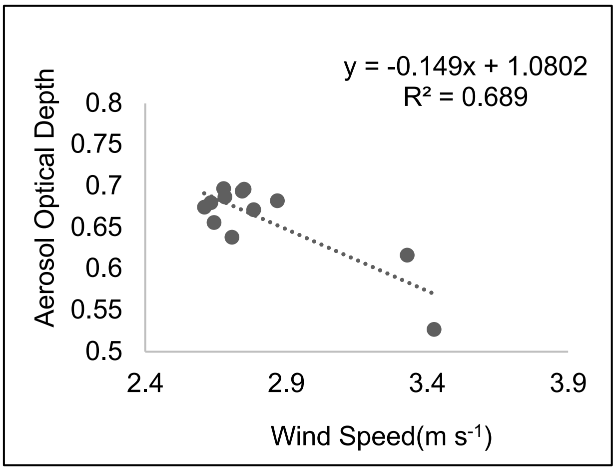


(a)

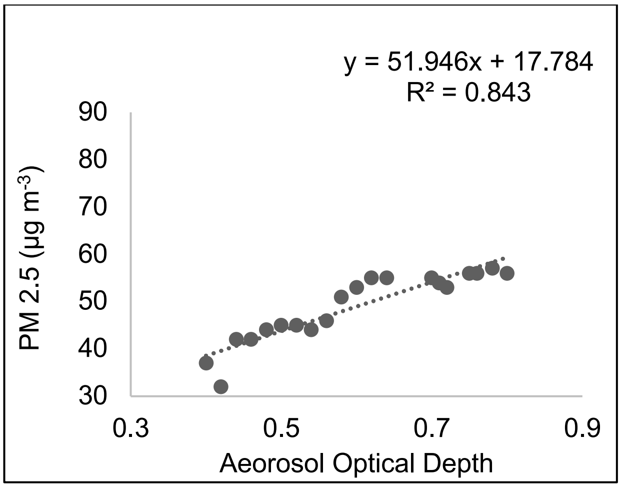


(b)

Fig. 7: (a) Mean wind speed map, (b) Mean $PM_{2.5}$ map of Lalpur Upazila, March 2024.



(a)



(b)

Fig. 8: Scatter plots between (a) AOD and Wind Speed, (b) AOD and $PM_{2.5}$.

3.2 Air Pollutants variation in and around brick kilns

Pollutant levels (particulate matters) were found to decrease from the center of the brick kiln to the outer wards as shown in Fig. 9. They were highest within 50 meters of all kilns. Readings were taken at 0-50 meters, 50-100 meters and above 100 meters distances from the brick kilns. We conducted this experiment carefully using proper instrument, focusing on short distances because the kilns were very close together, which allowed pollutants to mix between them. The association between pollutants was analyzed using Pearson correlation, with p-values of less than 0.01 and 0.05 considered statistically significant. The results indicated a moderate to strong positive relationship between the pollutants, suggesting that they share a common source, namely, brick kilns.

A very strong correlation was observed between $PM_{1.0}$ and $PM_{2.5}$ (0.815**) and between $PM_{1.0}$ and PM_{10} (0.935**) mentioned in Table 2. A moderate relationship was observed recorded between $PM_{2.5}$ and PM_{10} (0.675*).

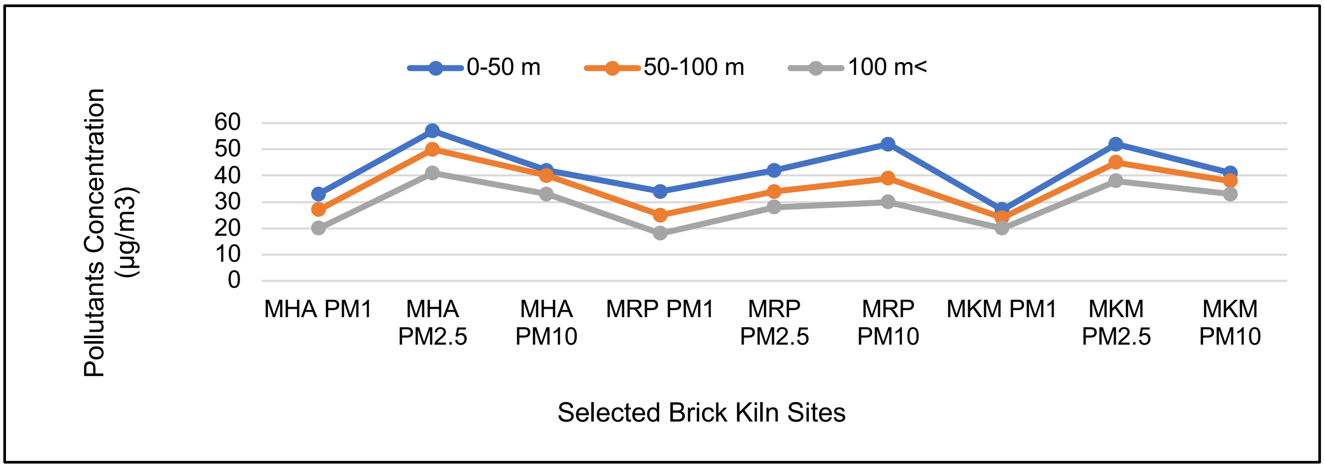


Fig. 9: Variation in concentration of air pollutants in and around of brick kilns (distance vs pollution level).

3.3 Brick kilns induced air pollution

The CO_2, SO_2, and NO_2 emissions were estimated based on the annual coal consumption rate. The greater the coal consumption, the higher the emission levels of these pollutants were observed as mentioned in Table 3. Among the kilns, MHA was noted as the highest consumer of coal, leading to a significantly larger emission of pollutants. With an annual coal consumption of 1,000 tons, MHA emitted 1,985.50 tons of CO_2, 20 tons of SO_2, and 23.03 tons of NO_2. While MRP, which consumed only 600 tons of coal per year, the least among the three kilns, emitted 1,191.30 tons of CO_2, 12 tons of SO_2, and 13.82 tons of NO_2.

Table 3: Amount of CO_2, SO_2, and NO_2 emission from brick kilns based on annual coal consumption

Name of Brick Kiln	**Coal Consumption (ton/year)**	**Emission of Air Pollutants (ton/year)**		
		CO_2	**SO_2**	**NO_2**
MHA	1000	1985.50	20	23.03
MRP	600	1191.30	12	13.82
MKM	700	1389.85	14	16.12

CO, $PM_{2.5}$, and PM_{10} emissions were estimated based on the annual brick production rates. A higher annual brick production rate was observed to increase the emissions of these pollutants. Similar to the yearly coal consumption rate, MHA produced the highest number of bricks among all. Approximately 5 million bricks are produced annually at this location, resulting in significant emissions of CO, $PM_{2.5}$, and PM_{10}, which were found to be 28.7 tons, 102.62 tons, and 342.02 tons, respectively.

The Fig. 10 shows that PM_{10}, which represents coarse particulate matter was the most dominant pollutant compared to others. Due to its weight, it settled around the brick kiln and polluted the local area. In contrast, fine particulate matter like $PM_{2.5}$ and other gases can travel a longer distance with the wind, thereby having less impact on the immediate surrounding.

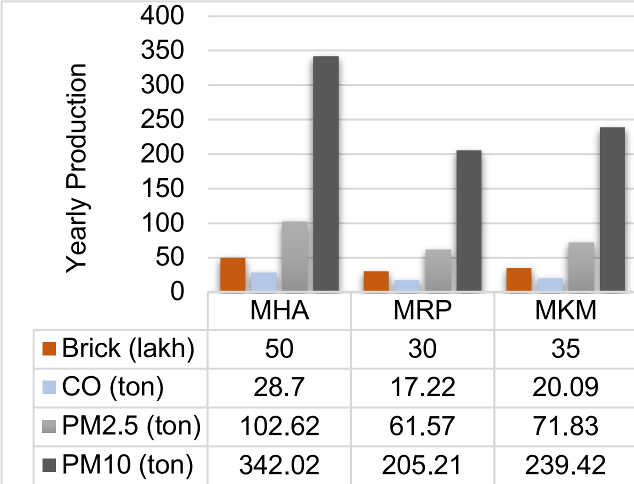


Fig. 10: Amount of CO, $PM_{2.5}$, and PM_{10} emission from selected brick kilns based on annual brick production.

4. DISCUSSION

The Brick kiln industry in Bangladesh contribute to economic prosperity and provide significant employment opportunities. However, the use of low-quality coal and other substandard materials makes these kilns a major source of air pollution in local areas. The present study aimed to identify the polluted areas with brick kilns density and assessing the pollution levels caused by brick kilns in Lalpur upazila. The observed mean AOD values (ranged from 0.459-0.872) were high in the study area illustrated in Fig. 5. The deep blue pixels indicated the highest AOD values (~0.8), which were recorded in the areas with brick kilns density. These areas indicated very poor air quality with high aerosol loading according to the US NOAA's guidelines as presented in Table 4 (Lindstrom, 2018).

Table 4: Potential air quality based on AOD values provided by NOAA

AOD Range	Aerosol Loading Level	Potential Air Quality
0.1-0.15	Typical	Good to Moderate Air Quality
0.15-0.5	Medium	Poor Air Quality
0.5<	High	Very Poor Air Quality

Fig. 7(b) indicates that the average ground level $PM_{2.5}$ concentrations in the study area for March ranged between 41.62 to 63.09 µg m^{-3}. This corresponds to an Air Quality Index (AQI) of 101-150, which is considered unhealthy for sensitive groups and exceeds the standards set by the WHO (5µg m^{-3}) and Bangladesh (15µg m^{-3}). The concentration of particulate matter was found to decline at study sites as the distance from the brick kilns increases. This finding is consistent with another study conducted in Gujrat, which estimated air pollutants from brick kilns using an air dispersion model (Hassan et al., 2012). In this study, the annual estimation of pollutants has been carried out using various relevant emission factors specific to coal-fired brick kilns.

These factors accurately reflected the pollution levels in the study area. As shown in Fig. 11, there is a significant difference between the two estimation methods (EPA's AP-42 and Local observation) when considering the production of 5 million bricks per year. However, the observed values using local estimation factors are more relevant for Bangladesh due to their consideration of local coal types and meteorological conditions.

This study did not include models to estimate the transported pollutants owing to technological limitations. If appropriate instruments had been available, the results would have been more accurate and effective. The dataset used in this research was collected over a few days; however, a more extensive dataset would provide valuable insights into the reliable understanding of the spatial and temporal patterns of pollutants within the study area. Coal consumption and brick production are significantly influenced by the dry seasons. The longer the dry season lasts, the longer the kilns can operate. Consequently, the emission of pollutants also varies from year to year. We made an effort to illustrate the pollution scenario based on the estimated brick production and coal consumption for a typical year.

5. CONCLUSION

This study aimed to achieve all the objectives effectively. The combination of geospatial techniques and in-situ measurements provided in-depth findings regarding air pollution caused by brick kilns in the study area. High levels of aerosol loading were observed, ranging from 0.4590 to 0.8723, which indicated poor air quality. A moderate to strong positive correlation ($PM_{2.5}$ with PM_{10}: $r=0.935$, $p<0.01$; $PM_{1.0}$ with $PM_{2.5}$: $r=0.815$, $p<0.01$; $PM_{1.0}$ with PM_{10}: $r=0.675$, $p<0.05$) was found among various air pollutants, which helped in identifying brick kilns as the primary source of pollution. The use of outdated technology in brick production has led to these kilns emitting significant amounts of various air pollutants annually. These emissions will not cease without proper regulation and the introduction of modern technology.

Although improved technologies exist, their adoption in Bangladesh is hindered by high initial costs, lack of workforce regulation, and insufficient technical knowledge. Therefore, the Government of Bangladesh must establish hard lines to minimize emissions, while ethical change among the owners of the kilns is equally necessary to ensure long-term sustainability. Local authorities should consider establishing buffer zones around kilns to minimize their impact on nearby communities and ecosystems.

Additionally, regular monitoring and enforcement of environmental regulations are crucial to ensure compliance and reduce the overall pollution burden in the region. The findings of this study will help reinforce regulation and policy-making based on the data provided regarding serious pollution scenarios.

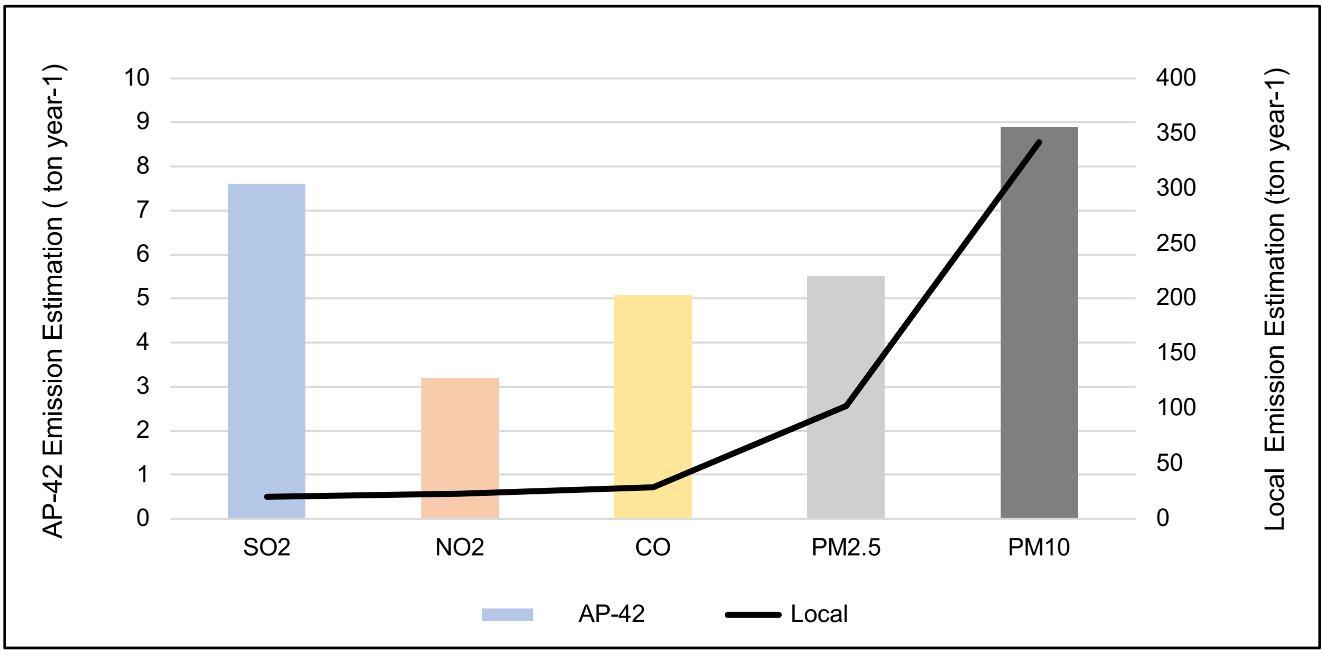


Fig. 11: Comparison of different air pollutants data (AP-42 vs local observation).

ACKNOWLEDGMENTS

The authors express gratitude to NOAA and MODIS mission scientists for providing valuable datasets. We also appreciate insights from other national and international agencies such as the US EPA, NPTEL, and DoE.

AUTHOR'S CONTRIBUTIONS

Kaniz Fatema: conceptualization, methodology, data collection and analysis, visualization, writing. Md. Rahedul Islam: conceptualization, methodology, visualization, review and editing, supervision. Mis. Shukhi Khatun: data collection and analysis, visualization.

REFERENCES

Ahmed, S., & Hossain, I. (2008). Applicability of Air pollution Modeling in a Cluster of Brickfields in Bangladesh. *Chemical Engineering Research Bulletin*, 12(0), 28–34. https://doi.org/10.3329/cerb.v12i0.1495

Akhi, S., Usha, K. F., Basher, F., Auyon, S. T., & Baten, A. (2023). *Estimation of Air Pollutants and Greenhouse Gas Emission from Brick Kilns in Mymensingh*. 21(4), 516–525.

Banglapedia. (2023). Lalpur Upazila. Banglapedia; Asiatic Society of Bangladesh. https://en.banglapedia.org/index.php/Lalpur_

Upazila

Bhat, M. S., Afeefa, Q. S., Ashok, K. P., & Bashir, A. G. (2014). Brick kiln emissions and its environmental impact: A Review. *Journal of Ecology and The Natural Environment,* 6(1), 1–11. https://doi.org/10.5897/jene2013.0423

Chowdhury, M. S. S., Haque, M. J., & Hossain, R. (2022). *GREEN ECO-BRICK, BRICK KILNS EMISSION AND IT'S ENVIRONMENTAL IMPACT* [International University of Business Agricultural and Technology]. https://doi.org/10.13140/RG.2.2.32028.77449

Ettehadi, P., Kaya, S., & Sertel, E. (2019). *Evaluation of Satellite AOD Observations for Monitoring Air Quality.* (8 February 2020). https://www.researchgate.net/publication/337185530

Fuller, R., Landrigan, P. J., Balakrishnan, K., Bathan, G., Bose-O'Reilly, S., Brauer, M., Caravanos, J., Chiles, T., Cohen, A., Corra, L., Cropper, M., Ferraro, G., Hanna, J., Hanrahan, D., Hu, H., Hunter, D., Janata, G., Kupka, R., Lanphear, B., Yan, C. (2022). Pollution and health: a progress update. *The Lancet Planetary Health*, 6(6), e535–e547. https://doi.org/10.1016/S2542-5196(22)00090-0

Guttikunda, S. K., Begum, B. A., & Wadud, Z. (2013). Particulate pollution from brick kiln clusters in the Greater Dhaka region, Bangladesh. *Air Quality, Atmosphere and Health*, 6(2), 357–365. https://doi.org/10.1007/s11869-012-0187-2

Hassan, M., Mumtaz, W., Raza, I., Ahmad, W., Syed, A., & Ali, S. S. (2012). Application of Air Dispersion Model for the Estimation of Air Pollutants From Coal-Fired Brick-. *Science International (Lahore),* 24(4), 141–145.

Health Effects Institute. (2021). *Health Effects Institute Annual Report 2020 Valuing Science, Informing Decisions*. https://www.healtheffects.org/annual-report-2020

Lindstrom, S. (2018). *Quick Guide: Baseline Aerosol Optical Depth. Cooperative Institute for Meteorological Satellite Studies (CIMSS)*, University of Wisconsin-Madison. https://cimss.ssec.wisc.edu/goes/OCLOFactSheetPDFs/ABIQuickGuide_BaselineAerosolOpticalDepth.pdf

Rahman, A. M. (2022). CO2 Emission from Brickfields in Bangladesh: Can Ethical Responsibility by Doing Reduce Level of Emission? *Athens Journal of Social Sciences*, 9(3), 255–272.https://doi.org/10.30958/ajss.9-3-3

Saadat, A. H. M., Hossain, I., & Bhuiyan, M. R. (2008). Estimation of Carbon Dioxide Emission from Brick Kilns in Bangladesh. *ResearchGate*, February 2017, 2–6.

Saju, J. A., Debnath, P., & Nayan, S. B. (2020). Impacts of Air Pollution on Human Health and Environment Due to Brick Kilns Emission : A Review. 2nd International *Conference on Research and Innovation in Civil Engineering*, January, 0–9. https://www.researchgate.net/publication/338544052

Siddik, A. B., Kudrat-E-khuda, Hannan, A., &

Mou, M. A. (2021). Environmental pollution by brick kiln in bangladesh: An analysis of the existing legal framework. *Pollution Research*, 40(1), 345–349.

Skinder, B. M. (2014). Brick kilns: Cause of Atmospheric Pollution. *Journal of Pollution Effects & Control*, 02(02). https://doi.org/10.4172/2375-4397.1000112

World Bank. (2012). *Operationalizing Political Economy Brick Industry in Bangladesh* (English) (Issue 2). http://documents.worldbank.org/curated/en/870271468006631092/Operationalizing-political-economy-brick-industry-in-Bangladesh

World Bank. (2014). *Cleaning Dhaka and Bangladesh's Air.* https://www.worldbank.org/en/news/feature/2014/07/24/cleaning-dhakas-air-bangladesh

World Bank. (2018). *Clean and Resilient Growth in Bangladesh.* https://www.worldbank.org/en/news/feature/2018/09/16/clean-and-resilient-growth-in-bangladesh

Zaman, S. U., Pavel, M. R. S., Joy, K. S., Jeba, F., Islam, M. S., Paul, S., Bari, M. A., & Salam, A. (2021). Spatial and temporal variation of aerosol optical depths over six major cities in Bangladesh. *Atmospheric Research*, 262(March), 105803. https://doi.org/10.1016/j.atmosres.2021.105803