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Air Pollution from Brick Kiln Industry and its Effects on the Kiln Workers and nearby Agricultural Lands

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ABSTRACT

The brick kiln industry plays a crucial role in supporting local economies, particularly in developing countries; however, it is also associated with significant environmental and occupational health concerns. This study aims to identify pollution levels through real-time monitoring. The study found higher concentrations of various pollutants such as PM_{10}, $PM_{2.5}$, CO, TVOC, and HCHO during kiln operation stages. Among the different pollutants, particulate matters ($PM_{2.5}$ and PM_{10}) and CO_2 are invariably high in operational period than pre- and post-operational periods. However, other pollutants like CO, HCHO, TVOC etc are exhibited marginal difference between the pre, post and operational periods. The results also revealed that the heavy metals like Cu decreased, while Zn increased during the operational period, and Cd was not detected. Health issues such as headache, breathlessness, eye irritation, skin problems, asthma, and digestive problems were more prevalent among brick kiln workers. Therefore, brick kiln sector requires a careful monitoring considering both emission quality of kiln and health status of kiln workers.

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INTRODUCTION

The quality of air is deteriorated by various industries activities such as vehicle exhaust, road dust etc (Anjum et al., 2021). However, among these sources, brick kiln industry is a major contributor of air pollution (Abba et al., 2022). Moreover, this particular industry is a significant consumer of coal for heat generation and this industry is treated as informal and largely unregulated (Elsoragaby et al., 2020). Despite the havoc use of coal, nowadays, the brick kilns industries of South Asian region were also using high-caloric industrial waste which discharges hazardous pollutants such as per- and poly-fluoroalkyl substances (Baqar et al., 2024). Previous literature (Rajarathnam et al., 2014) highlighted that mostly developed countries are using energy efficient less polluting brick production units than the South Asian countries those are using most polluting substances for brick production industries (Weyant et al. 2016). According to WHO (WHO 2014), the death per annum is about 6.5 million people. Similarly, World Bank

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Group (2016) report revealed that about 5.5 million people are experiencing premature death due to breathing of poor air.

India is the second-largest brick producer after China (Hamid et al., 2023) and mostly Fixed Chimney Bull's Trench Kilns (FCBTKs) were used which is traditional and outdated technology (Murmu and Patel, 2018). This FCBTKs are less efficient and followed very poor heat transfer mechanism with higher rate of fuel consumption and very high rate of emissions (Abbasi et al., 2021). In contrary, Zig-Zig Kilns are following more cleaner technology and both fuel consumption and emissions are low (Potolovskii et al., 1980). In general, brick kiln industries are established on the agricultural land for easy collection of clay through excavation of surface soil (Kumar et al., 2021). Therefore, the ultimate result of brick kiln industry is the land degradation (Bisht and Neupane, 2015). Previous research also highlighted that brick kiln industry causes more negative impact on the environment with respect to bad air quality, soil health, quality of crops etc (Abbas et al., 2023). Mohan et al. (2024) reported the soil quality around the brick kiln industry of Jammu and Kashmir district, are very poor, with respect of pH, electrical conductivity, organic carbon, organic matter, heavy metals etc. The same researchers were also reported the availability of heavy metals in agricultural land soil (near the brick kiln industry) as Cd > Pb > Cu> Zn> Mn > Fe. These heavy metals can pollute the surrounding soil and subsequently the food chain (Bhat and Gaga, 2022; Sahaya Sakila and Manohar, 2024). The chimneys of brick kiln industry were also released various particulate matter along with airborne heavy metals which settle on nearby agricultural land and migrated throughout the soil ecosystem (Mohan et al., 2024). Apart from soil pollution, brick kiln industry also majorly impacted on air quality through releasing various gaseous and particulate pollutants such as CO_2, CO, SO_2, black carbon, particulate matter (PM)($PM_{2.5}$, PM_{10} etc.), HCHO, VOC etc. (Setu et al., 2024). Very recently, Sarwar et al. (2025) highlighted the impact of brick-kiln emission, particularly on fine particles. Moreover, brick kiln workers were exposed by various airborne pollutants throughout the brick making processes (Nicolaou et al., 2024). Emissions from brick kiln industries have adversely impacted on air pollution and the health of kiln workers and individuals, who lived very close to the kiln. Similarly, agricultural lands nearby kilns were also degraded day by day. However, evidence of their impacts remains limited. Keeping in mind the above fact, present study was conducted to check the air quality near the seven brick kilns along with soil quality of the agricultural land in and around the brick kiln of Hooghly District of West Bengal and also a health study was performed among the inhabitants those are the workers of the brick kiln and nearby inhabitants.

MATERIALS & METHODS

Selection of study area and subjects

The study was conducted from January 2024 to May 2024 covering six brick-kiln industries along with control areas. These areas are under Hooghly District, West Bengal, India. There are approximately 100-150 families in each brick-kiln industry, and they are primarily dependent on agriculture and brick kilns activities.

Study areas

All the six Brick-kilns are located in the Hooghly district of West Bengal (Fig. 1).

Sampling time period and collection of samples

The entire sampling was performed in three stages and the stages are: Pre-operational sampling, Operational sampling, and Post operational sampling. The air pollutants were

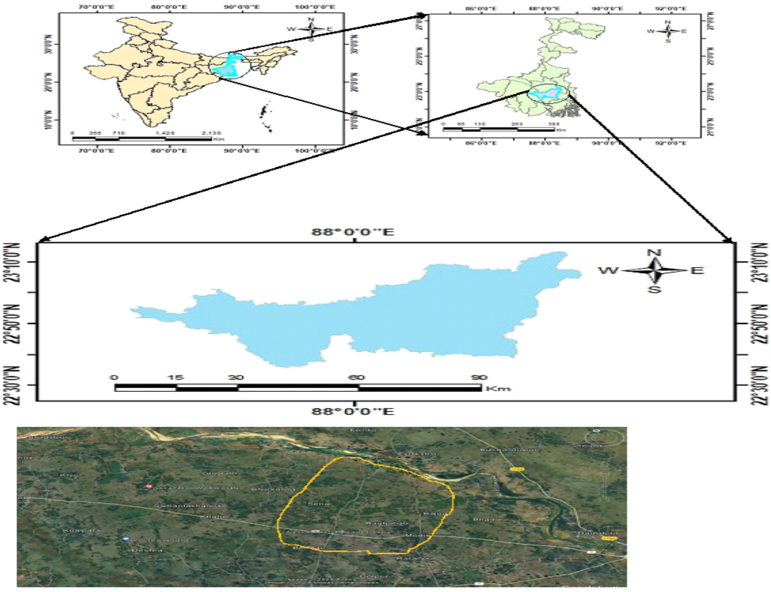

Fig. 1. Study area map

monitored at least 10-15 m away from the stack. We have two digital air pollutant measurement meters (BIS, 1985). The parameters such as $PM_{2.5}$, PM_{10}, CO, CO_2, TVOC, and HCHO along with temperature and humidity were measured by following standard method. Digital meter (SMILEDRIVE) was used for particulate matters and gaseous components. Similarly, soil samples were collected from the different sides of brick kiln. The surface soils were collected at least 50-60 m away from the stack.

Measurement of air quality

Measurement of temperature and relative humidity in the brick kiln environment

The brick kiln's temperature and relative humidity were recorded. Additionally, it was recorded in the kiln at the pre-, during, and post-operational phases. The HTC-1 Digital Hygrometer Thermometer Humidity Meter (Model No. AP-IS11A056FBA) was used to take this measurement. Before every monitoring, this instrument underwent calibration (accuracy: ± 0.1 °C; range: 0 °C to +70 °C).

Gaseous pollutants

Brick kilns produce a variety of air pollutants in the atmosphere. Average emission factors per 1,000 bricks were 6.35–12.3 kg of CO, 0.52–5.9 kg of SO_2 and 0.64–1.4 kg of particulate matter (PM_{10}). The total emissions from the brick manufacturing in the Greater Dhaka region has been estimated at 23,300 t of $PM_{2.5}$, 15,500 t of sulphur dioxide (SO_2), 302,000 t of carbon monoxide (CO), 6,000 t of black carbon and 1.8 milliontons of CO_2 emissions from the clusters of brick kilns, to produce 3.5 billion bricks per year. (Skinder, 2014).

Measurement of HCHO, TVOC, Relative Humidity and Temperature

Formaldehyde (HCHO), Total Volatile Organic Compounds (TVOC), Relative Humidity, and Temperature were measured by SMILEDRIVE® portable air quality pollution meter (Model No. SDMIS915I1197CH1704). These measurement was taken during pre-operational, operational, and post-operational time. Before measurement, the meter was calibrated according to the manufacturer's guidelines.

Measurement of particulate matter ($PM_{2.5}$)

$PM_{2.5}$ samples were taken from the sampling site at a flow rate of 2 L/min using an air sampler (SKC AirChek Touch, USA) and a pre-weighed 37 mm quartz glass filter. TSI flow meters were used to calibrate all equipment, both before and subsequent to field calibration. The filter paper was wrapped in aluminium foil, sealed in a filter cassette, and refrigerated at 4 °C to avoid photodegradation. The data of particulate matter and gaseous contaminants were collected every five minutes for a total of one hour every day.

Nearby soil and rubbish characteristics

The soil and rubbish samples were collected from each brick industry. A sterile zipper bag was used to collect the soil and rubbish samples. The collected soil samples were dried in shade followed by grinding and sieving to get uniform size. Then after sieving, soil and rubbish were stored for further analysis.

Measurement of soil electrical conductivity

A weight of 20 g air-dry soil was placed into a 100 mL beaker along with 50 mL distilled water. The soil mixture was stirred at regular intervals for 1 hour. After completing the settle for 30 minutes it was filtered through a dry Whatman No. 42 filter paper electrical conductivity was measure by conductivity meter (Systronics 304).

Measurement of organic Carbon

Soil organic carbon content was estimated following Walkley–Black's rapid titration method (Walkley and Black 1934).

Measurement of different heavy metals

The dried sam-ples were separately grinded to powder and 0.1 gm of the grinded sample was digested with concen-trated HNO_3: $HClO_4$; (V/V 9:1) for 2 h. Residues were filtered through Whatman filter paper and dilutedto 100 ml with double-distilled water. Concentrations of heavy metals from the digested sampleswere analyzed using Atomic Absorption Spectrophotometer (GBC Avanta) (Dey and Mondal, 2016)

Statistical analysis

The statistical calculation was performed by the statistical package Minitab version 17.0 and all graphs were produced by OriginPro 8.5 software. The data were presented as mean ± SD and ANOVA along with posthoc analysis to establish the significant difference. The reported p value was considered as $p < 0.05$ and $p < 0.01$ as significant.

RESULTS AND DISCUSSION

Analysis of Temperature, humidity, and air quality near brick kiln manufacturing area and control area

The pollutants (Table not supplied) such as formaldehyde (HCHO), total volatile organic compounds (TVOC), carbon mono-oxide (CO), carbon dioxide (CO_2), particulate matter ($PM_{2.5}$ and PM_{10}), temperature, and humidity were recorded along with the temperature and humidity as well near the brick manufacturing area and the results have been presented in (Table not supplied). During seasonal variation (pre-operational -January, operational-March, post-operational-July), aerial temperature was recorded during the pre-operational, operational, and post-operational time near the brick kiln industry. Table 1 clearly indicate that the mean temperature and other parameters in all the studied areas including control area under different operational periods. Again one way ANOVA analysis revealed that all the parameters are statistically significant ($p < 0.001$) among different operational periods (Table 1). Results also revealed that among the different parameters, only particulate matters ($PM_{2.5}$ and PM_{10}) are significantly higher in brick manufacturing areas than control area. It is also interesting to note that the particulate matter in operational period is much higher than pre and post- operational periods (Table 1). However, other parameters like CO, CO_2, formaldehyde (HCHO), and TVOC levels are exhibited marginal difference between operational and pre- and post-operational period.

Similarly, from the Figure 2a –f, it is clearly visible that the fluctuation of different pollutants concentration during different operational stages. Figure 2a-f also demonstrated the parameters HCHO, TVOC and CO_2 are high in all operational conditions in comparison to $PM_{2.5}$, PM_{10} and CO levels. However, these observations were endorsed by ANOVA also (Table 1). Therefore, these air pollutants parameters definitely impacted on the environment in different operational periods. Le and Oanh (2010) reported that CO could be a contributing factor to poorer air quality as it keeps cold, dense air close to the ground and prevents carbon monoxide from rising through warm air. The World Health Organisation states that an 8-hour average of 9 parts per million of CO is the acceptable exposure threshold. All the time of recorded data the concentration of CO was higher than the normal range. Even though in summer time, a significant quantity of CO was emitted from the brick kiln during operation because the low-quality coal burns. As to the ACGIH, physical signs of CO exposure might be observed in individuals exposed to a concentration of 25 ppm for 6-8 hours. The CO content is still quite low in the post-operational period because of the off season and the seasonal variation where the CO goes upward with the warm air. Various symptoms such as headache, dizziness, nausea, confusion, and shortness of breath could happen due to excessive exposure to CO. Excessive breathing of CO also leads to direct poisoning (Manisalidis et al., 2020). Carbon monoxide has a tremendous affinity towards hemoglobin than oxygen. Therefore, serious poisoning may occur in the vein during exposure to high levels of Carbon monoxide for a longer time.

Table 1. Various studied parameters during different operational periods and ANOVA analysis

Parameters	**Pre- Operational (November 2023)**		**Operational (March 2024)**		**Post-Operational (July 2024)**			
	Brick kiln area	Control area	Brick kiln area	Control area	Brick kiln area	Control area	F value	P val
Temperature (Mean ± SD)	31.512± 1.836	29.420±0.642	36.164± 2.345	37.153±1.279	38.182± 1.912	37.053±0.696	14.01	< 0.0
Humidity (Mean ± SD)(%)	40.385± 2.881	36.700±0.851	51.551± 3.177	44.190±1.777	53.408± 2.589	52.657±1.040	29.66	< 0.0
CO (Mean ± SD) (ppm)	16.095± 3.084	11.893±0.157	20.335± 0.581	15.990±0.522	11.647± 0.699	10.690±0.473	27.38	< 0.0
CO_2 (Mean ± SD) (ppm)	530.819± 4.408	522.793±0.921	539.006± 7.079	530.110±0.456	522.024± 1.258	517.243±0.800	15.21	< 0.0
HCHO (Mean ± SD) (ppm)	0.843± 0.043	0.831±0.003	0.933± 0.019	0.854±0.006	0.869± 0.004	0.857±0.006	14.53 46.35	< 0.0
$PM_{2.5}$ (Mean ± SD) (µg/m³)	26.479± 2.882	15.797±3.209	48.193± 9.023	19.250± 0.680	15.313± 0.866	13.893±0.225	140.64	<0.0(
PM_{10} (Mean ± SD) (µg/m³)	32.550± 2.611	19.650±2.305	65.896± 7.654	22.300± 0.557	17.213± 0.819	16±0.340	31.12	< 0.0 < 0.0
TVOC (Mean ± SD) (ppm)	4.808±0.091	4.509±0.016	5.273± 0.161	4.724±0.071	4.498± 0.036	4.659±0.075		

As a result, hypoxia, ischemia, and cardiovascular diseases are observed (Manisalidis et al., 2020). However, CO also affects greenhouse gasses which are intimately connected with global warming and climate and subsequently increase the soil and water temperatures and extreme weather such as storms (Emberson et al., 2018). Similarly, CO_2 is another dangerous pollutant and highest concentration was observed during operational stage of brick kiln industry.

According to Saha et al. (2020), the biyearly mean concentration of CO_2 in ambient air samples was 504.56 and 651.37 ppm in Rajshahi and Gazipur during the operational time, of brick kilns respectively. It is still safe for human health and is within allowable limits. In both cases, the CO_2 value remains under the normal exposure level. US Environmental Protection Agency (EPA) identified 187 hazardous air pollutants, among them formaldehyde is a dangerous carcinogenic in the outdoor air (Chen et al., 2021). For near brick kiln areas, during the operational time, the concentration of formaldehyde in the air was varied from (0.914 to o.952 ppm), and in pre-operational (0.8 to 0.866 ppm) and post-operational (0.865 to 0.873 ppm) data (Table not supplied). ANOVA analysis revealed that there is a significant difference ($p< 0.001$) between the three operational periods (Table 1).

A weight of evidence-based formaldehyde exposure limit of 0.1 ppm (100 ppb) is recommended as an outdoor air level for all individuals for odour detection and sensory irritation. Exposure to a mean formaldehyde concentration of 1 µg/m³ may cause nasopharyngeal cancer (EPA, 2011). It has recently been suggested by the International Agency for Research on Cancer (IARC), the National Toxicology Program (NTP), and the US Environmental Protection Agency (US EPA) (Golden, R. 2011). So the HCHO level is too high near the brick kiln areas during entire sampling period. Therefore, there is concern for both the safety of the workers and the homes nearby. Formaldehyde is a colourless, flammable gas that is emitted when wood and coal are burned. Inhaling formaldehyde fumes can result in burning in the nose, throat, and eyes as well as watery eyes. Additional symptoms include rashes and skin irritation, nausea, tightness in the chest and coughing, upset stomach, and difficulty breathing. People who have asthma may get an attack if they breathe in formaldehyde. Among the various pollutants, particulate matter is most crucial. However, the present result showed a much lower level of $PM_{2.5}$ than the earlier result as reported by Ahmad et al., (2024) near the brick kiln site (509 ± 32.3 µg/m³) in Lahore, Pakistan. As per WHO 24-hour average exposures of $PM_{2.5}$ should not exceed 15 µg/m³ more than 3 - 4 days per year. There are several reasons for this, including the custom of burning agricultural waste in crop fields and the improper use of open-flame kitchens in India. During winter, ambient air is very dense, and PM particles remain on the ground during the winter and are unable to go forward, moreover, the PM also acts as a vector of many pollutants such as heavy metals, PAH, nitrates, sulphates, ammonia, etc. (Chen et al., 2021; Fan et al., 2021; Zhang et al., 2021). The primary fuel used in brick kilns is coal, which emits SO_2 and particulate matter (PM) (Sarwar et al., 2025). This leads to poor air quality and related health issues such as lung cancer, trachea, bronchus, and asthma attacks, as well as lower respiratory infections and stroke. (Guttikunda et al., 2013) stated that brick kilns emitted $PM_{2.5}$ and it is considered harmful to humans because it has the capacity to travel deeper into the respiratory system and cause premature mortality and respiratory ailments (Sahaya Sakila and Manohar, 2024). It is noted that the PM_{10} concentration exceeded the National Ambient Air Quality Standards (15 µg/m³) (Nazarenko et al., 2021) at all sampling locations. The study results showed that the brick kiln emitted the highest PM_{10} among the three sites (Le and Oanh, 2010). Air pollution in brick kilns is produced both through the stack emissions as well as the fugitive emissions. PM_{10} is likely to deposit on the surfaces of the larger airways of the upper region of the lung. Particles deposited on the lung surface can induce tissue damage and lung inflammation (Joshi et al., 2025). Additionally, Ganguly et al. (2025) reported a statistically significant association between blood glucose levels and particulate matter exposure ($p < 0.05$).

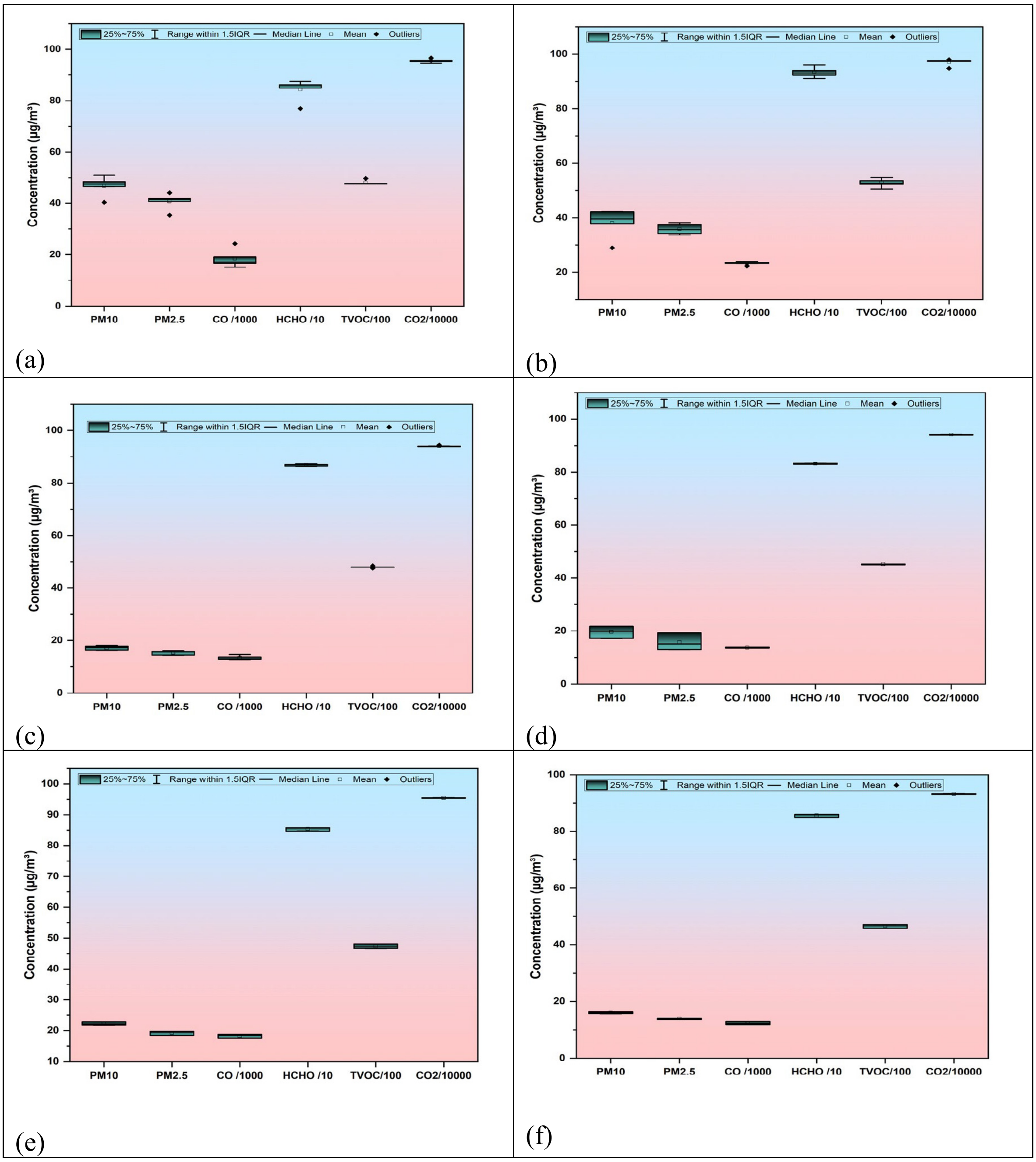

Fig. 2. (a) Box plot showing pollutant concentration of different area of brick-kiln industry pre-operational time. The box edges are quartiles, so the difference between the third and first quartile is regarded as the interquartile range (IQR). The median is marked by a line within the box,(b) Box plot showing pollutant concentration of different area of brick-kiln industry operational time. The box edges are quartiles, so the difference between the third and first quartile is regarded as the interquartile range (IQR). The median is marked by a line within the box. (c) Box plot showing pollutant concentration of different areas of brick-kiln industry post-operational time. The box edges are quartiles, so the difference between the third and first quartile is regarded as the interquartile range (IQR). The median is marked by a line within the box. (d) Box plot showing pollutant concentration in control areas pre-operational time. The box edges are quartiles, so the difference between the third and first quartile is regarded as the interquartile range (IQR). The median is marked by a line within the box., (e) Box plot showing pollutant concentration in control areas operational time. The box edges are quartiles, so the difference between the third and first quartile is regarded as the interquartile range (IQR). The median is marked by a line within the box., (f) Box plot showing pollutant concentration in control areas post-operational time. The box edges are quartiles, so the difference between the third and first quartile is regarded as the interquartile range (IQR). The median is marked by a line within the box.

Present study also measures the level of volatile organic compounds. Volatile organic compounds such as Toluene, Benzene, Xylene, etc. are strongly associated with cancer in human beings (Alibekov et al., 2025). Study results also revealed the concentration level of TVOC is high near the brick kiln areas. (Hagerman et al., 1997) reported that TVOCs are a vital group of air pollutants, which are often referred to as toxic or hazardous air pollutants. TVOCs also play a vital role in the formation of ozone and fine particulate matter by photochemical smog and also contribute to the most serious impacts in human health (Hagerman et al., 1997). Total Volatile Organic Compounds (TVOC) are a group of compounds containing carbon that have a high vapour pressure present in the air. There are abundant VOC emitted from everyday activities among which some are colourless and some odorless and some are toxic. Thus, it is unsettling for the workers and neighbouring homes. Frequent health consequences linked to volatile organic compounds (VOCs) exposure include headaches, nausea, dyskinesia, and irritation of the eyes, nose, and throat. Some VOCs can harm the kidneys, liver, or central nervous system. Some, like formaldehyde and benzene, are known or believed to be carcinogenic. Exposure to volatile organic compounds (VOCs) can cause skin rashes, watery or itchy eyes, headaches, exhaustion, disorientation, breathing difficulties, nausea, vomiting, nosebleeds, and irritation of the throat and nose.

Analysis of pH and conductivity of soil and rubbish waste from selected areas

Soil samples were collected from agricultural land which are in the vicinity of (2.0 km) brick kiln industry, along with three control areas (Table not supplied). The parameters like soil pH, soil conductivity, rubbish pH, and rubbish conductivity were measured both in pre-operational time and post-operational time. In pre-operational time, the brick kiln area's pH varied from 6.521 to 7.251. In the post-operational time, this value decreases from 6.040 to 6.428. It is clearly visible that due to the operational period, the soil pH became acidic in each and every brick manufacturing area with a large decrease in value. Whereas in the pre-operational period, the control area's pH was 7.018 to 7.341 and in the post-operational period it was 6.823 to 6.898. The pH value of farm soil samples is followed in the order: of preproduction season> post-production season > production season (Saha et al., 2021).

Results also revealed a similar type of outcomes where pre-operational pH was higher than post-operational pH. The pH was slightly higher due to the accumulation of air pollutants in the air along with some other factors. (Saha et al., 2021) reported that the brick kilns emitted toxic pollutants containing sulphur dioxide (SO_2), oxides of nitrogen (NO_X), and other different gaseous compounds (Abbas et al., 2021). The pH of some farm soil samples was a critical condition for crop production (Holland et al., 2019). These compounds might be responsible for the deterioration of the air quality and acid rain syndrome surrounding the brick kiln areas, which hamper the soil pH. So, it is proved that the due to brick kiln the soil became acidic. Acidification of the surrounding soil can result from the production of sulphur compounds and other pollutants during brick kiln operations, which reduce the pH of the soil. This may impair soil fertility, interfere with plant development, and upset the microbial balance.

Analysis of heavy metals

The concentration of Cu in brick kiln areas varied from 0.134 to 0.380 ppm in the pre-operational season and 0.289 to 0.481 ppm in the post-operational period (Table not suppled). Whereas in control area, the concentration of Cu was recorded as 0.200 to 0.208 ppm and from 0.200 to 0.209 ppm during the pre-operational and post-operational period, respectively. The Cu concentration has increased in all brick kiln manufacturing areas. The results of comparative study showed that available Cu status was higher in brick field than that of agricultural field.

This might be due to accumulation of brick field wastes and particulate matters (Majumdar et al., 2023). In the case of rubbish waste, the concentration of Cu varied from 0.2238 to 0.512 ppm in the pre-operational stage and from 0.299 to 571 ppm in the post-operational stage. These might occur for several reasons, such as the fact that huge amounts of soil must often be removed to extract clay and other elements needed to produce bricks, which can disrupt naturally occurring heavy metal deposits. The concentration of Zn in brick kiln areas varied from 0.311 to 1.726 ppm in the pre-operational season and 0.671 to 1.771 ppm in the post-operational stage (Table not supplied). Whereas the control area has a concentration during the pre-operational stage of 0.684 to 0.926 ppm and from 0.699 to 1.038 ppm in the post-operational stage following the same process in all cases, the concentration of Zn has been increased in all the cases measured in brick kiln areas. Natural clays used in brick-making may already contain trace amounts of heavy metals like Zn. When these clays are processed and the by-products are returned to the environment, they can concentrate heavy metals in certain areas, particularly around extraction sites. In the case of rubbish waste, the concentration of Zn varied from 0.193 to 0.968 ppm in the pre-operational stage and from 0.757 to 1.456 ppm in the post-operational stage. The selected heavy metal concentration in the farm soil samples followed in the order: production season> post-production season> pre-production season (Saha et al., 2021). On the other hand, none of the soil samples indicate the existence of cadmium (Cd).

Analysis of soil organic carbon

The organic carbon of the surface soils were estimated and it was varied from 0.407% - 0.495%. Similarly, in control area, soil organic carbon varied from 0.547% - 0.562% (Table not supplied). Crop residues that are left on the soil's surface help to maintain soil moisture and add more carbon to the soil

Self-reported respiratory and other problem

From the self-reported health symptoms (Table 2) it was observed that 45% of inhabitants of brick kiln areas are facing eye irritation problems whereas only 10% of inhabitants of control areas are suffering from these problems which are statistically significant ($p < 0.021$). This is because of the smoke stays for a long time and is exposed directly to the eyes. Around 60% of brick kiln area's people suffered from headache problems whereas, this number is much less for control areas people (20%) which is also statistically significance ($p < 0.013$). Exposure to biomass fuel smoke is significantly associated with the prevalence of symptoms of headaches (Lin et al., 2022). It is also observed that 20% of inhabitants of brick kiln areas are facing sleeping abnormality problems whereas only 5% of control areas are suffering from these problems which are statistically significant ($p < 0.018$). Most of the people (30%) in brick kiln areas were suffering from asthma problems whereas this number is very low for control areas people (10%) which is also statistically significance ($p < 0.012$). This is probably due to the exposure of particulate matter released from the brick kiln stack mainly in the operational phase. Around 60% of brick kiln area's people suffered from allergetic problems whereas this number is much less for control areas people (15%) which is also statistically significance ($p < 0.001$). It is recorded that 55% of households near the brick kiln suffered from breathlessness whereas this number is very low for control areas people (20%) which is also statistically significant ($p < 0.026$). This is due to the exposure of particulate matter which can penetrate deep into the lungs and cause inflammation and damage to the airways. CO is a colorless, odorless gas that can bind to hemoglobin in the blood, preventing it from carrying oxygen. This can lead to shortness of breath. Chronic exposure to combustion is associated with an increased prevalence of respiratory symptoms (Mitra et al., 2025b). Exposure to smoke is responsible for

Table 2. Self-reported health symptoms associated with brick kiln workers

Parameter	Area Type	Frequency (%)	ODD Ratio		
			OR	95% CI	P Value
Irritation of eyes	Near brick kiln (n=20)	9 (45)	7.36	1.337 -40.54	< 0.021
	Control area(n=20)	2 (10)			
Headache	Near brick kiln (n=20)	12 (60)	6	1.458 -24.686	< 0.013
	Control area(n=20)	4 (20)			
Sleeping abnormality	Near brick kiln (n=20)	4(20)	4.75	0.481 -46.907	< 0.182
	Control area(n=20)	1 (5)			
Asthma	Near brick kiln (n=20)	6 (30)	3.86	0.672 -22.11	< 0.012
	Control area(n=20)	2 (10)			
Skin related problems	Near brick kiln (n=20)	13 (65)	9.33	2.1798 -39.963	< 0.002
	Control area(n=20)	4 (20)			
Allergy	Near brick kiln (n=20)	12 (60)	13.22	2.789 -62.671	< 0.001
	Control area(n=20)	3 (15)			
Breathlessness	Near brick kiln (n=20)	11 (55)	4.88	1.198 -19.942	< 0.026
	Control area(n=20)	4(20)			
Chronic Cough	Near brick kiln (n=20)	4 (20)	4.75	0.481 -46.907	< 0.182
	Control area(n=20)	1(5)			
Digestive problem	Near brick kiln (n=20)	14 (70)	3.5	0.944 -12.966	< 0.06
	Control area(n=20)	8 (40)			
Weakness	Near brick kiln (n=20)	11 (55)	4.88	1.198 -19.942	< 0.026
	Control area(n=20)	4 (20)			

respiratory health problems in women (Sana et al., 2019). About 20% of households near brick kilns are suffering from runny nose health symptoms which is also statistically significant ($p < 0.001$) (Mitra et al., 2025a). It was also noticed that 20% of near brick kiln areas were suffering from a chronic cough and only 5% of participants were suffering (Shaikh et al., 2012). This is due to the exposure of fine particulate matter ($PM_{2.5}$) in smoke. The majority of inhabitants (70%) expressed their digestive problems near brick kiln areas and only a few (40%) were recorded in controlled areas. From the data, it is also noticed that 55% people of near brick kiln areas suffer from weakness, whereas only 20% were suffered with same symptoms in control areas (Table not supplied). Some other symptoms such as tuberculosis (6%), Chronic Phlegm, Chronic bronchitis, were also reported from households residing near brick kiln areas (Table 2). However, very few of the residents in the control areas were reported the above symptoms.

CONCLUSION

The finding of the present study highlighted that the pollution load in operational time is higher than in post-operational and pre-operational time. Sometimes the pre-operational value shows greater, because the pre-operational time is winter. During winter, and low wind flow support to stagnant the pollutants near the ground. The measurement also revealed that the pollutants such as formaldehyde, TVOC, and particulate matter are present above the normal ambient level in the brick kiln areas due to the incomplete combustion of solid fuels. However, much lower level of pollutants loads was recorded in the control areas. This is because the control areas did not emit too much pollutants. Brick kilns generate huge pollutants because biomass fuels are not completely burned. Study results also established significant correlations between particulate matter ($PM_{2.5}$ and PM_{10}). ANOVA analysis of all the pollutants significantly differs between different operational stages. It was also recorded that the soil became acidic due to the brick kilns. Upon reviewing the survey data, it was discovered that the majority of the biomass users were affected by various respiratory such as shortness of breath, eye-related health symptoms, wheezing, runny nose, sleeping abnormality, asthma, tuberculosis, allergy, eye irritation, etc. Therefore, different strategies should be implemented to reduce kiln's air pollution e.g., change the brick kiln technologies, use of renewable energy sources as much as possible, and establishment of brick kilns away from the livelihood. Moreover, the use of new technology plants can reduce the pollution load. Although it is not easy to provide greener fuels to every Kiln. Therefore, future research is extremely important for the development of new innovative strategies to curve the pollution level.

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STATEMENT AND DECLARATIONS

Ethical Approval

Not applicable.

Consent to Participate

All authors expressed that they have fully devoted themselves for this particular research work.

Consent to Publish

All authors gives their consent to publish this work.

Availability of data and materials

The entire experimental data will be provided on request without any reservation.

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

AUTHORSHIP CONTRIBUTIONS

Naba Kumar Mondal: Visualization, Investigation, Software, Validation, Supervision. **Nilanjan Koley**: Experiment conducted in field and laboratory, **Pradip Mitra**: Experiment conducted in field and laboratory, Manuscript preparation

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