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QUANTITATIVE ASSESSMENT OF ENVIRONMENTAL AND HEALTH RISKS FROM BRICK KILN EMISSIONS USING HAZARD QUOTIENT AND HEALTH INDEX IN RUPSHA CLUSTER, KHULNA

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ABSTRACT

A comprehensive health risk assessment was utilized in the study for quantifying the non-carcinogenic effects of the particulate matter and other gaseous pollutants, which were emitted from the brick kilns, present in the Rupsha cluster of Khulna District. The estimated hazard quotient (HQ) exceeded the safe limit (HQ>1) for both PM_{10} and SO_2 during active running period of the kiln, which signified the potential of health risk. Especially, the HQ for PM_{10} increased from 0.49 (brick kiln off) to 1.41 (brick kiln on) and HQ for SO_2 ranged from 2.46 (brick kiln off) to 5.75 (brick kiln on). Among the 6 pollutants, SO_2 showed the most significant and alarming HQ values indicating several health risks – including hypoxia, respiratory irritation and cardio-vascular health complications – in both active and inactive period of the kilns. High Air Quality Index (AQI) values found from the data obtained in the brickfield vicinity strongly confirms the severity of pollution, with AQI being 179 during active burning period of the kiln, which comes under “Unhealthy” category. The value indicates the drastic deterioration of air quality around the brick kilns during active burning process of the bricks. Ground-level concentrations were only slightly impacted by ambient air conditions, according to correlation analysis, indicating high local emission dominance. An extremely unhealthy microenvironment is produced by the presence of dust, soot, and black carbon from incomplete combustion processes. Long-term exposure to such contaminated air greatly increases the risk of both non-carcinogenic and potentially carcinogenic health impacts for workers and households in the vicinity. During kiln operation, the total hazard index (HI) increased from 3.76 to 8.38, indicating a significant potential of non-carcinogenic risk. The significant concentration of PM_{10} and SO_2 in the total HI emphasizes how crucial those pollutants are for the declination of health. The results from the study describes the crucial need for mitigating the growing dangers of air pollution to the public health using well-established emission control systems, cleaner fuel consumption and suitable air quality monitoring.

Keywords: *Hazard Quotient, Health Index, Brick Kiln Emissions, Particulate Matter*

1. INTRODUCTION

The Global Air Quality Guidelines (AQGs) are established and regularly updated by World Health Organization (WHO), for the purpose of learning the far-reaching and dangerous health impacts of air pollution. According to the AQGs by WHO, Carbon monoxide (CO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), ozone (O_3), and particulate matter ($PM_{2.5}$ and PM_{10}) are the six main air pollutants. The death toll due to air pollution is very high and the death estimation stays on par with other global health risks like tobacco consumption and poor diet. World Health Assembly acknowledged the significance of air pollution, as a potential risk factor for illnesses like cancer, heart disease, asthma and chronic obstructive pulmonary diseases.

Nearly 90% of the 1500 billion bricks produced worldwide each year come from Asia. South Asia is the second-largest brick-producing region after China, with an estimated 310 billion bricks manufactured yearly. India, Pakistan, Bangladesh, and Nepal are the world's top manufacturers of bricks, accounting for over 25% of global production. The brick kiln industry is labor-intensive in low- and middle-income countries (LMICs), and most kilns are very polluting and energy inefficient. The fixed chimney Bull's trench kiln (FCBTK) is the most used technology in South Asia (Eil et al., 2020). It is also one of the most polluting technologies because of its poor heat transmission and high fuel consumption (Hamid et al., 2023). Only 1 in 1500 kilns in South Asia has been reported to have mechanized and efficient technology. As a result, there is a significant number of brick kilns, which operates in an un-organized way giving way to the possibility of significant air pollution in the vicinity of the kilns. The problem of significant air pollution exacerbates due to lack of management and emission control system by the government. (Eil et al., 2020). But presently, there are changes occurring in certain places where people acknowledge the adverse effects of air pollution and wants to protect the health of people and the environment. Due to the far-reaching effects of air pollutants on human health, a significant number of Government agencies and international organizations are encouraging the shift to more modern, less polluting technologies. A lot of brick kiln owners have chosen to convert their traditional FCBTKs to zigzag kiln (ZZK) technology, which is simple, affordable, and can drastically lower fuel costs because of its increased energy efficiency. (Abbas et al., 2022);(Bashir et al., 2023).

During the brick-making process, workers are exposed to a range of airborne pollutants. An estimated 16 million workers are exposed to these harmful pollutants in South Asia alone. Brick kilns are a major source of ambient air pollution, contributing up to 91% of total PM emissions in some cities. (Eil et al., 2020). As part of the airborne pollutants, it has been noted that Clay and brick dust have high concentrations of silica, and smoke from brick fires contains particulate matter (PM) and gaseous pollutants include sulfur dioxide (SO_2), carbon monoxide (CO), and nitrogen oxides (NO_x). (Eil et al., 2020). Compared to those people who were not exposed to such significant air pollution, brick kiln workers regularly reported health problems associated with increased respiratory symptoms, musculoskeletal problems, inflammation, and reduced lung functions. Due to repeated exposure to such harmful airborne pollutants, brick kiln workers are known to belong to the group where they are most likely to develop chronic respiratory symptoms and illnesses. (Boschetto et al., 2006).

Exposure to urban particle matter (PM) has been linked to a number of detrimental health impacts, according to epidemiological research. While short-term exposure peaks can exacerbate a number of respiratory conditions, such as bronchitis and asthma, and alter heart rate variability, long-term exposure to high PM concentrations raises the risk of lung cancer, respiratory disorders, and arteriosclerosis (Samet & Zeger, 2000). Comparing the bigger particles (>30 mm) to the lower size fractions (PM_{10} and $PM_{2.5}$), which have aerodynamic diameters of less than 10 and 2.5 mm, respectively, the larger particles are suspended for a comparatively short duration (Squadrito et al., 2001).

Micron and sub-micron particles from both natural and man-made sources, including wind-blown soils, sea spray, and burning fossil fuels, make up the majority of fine particle pollution in the atmosphere. ((Cohen, 1998); (Cohen et al., 1996)). The main source of $PM_{2.5}$ (fine particulate matter) is the burning of fuels, such as coal, biomass, and gasoline and diesel. (Arden Pope & Dockery, 1999). Because of its tiny size and chemical complexity, $PM_{2.5}$ and even smaller ultrafine particles (<0.1 mm) can overcome the respiratory tract's defensive systems and enter the alveoli, causing significant health repercussions as compared to PM_{10} and TSP. ((Squadrito et al., 2001); (Vinitketkumnuen et al., 2002)). Because of their characteristics and pervasiveness in the atmosphere, carbonaceous aerosols are among the most significant PM constituents ((Nunes & Pio, 1993)).

Particulate matter (PM) with an aerodynamic diameter smaller than 10 micrometers (PM10) exhibited detrimental effects on children's and adults' health both immediately and over time. (Heinrich, 2003); (Arden Pope & Dockery, 1999);(Karr et al., 2006)). Additionally, according to UNICEF, cooking indoors with polluting fuels is responsible for a startling 500,000 child fatalities, mostly in Asia and Africa. This is due to exposure to particulate matter, which can lead to cancer and respiratory and cardiovascular diseases.

The two most important gaseous pollutants that have an impact on regional and global air quality, human health, ecological circumstances, and climate change are nitrogen dioxide (NO_2) and sulfur dioxide (SO_2). (Ghosh et al., 2017). NO_2 is regarded as a serious contaminant by the World Health Organization (WHO) and the United States Environmental Protection Agency (US EPA). (Melamed et al., 2016). Because both NO_2 and SO_2 are toxic, they seriously endanger biodiversity, and a combination of the two is more detrimental to plants (Barker and Tingey, 2012).

Additionally, SO_2 causes ozone depletion, acid rain, human cancer, and respiratory diseases including asthma(Niu et al., 2011).The health issues caused by SO_2 emissions include bronchitis, bronchospasm, mucus production, and respiratory irritation. Since high NO_2 levels have been shown to reduce agricultural productivity and plant development efficiency, they are detrimental to vegetation and crops. Acid rain and soil acidification are two negative environmental effects that seem to be linked to SO_2 emissions. (T.-M. Chen et al., 2007). Two major effects of NO_2 and SO_2 pollution are eutrophication and global warming. There have been reports of a number of wildlife problems, including the toxicity of the air, soil, water, or entire ecosystems, which can cause health problems for animals including infertility. The burning of fossil fuels in industry, the combustion of coal and gas, vehicle exhaust, burning of biomass, and the production of electricity are the main sources of NO2 emissions. However, residential heating, burning sulfur-containing fossil fuels, electricity generation, industrial processes, power plants, and burning biomass all emit SO_2. (Ghosh et al., 2017).

A HQ (Hazard Quotient) for each particular component is used in the research and the final output was shown using HI (Health index). The U.S. EPA states that a THQ (Target Hazard Quotient) value of less than one indicates a non-significant risk. (Wang et al., 2015). Like the THQ, an HI value larger than 1 ($HI > 1$) denotes a higher probability of a toxicological reaction to the combination of substances and has a significant harmful effect on the health (Hertzberg & Teuschler, 2002).

(Abulude et al., 2022) state that variables that specify the concentration of certain pollutants have a significant impact on the IAQ (Indoor Air Quality) of building space. In the study by, (Ain et al., 2023), the authors introduced Health Risk Index (HRI) and Target Hazard Quotient (THQ), Estimated Daily Intake (EDI) which were all used to calculate the Health Risk. The ratio of exposure to the hazardous element to the dose at which negative health consequences are anticipated is known as the target hazard quotient, or THQ. The maximum amount at which this is anticipated is known as the reference dose. There are two categories of health concerns associated with HM exposure: non-carcinogenic risk (NCR) and carcinogenic risk (CR). (Rovira et al., 2010). Health Risk Index (HRI) and Daily Intake of metals (DIM) were calculated to evaluate the potential of chronic health risk due to food consumption & metal consumption through the food in the studies by (Jan et al., 2010) and (Khan et al., 2008). According to (US-EPA, 2002), HRI was calculated by the ration of Daily intake of metal with respect to the reference dose for each metal and $HRI<1$ was assumed to be safe.

Similarly, both (Liu et al., 2005) and (T.-B. Chen et al., 2005) calculated Pollution Load Index (PLI) for estimating the degree of soil pollution due to effect of each metal.

The primary objective of this study was to assess the impact of brick kiln operations on local air quality and human health. The specific objectives were to: (i) Measure and compare the concentration of major air pollutants ($PM_{2.5}$, PM_{10}, SO_2, NO_2, CO, and O_3) in the brick kiln area during kiln-off and kiln-on conditions. (ii) Evaluate the Air Quality Index (AQI) for both operational scenarios to determine the change in air quality status associated with kiln activity. (iii) Estimate the non-carcinogenic health risks through Hazard Quotient (HQ) and Hazard Index (HI) calculations for individual and cumulative exposure to brick kiln pollutants. (iv) Compare kiln-site pollution levels with regional background air quality data obtained from the Khulna air monitoring station to determine whether local pollution is influenced by external sources or driven predominantly by brick kiln emissions.

2. METHODOLOGY

2.1 Study Area

Khulna is the third-largest city in Bangladesh. It is the administrative seat of the Khulna District and the Khulna Division. As of the 2011 census, the city has a population of 663,342. The encompassing Khulna metro area had an estimated population of 1.022 million as of 2014. It is situated beside the bank of the of Rupsha and Bhairab rivers. There is a huge brickfields cluster of more than a hundred kilns developed on the other side of these rivers. For PM and Gaseous pollutant concentration assessment, the Nandanpur brickfield cluster of Rupsha Upazila is selected (Figure 1). The study area is located between 22.8263° and 89. 5893° East longitudes. On two different dates, the required pollutants' concentrations are taken. One in November when brick burning remains off and another one in March when brick burning remains on and emission occurs, so that air pollution due to the emission of the brick kiln with normal condition of this area can be compared.

Figure 1: Plan signifying the selected Nandanpur brickfields cluster. (Kilns are marked by black dots)

2.2 Data Collection

Ambient air samples were collected for six key pollutants—$PM_{2.5}$, PM_{10}, SO_2, CO, NO_2, and O_3—under two distinct operational conditions:

1. Kiln-Off Phase: When all brick kilns were inactive (November)
2. Kiln-On Phase: When full-scale brick burning and production were in progress. (March)

Size-segregated particulate matter (PM) was measured using a handheld laser particle counter (Model 3016), which records six particle size fractions (0.3–25 µm) at one-minute intervals. The instrument was calibrated using established coefficients to estimate $PM_{2.5}$, PM_{10}, and total suspended particles (TSP). Gaseous pollutants (CO, O_3, SO_2, and NO_2) were simultaneously monitored using a multi-probe environmental test meter. Measurements were conducted over an 8-hour period with portable monitors positioned at breathing height (1.5–2.0 m), and concentrations represent averages of repeated readings. Table 1 and Table 2 represents average concentration of air pollutant for both kiln inactive and active period.

Table 1: Average Concentrations of air pollutants with respect to time when brick burning was off (November)

		Time	**PM2.5 (µg/m³)**	**PM10 (µg/m³)**	**SO2 (µg/m³)**	**CO (µg/m³)**	**NO2 (µg/m³)**	**O3 (µg/m³)**
Location	Rupsha Brickfields	9.30 AM-10.30 AM	79.77	175.45	311.67	1216.75	38.67	103.16
Latitude	22.8263	10.30 AM-11.30 AM	67.95	164.10	332.87	1281.33	41.22	124.84
Longitude	89.5893	11.30 AM-12.30 PM	59.76	153.99	287.45	1312.59	65.44	109.00
Date	06-11-2023	12.30 PM-1.30 PM	55.32	154.03	320.33	1246.33	71.44	109.00
		1.30 PM-2.30 PM	55.51	140.73	314.33	1170.66	89.00	176.00
		2.30 PM-3.30 PM	55.65	146.99	279.67	1326.33	73.00	125.80
		3.30 PM-4.30 PM	52.89	136.66	218.09	1277.33	98.11	158.00
		4.30 PM-5.30 PM	53.51	139.70	343.30	1215.00	122.40	122.40

Table 2: Average Concentrations of air pollutants with respect to time when brick burning was on (March)

		Time	**PM2.5 (µg/m³)**	**PM10 (µg/m³)**	**SO2 (µg/m³)**	**CO (µg/m³)**	**NO2 (µg/m³)**	**O3 (µg/m³)**
Location	Rupsha Brickfields	9.30 AM-10.30 AM	74.39	644.00	714.33	1904.00	160.00	34.70
Latitude	22.8263	10.30 AM-11.30 AM	53.00	621.00	685.33	1822.67	99.53	35.60
Longitude	89.5893	11.30 AM-12.30 PM	54.50	443.87	726.33	1830.33	146.36	37.30
Date	19-03-2024	12.30 PM-1.30 PM	61.00	360.87	708.76	1846.00	254.20	37.20
		1.30 PM-2.30 PM	41.33	226.00	749.33	1927.33	188.67	35.40
		2.30 PM-3.30 PM	53.62	560.13	665.66	1826.00	57.83	38.60
		3.30 PM-4.30 PM	69.14	230.42	674.67	1905.00	30.50	38.80
		4.30 PM-5.30 PM	60.87	357.00	654.67	1826.67	275.00	37.60

2.3 Air Quality Index (AQI) Index

The Air Quality Index (AQI) was determined following the Bangladesh Department of Environment (DoE) and U.S. EPA standards to assess the overall air quality status. Sub-indices for each pollutant were computed using the following equation (1):

$$I_p = \frac{I_{Hi} - I_{Lo}}{BP_{Hi} - BP_{Lo}} * (C_P - BP_{Lo}) + I_{Lo} \tag{1}$$

where:

- I_p= AQI for pollutant *p*,

- C_p= Measured pollutant concentration,
- BP_{Hi} and BP_{Lo}= Breakpoints that are closest to C_p
- I_{Hi} and I_{Lo}= Corresponding AQI scale values.

2.4 Exposure Assessment

To estimate long-term human exposure, the chronic exposure concentration (EC) was calculated according to the U.S. EPA (1989) exposure model:

$$E_c = \frac{C*ET*EF*ED}{AT} \tag{2}$$

where:

- C = Pollutant concentration (μg/m³)
- ET = Exposure time (8 hours/day)
- EF = Exposure frequency (180 days/year; typical kiln operation period in Bangladesh)
- ED = Exposure duration (30 years)
- AT = Averaging time (ED × 365 × 24 = 262,800 hours)

This model reflects cumulative exposure for nearby residents and kiln workers under chronic environmental conditions.

2.5 Health Risk Estimation

The non-carcinogenic health risk was assessed through the Hazard Quotient (HQ) and Hazard Index (HI) approach. The HQ for each pollutant was computed as:

$$H_{Qi} = \frac{E_{Ci}}{RfC} \tag{3}$$

where RfC is the inhalation reference concentration (μg/m³) obtained from U.S. EPA's Integrated Risk Information System (IRIS)**:**
$PM_{2.5}$ = 35, PM_{10} = 150, SO_2 = 20, CO = 10,000, NO_2 = 40, O_3 = 100.

The Hazard Index (HI), representing cumulative health risk, was calculated as:

$$HI = \sum HQ_i \tag{4}$$

An HQ > 1 or HI > 1 indicates potential adverse non-carcinogenic effects (Hertzberg & Teuschler, 2002).

2.6 Source Influence Analysis

In order to evaluate the impact of brick kiln operations, the study assessed the relationship between the ground-level particulate concentrations with ambient air pollutants. There were ground monitoring stations nearby the source site which provided data. The analysis compared pollutant data recorded at the kiln site with the monitoring station data, under both kiln-off and kiln-on conditions.

3. RESULT & DISCUSSION

3.1 Variation of Air Pollutant Concentrations During Kiln-Off and Kiln-On Conditions

An extensive study was conducted in the Rupsha brick kiln site for the purpose of examination of the condition of local air quality due to the six major air pollutants during both inactive and active phase of brick production in the kiln. During the kiln-off period, $PM_{2.5}$ concentrations ranged from 52.98 to 79.77 µg/m³, with an average of 60.06 µg/m³, while PM_{10} levels varied between 136.66 and 175.45 µg/m³ (average 151.45 µg/m³).

During off period of the kiln, PM_{10} concentrations exceeded the limit of 150 µg/m³, as provided by WHO. The phenomenon suggested the influence of several possible factors, such as dust, unpaved roads, resuspended soil, and local traffic emissions for such high concentration. During the operational phase of the kiln, there was a significant change in the level of the particulate matter. $PM_{2.5}$ showed a concentration close to an average of 58.48 µg/m³, but PM_{10} concentrations increased rapidly to an amount of 430.41 µg/m³. The significant increment in the particulate concentration indicates the significance of ash dispersion, combustion-related particles during the firing process. Such conditions lead to reduced visibility and pose significant respiratory risks for communities living in the nearby regions. Gaseous pollutant levels also rose substantially during the kiln-on phase. Under kiln-off conditions, mean concentrations of SO_2, CO, NO_2, and O_3 were 300.96 µg/m³ (0.12 ppm), 1255.8 µg/m³ (1.10 ppm), 68.69 µg/m³ (0.04 ppm), and 128.53 µg/m³ (0.07 ppm), respectively. During active operation, these averages increased to 697.39 µg/m³ (0.27 ppm) for SO_2, 2099.38 µg/m³ (1.84 ppm) for CO, 151.51 µg/m³ (0.08 ppm) for NO_2, and 182.64 µg/m³ (0.09 ppm) for O_3.

Among all the pollutants, PM_{10} and SO_2 are found to be most crucial. The concentration of both pollutants crossed the permissible limits by a significant and large margin during kiln operation. PM_{10} levels nearly tripled compared to the recommended threshold indicating severe coarse particulate contamination ((Heinrich, 2003);(Arden Pope & Dockery, 1999)), while SO_2 concentrations almost doubled their allowable limit, reflecting intense sulfur emissions from coal and low-grade fuel combustion ((Ghosh et al., 2017)). These pollutants present significant respiratory and cardiovascular risks, making them key indicators of air quality degradation in brick kiln–affected regions. Figure 2 illustrates the variations in pollutant concentrations during both kiln-off and kiln-on periods.

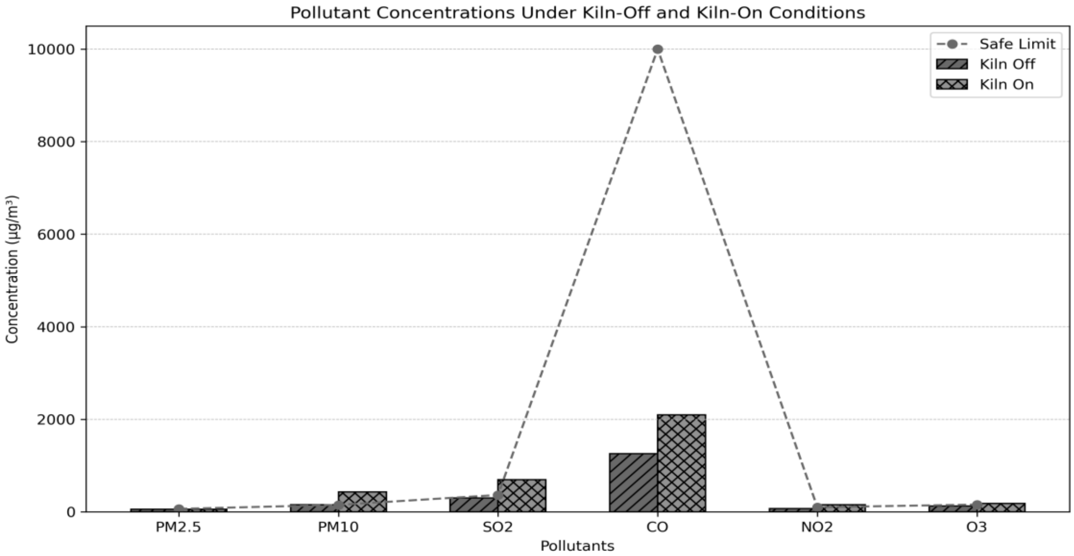

Figure 2: Pollutant concentration (Kiln Off vs Kiln On)

3.2 Air Quality Index (AQI) Index

To further evaluate the severity of air pollution, the Air Quality Index (AQI) was calculated for each pollutant during both kiln-off and kiln-on periods. The AQI results demonstrate a clear deterioration of air quality when brick kilns were operational. During the kiln-off phase, $PM_{2.5}$ (AQI 139.5) and O_3 (AQI 93) were the leading contributors to air quality degradation, placing the atmosphere in the "Unhealthy for Sensitive Groups" category. PM_{10} and SO_2 exhibited moderate AQI values of 99 and 89.21, respectively, while CO (11) and NO_2 (34) remained within satisfactory levels. However, a substantial shift occurred during kiln operation, with AQI values rising across all pollutants. PM_{10} increased from 99 to 177, transitioning into the "Unhealthy" range, indicating severe particulate exposure risk for the general population. SO_2 and O_3 AQI values escalated sharply to 179 each, also falling within the "Unhealthy" category, reflecting intensified sulfur emissions and secondary pollutant formation under high-temperature combustion. In contrast, CO (30) and NO_2 (79) remained comparatively lower contributors but still showed notable increases during the kiln-on period. These AQI trends reveal that PM_{10}, SO_2, and O_3 became the dominant drivers of poor air quality during active kiln operations. Their elevated AQI values indicate an increased likelihood of respiratory distress, eye and throat irritation, reduced lung function, and aggravated cardiovascular symptoms among exposed populations. The transition from moderately polluted to unhealthy air during kiln operation underscores the critical need for emission control, cleaner fuel use, and regulatory enforcement within brick kiln clusters. The dominance of PM_{10}, SO_2, and O_3 in the AQI during kiln-on conditions is consistent with typical brick kiln emission behavior. PM_{10} dominance reflects heavy ash dispersion and dust resuspension from soil and fuel combustion, whereas elevated SO_2 results from burning high-sulfur coal and low-grade fuels commonly used in kilns. The rise in O_3 further indicates active photochemical transformation of NO_x and VOCs into secondary pollutants, especially under sunlight, demonstrating the compounded air quality deterioration caused by brick kiln operations. Figure 3 represents Air Quality Index (AQI) assessment both for kiln off and on periods.

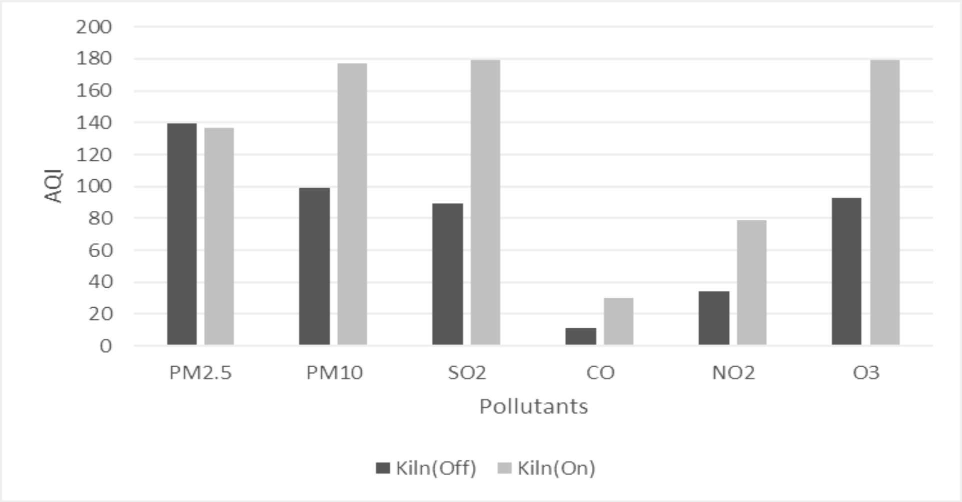

Figure 3: Air Quality Index (AQI) Assessment

3.3 Health Risk Interpretation

To evaluate the potential non-carcinogenic health risks associated with exposure to brick kiln emissions, the Hazard Quotient (HQ) and Hazard Index (HI) were calculated for each pollutant during both kiln-off and kiln-on conditions. An HQ value greater than 1 indicates a potential health concern for individual pollutants, while an HI value exceeding 1 suggests combined adverse health risks from multiple pollutants. During the kiln-off period, SO_2 (HQ = 2.47) and PM_{10} (HQ = 0.50) emerged as the most influential pollutants in terms of health risk, with SO_2 exceeding the safe threshold (HQ > 1).

Although $PM_{2.5}$ (HQ = 0.28) and O_3 (HQ = 0.21) remained below the risk level individually, their cumulative contribution raised the overall HI to 3.77, indicating a moderate level of health risk even when kilns were not operating. CO and NO_2 exhibited minimal risk during this phase, with HQ values significantly lower than 1. A substantial escalation in health risk was observed during kiln-on conditions. PM_{10}, SO_2, and $PM_{2.5}$ displayed HQ values of 1.41, 5.75, and 0.27 respectively, demonstrating that coarse particle exposure and sulfur emissions pose the most serious non-carcinogenic health threats during kiln operation. The combined HI increased sharply to 8.39—more than double the kiln-off value—signifying high cumulative health risk for the exposed population. This reflects increased likelihood of respiratory distress, aggravated asthma, lung inflammation, cardiovascular complications, and reduced pulmonary function due to prolonged exposure. It is noteworthy that SO_2 consistently remained the strongest contributor to health risk under both scenarios, followed by PM_{10} and $PM_{2.5}$ during kiln-on conditions. The rise in PM-related HQ values during kiln operation highlights the direct impact of ash dispersion, particulate combustion, and poor emission control in traditional brick kiln systems. HQ > 1 and HI > 1 indicate potential non-carcinogenic health risk (Shaheen et al., 2016). SO_2 and PM_{10} exceed the safe limit (HQ > 1) during kiln-on conditions and are the leading contributors to health risks. ((Samet & Zeger, 2000); ((Niu et al., 2011)). The values of Hazard Quotient (HQ) for each pollutant and Hazard Index (HI) are represented below in Table 3.

Table 3: Health Quotient and Health Index

Pollutant	HQ (Kiln Off)	HQ (Kiln On)
PM2.5	0.28	0.27
PM10	0.50	1.41
SO2	2.47	5.75
CO	0.02	0.03
NO2	0.29	0.62
O3	0.21	0.30
HI	3.77	8.39

3.4 Relationship between Ground-level Pollutant Concentration and Ambient Air Pollutants

To assess the interaction between localized brick kiln emissions and regional ambient air quality, a comparative analysis was conducted using concentrations measured at the Rupsha brick kiln cluster and corresponding monthly averaged pollutant data obtained from the Khulna Air Quality Monitoring Station (AQMS). During the kiln-off phase, ground-measured $PM_{2.5}$ (60.06 $\mu g/m^3$) and PM_{10} (151.45 $\mu g/m^3$) showed a relatively close alignment with station-reported values (102 $\mu g/m^3$ and 194 $\mu g/m^3$, respectively), indicating a moderate background influence from regional sources such as vehicular movement, road dust, industrial activities, and transboundary pollution. However, SO_2 and NO_2 levels exhibited a large disparity, with kiln-site concentrations substantially higher than station data (SO_2: 300.96 vs. 5.02 $\mu g/m^3$; NO_2: 68.69 vs. 11.56 $\mu g/m^3$), suggesting that brick kilns act as localized point sources of combustion-derived sulfur and nitrogen emissions, not fully captured by regional monitoring. Upon kiln operation, the divergence between local and station data became more pronounced. PM_{10} and SO_2 recorded sharp increases at the kiln site (430.41 $\mu g/m^3$ and 697.39 $\mu g/m^3$), whereas AQMS values rose only marginally for PM_{10} (from 194 to 208 $\mu g/m^3$) and SO_2 (from 5.02 to 10.11 $\mu g/m^3$). This weak correspondence during kiln-on conditions indicates a low regional influence but strong localized emission dominance, reflecting limited dispersion and high pollutant accumulation near kiln clusters. Conversely, pollutants such as CO and O_3 showed relatively closer trends between the two datasets, implying partial regional transport and atmospheric mixing. The analysis confirms that brick kilns exert a substantial local impact on air quality, particularly for primary combustion pollutants such as PM_{10}, SO_2, and NO_2, whereas regional monitoring stations alone may underestimate local exposure risks in kiln-affected communities. Table 4 represents comparison between groud level pollutant data to Khulna Air Quality Monitoring Station data.

Table 4: Ambient air pollutant concentration data VS AQMS concentration data

Pollutant	Kiln-Off Kiln Data (µg/m³)	Kiln-Off AQMS Data (µg/m³)	Kiln-On Kiln Data (µg/m³)	Kiln-On AQMS Data (µg/m³)
PM2.5	60.056	102	58.48	84
PM10	151.45	194	430.41	208
SO_2	300.96	5.018	697.385	10.114
CO	1255.8	2337.636	2099.375	1902.19
NO_2	68.69	11.56	151.51	20.77
O_3	128.525	57.83	182.64	33.24

4. CONCLUSION

This study estimated and evaluated the influence of brick kiln operations on local air quality and subsequent health risks by comparing pollutant concentrations during kiln-off and kiln-on periods. A marked increase in PM_{10}, SO_2, NO_2, and CO levels during kiln-on conditions, with PM_{10} and SO_2 surpassing national safe limits, demonstrates the significant emission load from kiln activity. Health risk assessment revealed notably higher Hazard Quotients (HQ) and cumulative Hazard Index (HI) during kiln operation, indicating elevated non-carcinogenic health risks—primarily driven by fine and coarse particulate matter along with SO_2 exposure. Comparison with data from the Khulna air quality monitoring station showed a contrasting trend: while the regional background pollutant levels remained considerably lower, the kiln-site concentrations increased sharply during operation. This divergence confirms that the air quality deterioration in the brick kiln area is predominantly driven by localized emissions from the kiln itself rather than regional or external pollution sources. The findings underscore the critical need for stricter emission control, adoption of cleaner kiln technologies, and local-scale monitoring to mitigate health hazards and improve air quality in brick kiln–affected communities.

DECLARATION OF USE OF AI

The authors declare that an AI-assisted writing tool (Quill Bot) was used solely for language editing and improvement of clarity in the manuscript. The tool was not used to generate scientific content, results, interpretations, or conclusions. All technical content and final responsibility for the manuscript remain with the authors.

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