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# CENTURY'S LONGEST HEAT WAVE IN KOLKATA, INDIA: IMPACT ON AIR QUALITY PARAMETERS

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**Abstract:** Physico-chemicai parameters in the city air, responsible for the determination of air quality index, showed adverse effects on urban life during the heatwave period that started on 19 April and ended on 4 May 2024 in Kolkata, India. Some of these parameters were found to be correlated with the rising temperatures during heat waves.Further statistical analyses were also performed, and results were interpreted within the perspectives of environmental changes. The century's longest heat wave in Kolkata was caused by the influence of waning El Niño throughout the month of May that ultimately would be overturned to an incoming La Nina situation in June. The La Nina phenomenon will possibly cause huge precipitation resulting in more than average rainfall during the monsoon around the Indian subcontinent.

**Keywords:** Air quality, El Niño, Heat waves, Kolkata, Maximum temperatures

## 1. INTRODUCTION

Kolkata along with most of the districts of West Bengal, India were affected by severe heat wave from 19 April to 4 May 2024. Temperatures crossed 45°C in some parts of the state. On 25 April 1980, Koikata's maximum temperature had reached 41.7°C At 2:30 pm on 29 April 2024, Koikata's temperature again reached 41.7°C This was the second highest temperature in Kolkata in April 2024. The next day on April 30, Koikata's temperature touched 43°C, which is close to the city's all-time record high.

In terms of heat, 30 April 2024 set an all-time record in the state as the maximum temperature reached 47.2°C in Kaiaikunda of Paschim Medinipur (probably the country's highest temperature). According to the Aiipore Meteorologicai Department record (Weather Report) so far, the highest temperature record in the state was at Santiniketan in Birbhum. On June 10, 1966, the highest temperature there was 47°C. Kaiaikunda (maximum temperature 45.4°C) was the hottest place in the country on 29 April 2024 as recorded by India Meteoroiog-icai Department. Even the Sunderbans, the world's largest mangroves forest near the city of Kolkata, could not offer even a little relief from this heat wave [1, 2]. In this context, the main objective of this work is to determine the

correlation of temperature with air quality parameters during heat waves in the City of Joy.

## 2. PHYSIOGRAPHY AND CLIMATE OF KOLKATA

Kolkata is situated on the eastern bank of the Hooghly River. The last part (Hooghly River) of the river Ganga flows past Kolkata and after covering a distance of about 180 km it merges into the Bay of Bengal. Kolkata is located at 22°30' N and 88°30' E (22°30' North latitude and 88°30' East longitude) which elevation is 6.4 m above sea level. The area of Kolkata city is 1480 $km^2$ (square kilometre). The most striking aspect of Kolkata's layout is its rectangular north-south orientation. The city grew haphazardly, except for the central areas inhabited by Europeans in the east.

Kolkata has a subtropical monsoonal climate (rain-bearing winds). It is warm throughout the year. From June to September, is the rainy season. These months are very humid and sometimes smelly. Rainfall decreases in October and November. The winter months, from the end of November to the end of February, are pleasant and rainless; Fog and fog occasio-nally reduce visibility in the early morning hours during this season, and also cause dense smog in the evening.

During the summer months of May-June, the maximum temperature hovers between 24°C-42°C. Concrete construction, high rise and roads, insufficient vegetation with green canopy, and lack of wetlands and water-bodies in most areas of the city contribute to persistent temperature and increased relative humidity. Mainly due to these three reasons the atmosphere in the city of Kolkata during summer cannot be cooler at night that leads to the consequence of urban heat island effect. In winter, the minimum temperature hovers between 8°C-26°C during December-January. The humidity in summer is between 65-85%. But winter is very pleasant. The average rainfall from June to September is 158 cm.

## 3. CAUSES AND CONSEQUENCES

Continuous flow of dry north-westerly winds and the removal of moisture from the Bay of Bengal were identified as the main causes of prolonged heat waves and high temperatures in the city. Kolkata experienced a heat wave in three phases in April 2024 for the first time in this century. Global warming, combined with the El Niño phenomenon, has contributed to this rise of temperature in Kolkata [3]. In addition to that, human-induced climate change casts a long shadow over such extreme weather events, increasing their intensity and frequency though El Niño has reduced the number of nor'westers occurring during summer. The number of nor'westers during the timespan of March-April has decreased significantly in the last few years and replaced by periodic cyclonic storms [4]. Kolkata had none in 2022 and 2024 and only two in 2023, while the average number between March and April was 6. However, the current flow of southerly and south-westerly winds is unlikely to prevent the trend of hot and dry north-westerly winds over the region that extends the heatwave period.

The character of Kolkata summer has

changed. No sweat in this heat in and around the city. The heat wave started on 19 April 2024, though the temperature had been rising since April 2. The south wind was not coming in at all. So, the sweat will disappear. Moisture will disappear. Instead, hot air from North and West India, which mainly blows over Bihar, Jharkhand region, is freely entering the state of West Bengal. Sweating is less dangerous. Instead of sweating, the body becomes worse if the situation is loo. People get sick. Long dry summer spells are unprecedented in the state. There is almost no chance of rain because the moisture from the Bay of Bengal is not able to penetrate into the lower Gangetic plain [5].

As a consequence, urban heat islands are formed particularly in pocket areas in the absence of green. The urban heat island effect results from obstructed ventilation and heat trapping due to the proximity of high rise, heat generated directly from human activity, the heat-absorbing properties of concrete and other urban construction materials, and for the limited vegetation. A cyclonic anticlockwise motion has been observed over the Bay of Bengal on 29 April, which is very conducive to thunderstorm activity that can bring the mercury down a few notches though all the rivers in the lower Gangetic region have almost dried up due to the intense summer heat, so there is no possibility of generation of huge quantity of water vapours from the rivers as well [6].

## 4. CITY POLLUTING AGENTS

As environmental degradation levels rise throughout the city, it creates problems for urban people to live in. The polluting agents responsible for environmental degradation are sulphur dioxide, carbon monoxide, nitrogen dioxide, ozone, etc. Apart from these, fine particles from various sources become airborne and cause breathing problems and these air-borne fine particles are called particulate matter (PM2.5).

### 4.1. Ozone and CFC

Due to the onset of heat flow in the city of Kolkata, the use of air conditioners has increased dramatically. Now every apartment in this megacity has two air conditioners on average in every flat. To manufacture all these air conditioners CFC gas is widely used. As a result, the level of this gas in the atmosphere is increasing, resulting in the destruction of the ozone layer. CFC gas is not water-soluble, inert and non-flammable. For all these physical properties, CFC gas accumulates in the atmosphere for long periods of time [7]. The sun's ultraviolet rays release chlorine from this CFC gas. A free chlorine atom can destroy 1 lakh ozone molecules in a cyclic reaction.

$$CFCl_3 \rightarrow Cl^{\cdot} + CFCl_2$$

$$Cl^{\cdot} + O_3 \rightarrow ClO^{\cdot} + O_2$$

$$ClO^{\cdot} + O \rightarrow Cl^{\cdot} + O_2$$

Although the ozone gas level is very low for the atmosphere (0.00006%), this gas has an important role in the living world and human welfare. Ozone is a light bluish, irritant, and poisonous gas. Ozone varied from 20 to 54 ppbv (part per billion by volume) in the city atmosphere during the century's longest heat wave period that started from 19 April and ended on 5 May 2024.

### 4.2. Particulate Matter

Particulate matter varies from 27 to 49 $\mu g/m^3$ during the longest heat wave in Kolkata. Combustion of wood, coal, fuel oil, domestic and incineration of municipal wastes in the atmosphere of Kolkata metropolis creates particulate matter. Also due to loading, unloading, mixing of ore, stone, cement, chemicals etc., packaging of chemicals and fertilizers etc. also causes minute matter to circulate in the atmosphere in particles [8]. Fine particulate matter is generated during the processing of carbohydrates from food grains such as wheat, barley and corn. Particulate matters are produced during sawing and construction of wood sawing machines, wall boards, plastics, metal extrusion. Paper and textile industries also produce a myriad of smaller substances. Land preparation and backfilling for roads, houses, apartments, high rise and road construction generates large amounts of fine particulate matter. Air flow accelerates the dispersion of particulate matter like fine substances. Clearing and cleaning of dirt roads, sowing of crop seeds, import and distribution of poultry feed, engine fumes etc. are among various causes of particulate matter generation.

### 4.3. Sulphur Dioxide

Sulphur dioxide ($SO_2$) might disrupt the respiratory function in the human body, particularly in the lungs during the heatwave period in Kolkata. Apart from lungs, aerosols cause damage to the ciliary lining of other respiratory organs. Sulphur dioxide is a colourless gas with a pungent odour produced by the combustion of fossil fuels [9]. Sulphur dioxide carries small amounts of sulphur trioxide. These mixtures of sulphur oxides are collectively called SOx. The sulphur dioxide concentra-tion is categori-cally good in the surrounding atmosphere of Kolkata during the heatwave that ranges from 1 to 8 ppm (parts per million).

### 4.4. Nitrogen Dioxide

Nitrogen dioxide ($NO_2$) levels have been observed to be very low during urban heat waves that vary from 5 to 12 ppm. Nitrogen dioxide, along with other oxides of nitrogen, collectively known as NOx mixes with the blood after entering the human body. Due to the effect of this gas, the cells and tissues of the lungs in the human body begin to be destroyed. As the ozone gas rises to the atmosphere, it reacts with these oxides to form secondary pollutants like formaldehyde, aldehyde, Per-oxi Acetyl Nitrate (PAN), which together form photochemical smog [9]. They are very harmful to the physiological functions of the human body. Combustion of low temperature fuels does not produce nitric oxide or nitrogen dioxide. If fossil fuels are burned in the presence of sufficient air, the production rate of nitrogen oxides decreases.

### 4.5. Carbon Monoxide

By absorbing the infrared rays of sunlight radiated to the earth's surface, carbon monoxide (CO) plays the role of gradually heating the earth's surface. In the city of Kolkata, this gas is mainly produced from the exhaust fumes of motor vehicles. Respiratory distress in the human body is due to the effect of carbon monoxide. Because of this gas, the temperature of the atmosphere increases

gradually [10]. The tendency of carbon to mix with haemoglobin in human blood is about 300 times more than that of oxygen ($O_2$). This gas combines with haemoglobin to form carbo-amino-haemoglobin compounds, which cause severe respiratory distress in humans. Most carbon monoxide is released from the atmosphere naturally. However, carbon monoxide levels in Kolkata city ranged from 71 to 458 ppm during peak flow periods. Surprisingly, carbon monoxide levels were recorded at 526 ppm on May 8 despite 141 mm of rain in the 72 hours following the heat wave. The reason for such an occurrence is probably due to the effect of heavy rain and moisture in the surrounding area, due to which the carbon monoxide could not be released from the atmosphere. However, the excess of carbon monoxide during the heatwave period in the city atmosphere is probably due to the break-down of carbon dioxide ($CO_2$) in the intense heat to form carbon monoxide .

$$CO_2 \rightleftharpoons CO + O$$

## 5. Effects on Air Quality Parameters

The Air Quality Index (AQI) was almost moderate all over the heat wave period ranging from 61 to 96 with a mean of 86.31(SD 12.57) except poor on 19 April (AQI 102) and 1 May 2024 (AQI 106). Particulate Matter (PM 2.5) concentration in the air remained moderate varying from 31 to 49 $\mu g/m^3$ with a mean of 39.12 $\mu g/m^3$ (SD 7.38) though it turned to good on 21 April (27 $\mu g/m^3$) and 4 May 2024 (29 $\mu g/m^3$). The concentration of sulphur dioxide and nitrogen dioxide were low and considered categorically as good during the heatwave period ranging from 1 to 8 ppm with a mean of 4.81 ppm (SD 2.10) and 5 to 12 ppm with a mean of 7.81 ppm (SD 1.64) respectively. Ozone level was also good varying from 20 to 48 ppbv (parts per billion by volume) or Dobson unit with a mean of 34.88 ppbv (SD 12.14) only except 29 April and 1 May when it showed moderate concentration of 54 and 53 ppbv respectively. However, higher levels of carbon monoxide were observed throughout this heat period that lasted from 19 April to 4 May that ended on 5 May 2024. The carbon monoxide level was severe on 19, 22, 24 April, and 4 May, unhealthy on 20 April and 1 May, poor on 2 and 3 May 2024, and moderate on 21 and 27 to 30 April (Table 1). But surprisingly, carbon monoxide level on 8May 2024 shows 526 ppm after a huge spell of 71 mm overnight rainfall which was more than that of the hazardous value for carbon monoxide in the atmosphere. Carbon monoxide levels ranged from 71 to 458 ppm with amean of 248.8 ppm (SD 115.76) during the heatwave period. During extreme heat waves in the Kolkata megacity, air quality



**Fig. 1.** A void passage inside the National Library campus in Kolkata during the heatwave.

**Table 1**. Physico-chemical parameters in the urban atmosphere in Kolkata during heat wave.

| Dates (2024) | Maximum Temperature (°C) | AQI | $O_3$ (ppbv) | PM 2.5 ($\mu g/m^3$) | $SO_2$ (ppm) | $NO_2$ (ppm) | CO (ppm) |
|---|---|---|---|---|---|---|---|
| *19 April* | *40.8* | *102* | *35* | *45* | *6* | *12* | *355* |
| *20 April* | *40.2* | *75* | *20* | *31* | *2* | *9* | *212* |
| *21 April* | *40.3* | *67* | *22* | *27* | *1* | *9* | *180* |
| *22 April* | *39* | *89* | *20* | *39* | *5* | *9* | *332* |
| *23 April* | *39.3* | *94* | *24* | *46* | *7* | *9* | *458* |
| *24 April* | *40.5* | *94* | *39* | *49* | *7* | *8* | *350* |
| *25 April* | *41.6* | *93* | *38* | *40* | *8* | *9* | *450* |
| *26 April* | *39.7* | *80* | *23* | *40* | *3* | *7* | *244* |
| *27 April* | *41.1* | *77* | *43* | *32* | *3* | *7* | *184* |
| *28 April* | *41.3* | *75* | *43* | *35* | *3* | *7* | *119* |
| *29 April* | *41.7* | *96* | *54* | *48* | *5* | *7* | *122* |
| *30 April* | *43* | *94* | *48* | *47* | *8* | *7* | *71* |
| *1 May* | *42* | *106* | *53* | *47* | *6* | *7* | *231* |
| *2 May* | *39.2* | *88* | *45* | *39* | *5* | *7* | *191* |
| *3 May* | *39* | *90* | *30* | *32* | *4* | *6* | *171* |
| *4 May* | *39.1* | *61* | *21* | *29* | *4* | *5* | *310* |

*Source: India Meteorological Department (IMD) and Kolkata Air Quality Index (AQI)*

## 6. Effects on Urban Population

As temperature and humidity rise, the human body has to work harder to regulate its internal temperature. This can lead to dehydration, which affects human brain function and mood. Furthermore, constant exposure to sunlight can disrupt sleep patterns, leaving people feeling tired and irritable. The combination of physical discomfort and disrupted sleep can make people feel more stressed, anxious, and moody. Drinking plenty of water is extremely important during a heatwave. It is essential to give the human body a break from the scorching heat. If possible, people should try to stay indoors during the hottest part of the day which was visible throughout the city during the heatwave period – streets were deserted, and parks were desolate (Fig. 1). During heat waves, it is very important to include cold drinks and foods in one's diet. This includes fresh fruits and vegetables. Further, prioritizing getting enough sleep during a heatwave is essential.

## 7. Statistical Results

Pearson correlation coefficients for maximum temperature and air quality parameters were calculated. As illustrated through the correlation plot in Fig. 2, AQI, PM 2.5, $SO_2$ were slightly positively correlated with maximum temperature. Ozone was highly positively correlated with maximum temperature $NO_2$ had almost no correlation with maximum temperature. CO was slightly negatively correlated with maximum temperature.

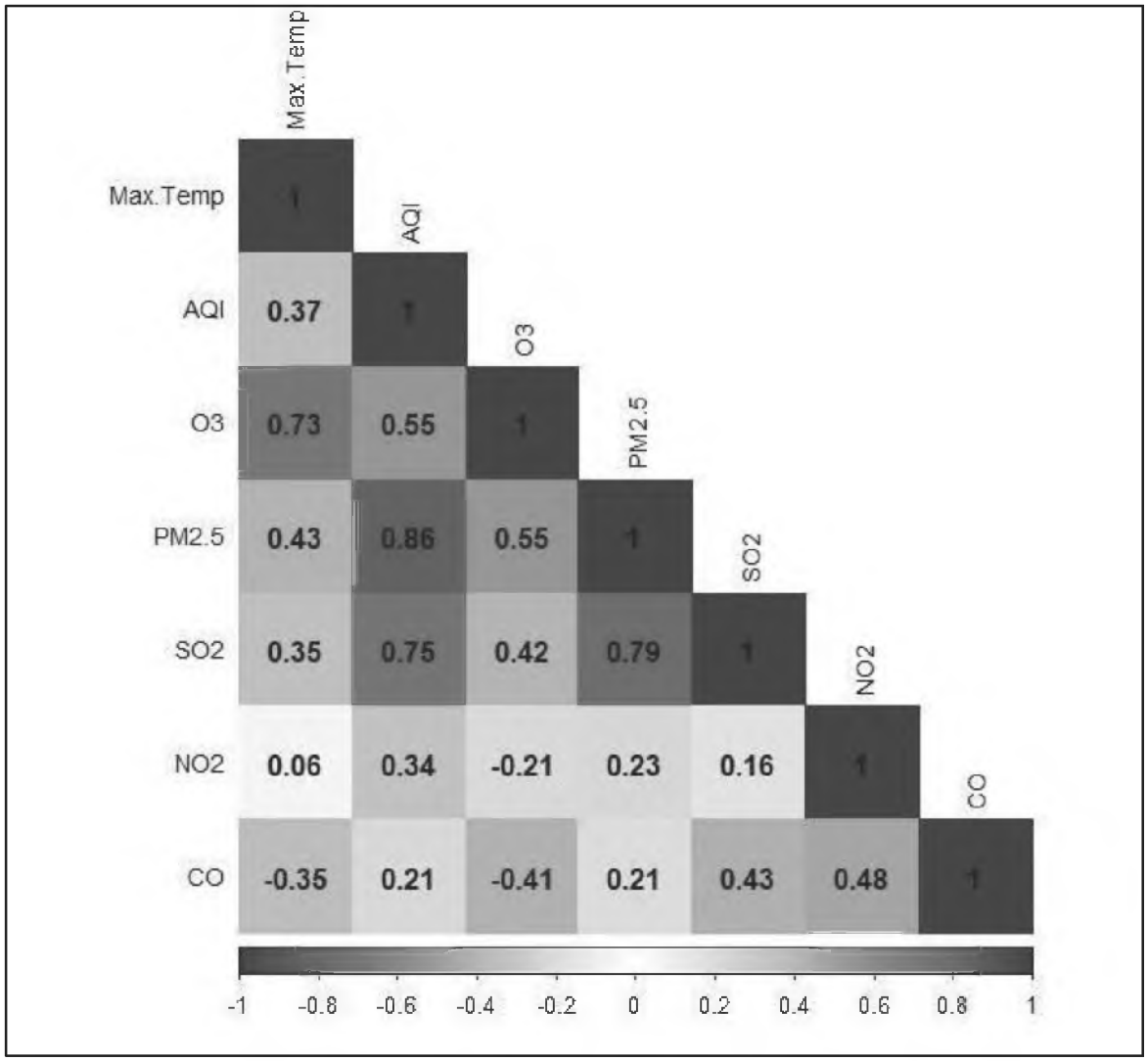



**Fig. 2.** *Correlation matrix showing their inter relationships of the air quality parameters.*

Furthermore, linear regression models were computed using the undermentioned formulae

$$\textbf{Model 1}: AQI = \beta_{10} + \beta_{11}(maximum\ temperature) + e_1$$

$$\textbf{Model 2}: O_3 = \beta_{20} + \beta_{21}(maximum\ temperature) + e_2$$

$$\textbf{Model 3}: PM_{2.5} = \beta_{30} + \beta_{31}(maximum\ temperature) + e_3$$

$$\textbf{Model 4}: SO_2 = \beta_{40} + \beta_{41}(maximum\ temperature) + e_4$$

$$\textbf{Model 5}: NO_2 = \beta_{50} + \beta_{51}(maximum\ temperature) + e_5$$

$$\textbf{Model 6}: CO = \beta_{60} + \beta_{61}(maximum\ temperature) + e_6$$

**Table 2.** Estimated effect of maximum temperature on air quality parameters.

| Model | Effect Estimate | 95% Confidence Intervals | p-value |
|---|---|---|---|
| *AQI ~ Maximum Temperature* | *3.742* | *-1.722, 9.206* | *0.164* |
| *$O_3$ ~ Maximum Temperature* | *7.225* | *3.352, 11.099* | *0.00131* |
| *$PM_{2.5}$ ~ Maximum Temperature* | *2.585* | *-0.528, 5.699* | *0.0966* |
| *$SO_2$ ~ Maximum Temperature* | *0.600* | *-0.321, 1.521* | *0.184* |
| *$NO_2$ ~ Maximum Temperature* | *0.078* | *-0.688, 0.843* | *0.830* |
| *CO ~ Maximum Temperature* | *-33.364* | *-83.929, 17.200* | *0.179* |

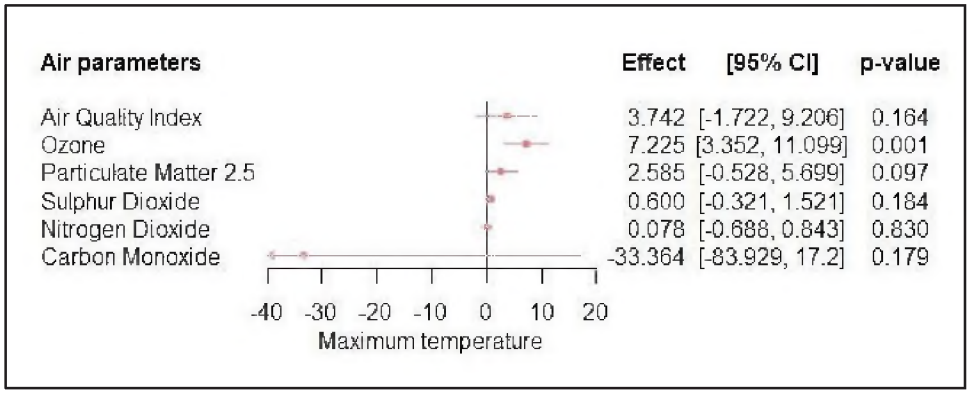



**Fig. 3.** Forest plot of regression models illustrating effect of different physico-chemical air quality parameters on maximum temperature.

The effects and 95% confidence intervals of maximum temperature on the air quality parameters estimated from the aforementioned regression models respectively are given in Table 2.

The mean observed maximum temperature between April 19 and May 4 was 40.49°C (SD 1.23). During the heatwave period, a 1° increase in observed maximum temperature led to an estimated increase of 3.74 (95% CI -1.72, 9.21) in expected AQI, an increase of 7.23 ppbv (95% CI 3.35, 11.10) of expected $O_3$, an increase of 2.58 μg/m$^3$ (95% CI -0.53, 5.70) of expected PM2.5, an increase of 0.6 ppm (95% CI -0.32, 1.52) of expected $SO_2$, an increase of 0.08 ppm (95% CI -0.69, 0.84) of expected $NO_2$, and a decrease of 33.36 ppm (95% CI -83.93, 17.20) of expected CO, independently of each other.

The wide confidence intervals and large p-values corresponding to the effect estimates for models 1, 3, 4, 5, and 6 indicate that there is not enough evidence in the data for the observed effect of maximum temperature on AQI, PM2.5, $SO_2$, $NO_2$, and CO being true. This is clearly evident from model 6 where the regression estimate of a negative effect of maximum temperature on CO contradicts the aforementioned physico-chemical criteria for CO formation. However, there is very strong evidence for the true effect of maximum temperature on $O_3$ from the observed data (Fig.3).

## 8. Conclusion

The El Niño phenomenon has the effect of controlling the wind circulation across India's landmass which combined with global warming caused a heat wave event from April 19 to May 4 in Kolkata. The El Nino phenomenon is set to end at the end of May 2024 i.e. El Niño is on the wane stage. Primarily due to climate change, the effects of the El Niño phenomenon have intensified and accelerated heat waves across the Indian subcontinent including the Kolkata metropolis. Due to intense heat waves, the levels of various parameters responsible for the determination of the Air Quality Index have increased comparatively and most of them showed their presence with severe concentration in the surrounding atmosphere in Kolkata, India. As the heat flux increases, the air quality parameters will increase and will become hazardous that will destroy the normal state of the atmosphere including the surroundings of the human habitation zone.

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