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**Research Paper**

# Deadly breath: Investigating the causes and consequences of hazardous atmospheric Air Quality Index (AQI) of Motihari town during winter season, a case study

Niraj Kumar
Department of Zoology, Laxmi Narain Dubey, College, Motihari, East-Champaran, (B. R. Ambedkar Bihar University, Muzaffarpur) Bihar, India
Orcid: https://orcid.org/0000-0002-0923-1900
*Email: dr.knirajj@gmail.com

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**Abstract:** Air pollution refers to the mixing of undesirable substances in the air, which alters the concentration of oxygen, either through anthropogenic activities or natural processes. The World Health Organization (WHO) defines air pollution as the presence of harmful materials in the air in concentrations that pose risks to human health and the environment. Globally, air pollution claims over 5.5 million lives every year, making it a critical public health concern that warrants attention and action. The present study explores the causes and consequences of the high and hazardous Air Quality Index (AQI) levels observed in Motihari during the winter season of year 2022-2023 (during winter months). Motihari, the headquarters of East Champaran district in Bihar, India, and is one of the fastest-developing towns in North Bihar but is currently facing suboptimal air quality. The AQI is a daily measurement system that evaluates air cleanliness and the associated health risks of polluted air. It focuses on five key pollutants: Particulate Matter (PM2.5 and PM10), ground-level ozone or $O_3$, carbon monoxide (CO), sulfur dioxide ($SO_2$), and nitrogen dioxide ($NO_2$). The AQI scale ranges from 0 to 500, with higher values indicating more severe pollution and increased health risks. During the study period (winter season of 2022-2023), Motihari frequently ranked as one of the most polluted areas in the country, with AQI readings of 419 on November 12, 2022, 448 on November 17, 2022, 421 on November 20, 2022, 423 on November 21, 2022 and so on. This study highlights the need for urgent policy interventions; strict implication of law including emission control measures etc. for maintaining good AQI.

**Keywords:** Motihari, AQI, air pollution, PM2.5, PM10, asthma, carcinogenic, volatile organic compounds, polycyclic aromatic hydrocarbons, public health.

## Introduction:

Air is one of those fundamental necessities, without which life cannot exist in its current form (Li et al., 2018). Globally, many cities continuously assess air quality using monitoring networks designed to measure and record air pollutant concentrations at several points deemed to represent exposure of the

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population to these pollutants (Kanchan *et. al.,* 2015). Recently Motihari town gained notoriety for being among the most polluted city in the country with alarming air quality indices. Since the industrial revolution, the rate of industrialization and urbanization has surged dramatically. As a result, certain regions, primarily in developing countries, have faced significant challenges, with environmental issues, particularly air pollution, being of major concern (Hamedian *et. al.,* 2016). Air is a vital and principal resource for the survival of human life, along with water and land. Air pollution is considered a serious environmental threat in Asian cities, especially India. Most of the Indian population is exposed to poor air quality, thus, leading to severe health hazards, responsible for various health problems such as the risk of developing cancers, respiratory diseases, and others (Shah and Patel, 2021). Air pollution is a well-known environmental problem associated with urban areas around the world (Bishoi *et. al.,* 2009). Air pollution has been consistently
linked to substantial burdens of ill-health in developed and developing countries (Gorai *et. al.,*2014; Bruce *et. al.,*2000; Smith *et. al.,* 2000; WHO, 1999 and Schwartz, 1994). It would be insightful to understand that worldwide, every year more than 5.5 million people die annually due to air pollution (Shah and Patel, 2021). Air quality indices are the most widely used tools which mainly indicate the quality of air in a specific region in a specific region (Hamedian *et. al.,* 2016). The Air Quality Index (AQI) is a daily measure of air quality that indicates whether the air is clean or unhealthy to breathe. It provides vital information on potential health risks associated with poor air quality, highlighting the short-term health effects that may occur within hours or days of exposure. The AQI is classified into following six distinct color-coded categories (fig. 1), each accompanied by specific health advisor

**Air Quality Index**

| AQI Category and Color | Index Value | Description of Air Quality |
|---|---|---|
| Good<br>Green | 0 to 50 | Air quality is satisfactory, and air pollution poses little or no risk. |
| Moderate<br>Yellow | 51 to 100 | Air quality is acceptable. However, there may be a risk for some people, particularly those who are unusually sensitive to air pollution. |
| Unhealthy for Sensitive Groups<br>Orange | 101 to 150 | Members of sensitive groups may experience health effects. The general public is less likely to be affected. |
| Unhealthy<br>Red | 151 to 200 | Some members of the general public may experience health effects; members of sensitive groups may experience more serious health effects. |
| Very Unhealthy<br>Purple | 201 to 300 | Health alert: The risk of health effects is increased for everyone. |
| Hazardous<br>Maroon | 301 and higher | Health warning of emergency conditions: everyone is more likely to be affected. |

**Figure: 1. Showing AQI category, colour, index value and description of air quality with health risk** (Image ©: https://www.epa.gov/)

According to USEPA (2014) the AQI value between 0 and 50 is satisfactory and poses little or no health risk. The AQI is between 51 and 100. Air quality is acceptable; however, pollution in this range may pose a moderate health concern for a very small number of individuals. People who are unusually sensitive to ozone or particle pollution (particulate matter 2.5 & 10) may experience respiratory symptoms. When AQI values are between 101 and 150, members of sensitive groups may experience health effects, but the general public is unlikely to be affected. Everyone may begin to experience health effects when AQI values are between 151 and 200. Members of sensitive groups may experience more serious health effects. AQI values between 201 and 300 trigger a health alert, meaning everyone may experience more serious health effects. AQI values over 300 trigger health warnings of emergency conditions. The entire population is even more likely to be affected by serious health effects.

## Materials and Methods:

Several surveys were undertaken to identify possible causes of increased AQI in various areas of Motihari town. A handheld GPS was used to record the latitude, longitude and elevation of various locations which were supposed to be most polluted and where major construction projects were ongoing. Some data of AQI of Motihari town were fetched from LED screen installed by Bihar State Pollution Control Board (Patna) at District Collectorate gate (Gandak Colony), Motihari (fig. 2) on regular basis. The Air Quality Index (fig. 3) is a widely used metric in air quality management/monitoring programs, with the AQI developed by the US Environmental Protection Agency (USEPA) being the most commonly applied index globally. Using the Air Quality Index, air quality can be calculated by inputting the concentrations of pre-determined key pollutants, including particulate matter (PM2.5 and PM210), ozone ($O_3$), carbon monoxide (CO), sulfur dioxide ($SO_2$) and nitrogen dioxide ($NO_2$).

## Study Area

Motihari is located at N26.65620° (latitude) and E84.90455° (longitude) with variable elevation (Table 1). Motihari is the headquarter of East Champaran district situated in North-West part of the State of Bihar, India (fig. 4, 5 & 6). There are 6 sub-divisions (Tehsils) and 27 Community Development Blocks in the district. There are 1293 villages, 405 panchayats and 10 statutory towns in the district. According to the 2011 census, East Champaran district in Bihar ranks second in population with approximately 50,99,371 residents and third in terms of area, covering 3,968 square km. In terms of population density, East Champaran is the 11th most densely populated district in the state, with 1,285 people per square kilometer, surpassing the state's average of 1,106 people per square kilometer.

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**Table: 1. Geocoordinates and Elevation of different sites of observation in Motihari Town.**

| SN | Observation Site | Geo-coordinates | Elevation |
|---|---|---|---|
| 1 | Awadhesh Chowk | 26.66872º North and 84.92352º East | 54 Meter ASL |
| 2 | Chhatauni Chowk | 26.64863º North and 84.92857º East | 47 Meter ASL |
| 3 | Janpul Chowk | 26.66364º North and 84.91164º East | 54 Meter ASL |
| 4 | M. S. College Road, Chandmari | 26.65596º North and 84.90447º East | 53 Meter ASL |
| 5 | Chandmari Chowk | 26.65199º North and 84.90380º East | 37 Meter ASL |
| 6 | Balua Market | 26.65068º North and 84.90359º East | 52 Meter ASL |
| 7 | Motihari Railway Station | 26.65447º North and 84.90572º East | 54 Meter ASL |
| 8 | Gandhi Museum | 26.65769º North and 84.90974º East | 51 Meter ASL |
| 9 | Motijheel | 26.65231º North and 84.91179º East | 63 Meter ASL |


**Figure: 2. Large LED Monitor (installed by BSPCB, Patna) displaying AQI near Collectorate Gate (Gandak Colony) Motihari** (Image © Dr. Niraj Kumar)

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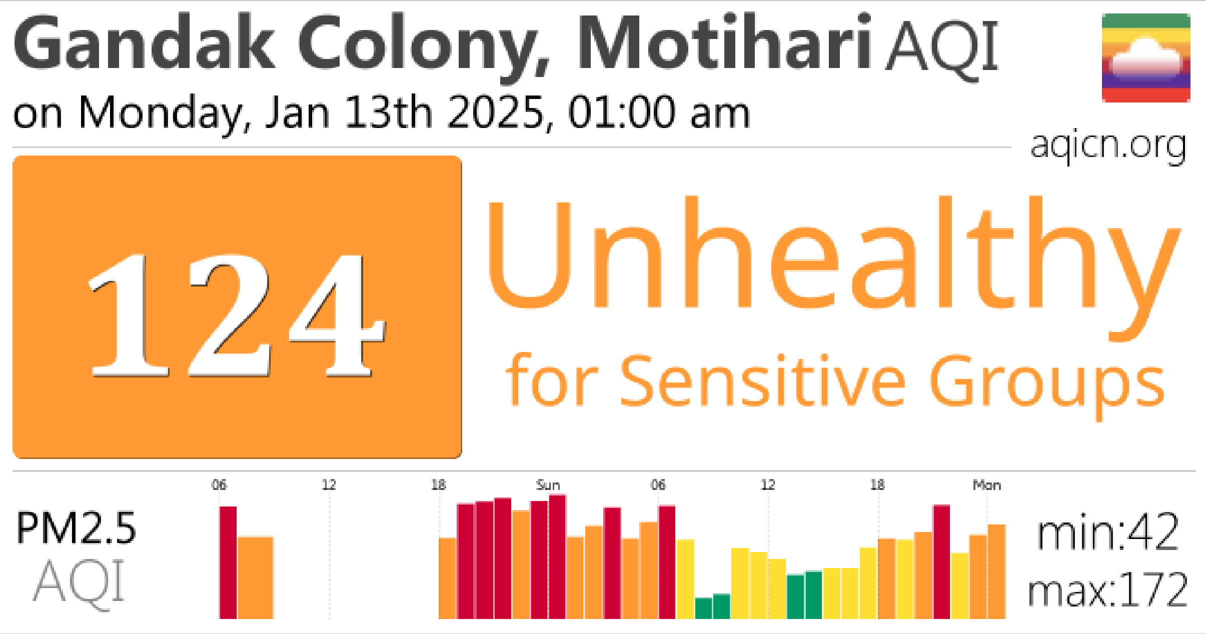


**Figure: 3. AQI of Gandak Colony, Motihari on Monday, January 13, 2025**
(Image © aqicn.org)


**Figure: 4. Man of India & Bihar (map not to scale)**

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## Observation and Discussion:

Nestled in the Himalayan foothills, the quaint town of Motihari (geo-coordinates: 26.65620°N and 84.90455°E) has recently gained notoriety for being among the most polluted areas in the country. Motihari, a city in Bihar, held the dubious distinction of being India's most polluted city on November 11, 2022, with a hazardous AQI of 413, as reported by the Central Pollution Control Board (CPCB).

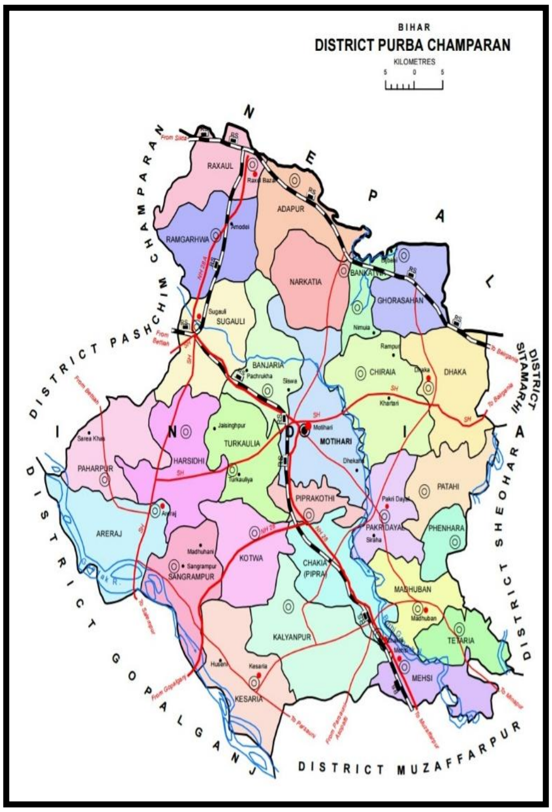


**Figure: 5. Map of East Champaran**

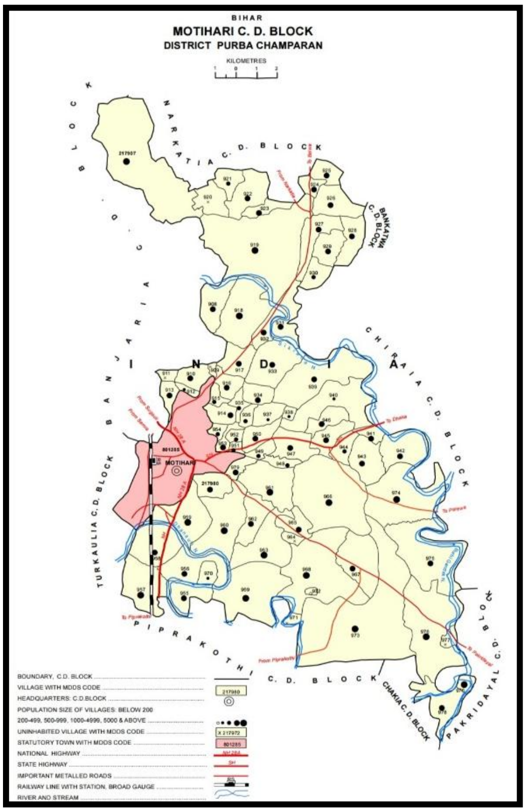


**Figure: 6. Map of Motihari Town**

The city's air pollution woes continued for several days, with Motihari, Siwan, and Darbhanga ranking among the most polluted places in the country on November 12, 2022, with AQI values of 419, 417, and 404, respectively. Motihari's poor air quality persisted, topping the list of India's most polluted towns on multiple occasions, including November 17, 2022 (AQI 448), November 20, 2022 (AQI 421), November 21, 2022 (AQI 423), November 28, 2022 (AQI 402), November 29, 2022 (AQI 418) and December 22, 2022 (AQI 171). In the last week of October 2023, Motihari's Air Quality Index (AQI) fluctuated significantly. The AQI readings were as follows: October 25: (AQI 111), October 26: (AQI 154), October 27: (AQI 199), October 28: (AQI 185), October 29: (AQI 186), October 30: (AQI 216) and October 31: (AQI 205). This period saw a notable deterioration in air quality, with the AQI crossing the 200 marks on multiple days, indicating poor air quality. These alarming AQI values indicate severe air pollution, posing serious health risks to residents & visitors alike.

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**Table: 2. AQI of Motihari town during November & December 2022 and October 2023.**

| 2022 | | | 2023 | | |
|---|---|---|---|---|---|
| Date | **AQI Value** | **Health Risk** | **Date** | **AQI Value** | **Health Risk** |
| **November 12, 2022** | 419 | Hazardous. | October 25, 2023 | 111 | Unhealthy for sensitive groups. |
| **November 17, 2022** | 448 | Hazardous. | October 26, 2023 | 154 | Unhealthy. |
| **November 20, 2022** | 421 | Hazardous. | October 27, 2023 | 199 | Unhealthy. |
| **November 21, 2022** | 423 | Hazardous. | October 28, 2023 | 185 | Unhealthy. |
| **November 28, 2022** | 402 | Hazardous. | October 29, 2023 | 186 | Unhealthy. |
| **November 29, 2022** | 418 | Hazardous. | October 30, 2023 | 216 | Very unhealthy. |
| **December 22, 2022** | 171 | Unhealthy | October 31, 2023 | 205 | Very unhealthy. |

**Potential Causes of High AQI observed in Motihari Town**

Field observations (Table 2) reveals that rapid urbanization, increased vehicular emissions, road congestion, plastic burning by shopkeepers & roadside vendors especially during morning time in urban settlements (fig. 7, 8 & 9), domestic or household air pollution, construction works (including several ongoing projects of flyover /ROB construction at Chandmari – Balua Tal – Town Police Station Road (fig. 10), & Chhatauni Chowk; Motihari railway station upgradation work, road construction works etc.), toxic emissions from several brick factory situated around Motihari town, increased practice of burning egg trays (cardboard egg carton) as mosquito repellent by almost all vegetable and other roadside vendors in urban markets during evening, loading/unloading cement bags from railway goods wagon on trucks or trolleys at Banjaria/Ambika Nagar area, loading/unloading of sand and stone chips or concrete in residential areas from trucks to trolleys (fig. 11 & 12), dumping and burning of medical wastes by private nursing homes and hospitals, stubble burning, waste cloth burning, burning firecrackers during festival time, biomass burning and other anthropogenic activities are major contributors to the poor air quality of Motihari town. Motihari municipal Corporation, itself, dumps and burns domestic wastes including several tons of plastic daily at several places including near Tata Motors Showroom (Chhatauni-Bettiah bypass NH 28) causing severe health crisis to the city dwellers. Additionally, meteorological factors such as temperature, humidity, and wind speed play a significant role in exacerbating air pollution.

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**Figure: 7. Burning used plastic containers by a shopkeeper in Chandmari area of Motihari** (Image ©: Dr. Niraj Kumar)

## Consequences of High AQI on Human Health

Air pollution poses a significant and ongoing threat to human health and ecological stability (Guo et al., 2024). Global population growth has led to increased populations living in urban areas, subsequently, enhancing stresses on space, ecosystems, infrastructures, facilities and personal lifestyles (Silva and Mendes, 2017). Problems related to quality of life in cities are increasingly relevant, especially with regard to environmental issues. Air pollution is the biggest environmental health crisis of our time. Globally, air pollution claims over 5.5 million lives every year, making it a critical public health concern that warrants attention and action. The potential rather fatal consequences of high AQI on human health, including increased morbidity and mortality due to respiratory and cardiovascular diseases, are also increased in recent period. In 2017, half of the deaths caused by air pollution were in China and India, the world's two most populous developing countries, while the air pollution mortality rate in high-income countries was below the global average (China Power Team & Wu et al., 2021). Globally, air pollution is increasingly recognised as a trigger for the exacerbation of cardiovascular and respiratory conditions such as chronic cough, asthma, chronic obstructive pulmonary disease (COPD) and heart attacks (Smallbone; Bellamy and Harris, 2005; Holgate and Polosa, 2006; Niedell and Kinney, 2008; Grineski et al., 2010; Silverman and Ito, 2010).

Accurate determination of the atmospheric particulate matter mass concentration and chemical composition is helpful in exploring the causes and sources of atmospheric enthalpy pollution and in evaluating the rationality of environmental air quality control strategies (Wang et al. 2019). The deleterious effects of Particulate Matter exposure on human health, particularly when particle diameters are below 2.5 µm (PM2.5), are well known. PM2.5 plays a particularly nasty role in human health during winter months, when its concentration often spikes and exposure ramps up. During winter, PM2.5 levels surge due to increased emissions from heating sources (think coal, wood, or diesel burned for warmth), vehicle exhaust, and industrial activity, all while cold, stagnant air and temperature inversions trap these particles close to the ground. Unlike larger particles, PM2.5 is small enough to penetrate deep into the lungs and even cross into the bloodstream, making it a stealthy health wrecker.

On the respiratory front, it's a major irritant. In winter, when immune systems are already battling colds and flu, PM2.5 aggravates conditions like asthma and chronic obstructive pulmonary disease (COPD). It inflames airways, triggers coughing, and worsens shortness of breath, hospital admissions for these issues often surge when AQI hits hazardous levels. For kids and the elderly, whose lungs are less resilient, the risk is even higher. Beyond the lungs, PM2.5 messes with the cardiovascular system. Once in the bloodstream, it causes inflammation and oxidative stress, ramping up the risk of heart attacks, strokes, and hypertension. Studies show winter spikes in PM2.5 correlate with more cardiac emergencies, cold weather already strains the heart, and this stuff pours fuel on the fire. Then there's the long-term toll. Prolonged exposure during winter months, especially in smog-choked cities, is linked to chronic diseases like lung cancer and diabetes. It's not just a seasonal nuisance - PM2.5 particles carry toxic hitchhikers (heavy metals, polycyclic aromatic hydrocarbons) that build up in the body over time. Winter makes it worse because people are cooped up indoors with poor ventilation or stuck outside breathing the same foul air. Masks help, but not everyone wears them, and indoor heaters can churn out more PM2.5 if they are dirty or fuel-based.

**Figure: 8. Shopkeepers burning plastic wastes outside their shops at very busy Balua Market, Motihari** (Image ©: Dr. Niraj Kumar)

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**Figure: 9. A rickshaw puller sitting near the burning tyre for heat (Town Police Station Road, Motihari)** (Image ©: Dr. Niraj Kumar)

In addition to its designation by the International Agency for Research on Cancer as a Group 1 human carcinogen (Ji et al., 2018; Bray et al., 2018; Parkin et al., 2005 and Davila et al., 2004), particulate matter inhalation has been implicated in a range of other pathologic processes including asthma, lung cancer, cardiovascular disease, and cerebrovascular disease (Anderson et al., 2012 and Davila et al., 2004).

Approximately 300 million individuals globally suffer from asthma, and by 2025, an additional 100 million people are expected to be impacted (Tattersfield et al., 2002; Masoli et al., 2004; Taur & Patil, 2011 and Hebbar et al., 2024).

**Figure 10: Figure 10: Flyover construction work in progress at Chandmari Chowk, Motihari** (Image ©: Dr. Niraj Kumar)

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International Agency for Research on Cancer (IARC) declared in 2013 that outdoor air pollution is a substance that is carcinogenic and contributes to lung cancer. This was supported by several studies which show an increased prevalence of adenocarcinoma, even in countries with a low prevalence of smokers. The presence of one or more substances in the air for longer periods or at higher concentrations than usual, which can potentially have negative effects, is called air pollution. Aside from carbon monoxide (CO), nitrogen dioxide ($NO_2$), lead, ozone ($O_3$), and sulfur dioxide ($SO_2$), particulate matter with < 2.5 µm diameter (PM2.5) has been identified to be associated with the risk of lung cancer (Kusumawardani et al., 2023). PM10 particles have a diameter of 10 micrometers or less, and PM2.5 particles are tiny and have 2.5 micrometers or less diameter. This enables them to invade alveolar tissue and tiny airways. Benzene, dioxins, PAHs, other organic and inorganic compounds, and metals constitute the complex mixture that makes up atmospheric PM. According to a European leading to carcinogenesis (Baj et al., 2022). Micro-plastics consists of particles that range in size from 0.1 to 5000 µm, and Nano-plastics ranges from 0.001 to 0.1 µm 27% (Xue et al., 2022).

cohort study, exposure to PM2.5 increases the risk of developing lung cancer, especially lung adenocarcinoma (Kusumawardani et al., 2023 and Li et al., 2018). Research also suggests that for every 10 µg/m3 increase in PM2.5 concentrations, the risk of dying from lung cancer increases by 15- Nowadays, we cannot imagine a world without plastic, even though we have only started using it recently (Baj et al., 2022 & Geyer et al., 2017). Microplastics enter the environment as a result of larger plastic items breaking down ('secondary') and from particles originally manufactured at that size (primary) (Anderson et al., 2016). In the past few years, over 360 million metric tons of plastic have been produced worldwide each year (Global Plastic Production 1950–2020), 40% of which is single-use packaging (Fast Facts about Plastic Pollution & Rhodes, 2018). Most of it is discarded into the environment (Baj et al., 2022; Ogunola et al., 2018 and Teuten et al., 2007). Micro- and nanoplatics have been already reported to be potential carcinogenic/mutagenic substances that might cause DNA damage, (EFSA, 2016), which are water-insoluble solid particles or polymer matrices of regular or irregular shape (Campanale et al. 2020).

**Figure 11: Plastic waste dump and unloading sand on trolley at Chandmari, M. S. College Road, Motihari** (Image ©: Dr. Niraj Kumar)

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**Figure 12: Dust particles mixing in atmospheric air by loading concrete (stone) chips on trolley near M. S. College, Chandmari, Motihari, Bihar** (Image ©: Dr. Niraj Kumar)

Primary MP particles are the ingredients of cleaning agents (Gregory, 1996), toothpastes (Sharma & Chatterjee, 2017), scrubs (Fendall & Sewell, 2009), hand soaps (Napper et al., 2015) or biomedical products (Shi et al., 2009). Burning plastics release particulate matter, volatile organic compounds (VOCs), and polycyclic aromatic hydrocarbons (PAHs), which can cause respiratory issues like asthma, bronchitis, and lung cancer. Burning plastics can also release neurotoxins like polybrominated diphenyl ethers (PBDEs), which can damage the nervous system and lead to cognitive impairment, memory loss, and other neurological problems. Long-term exposure to poor air quality from burning plastics can increase the risk of cardiovascular disease, including heart attacks, strokes, and high blood pressure. Long-term exposure to PM2.5 is also linked to anaemia in woman of reproductive age in India.

According to USEPA, Ozone, a gas made up of three oxygen atoms, exists in two distinct forms: beneficial upper-atmospheric ozone and harmful ground-level ozone. The latter, also known as tropospheric ozone, is not emitted directly but forms through chemical reactions between pollutants like nitrogen oxides (NOx) and volatile organic compounds (VOCs) (fig. 13). These reactions occur when emissions from sources such as vehicles, power plants, and industrial activities interact with sunlight.

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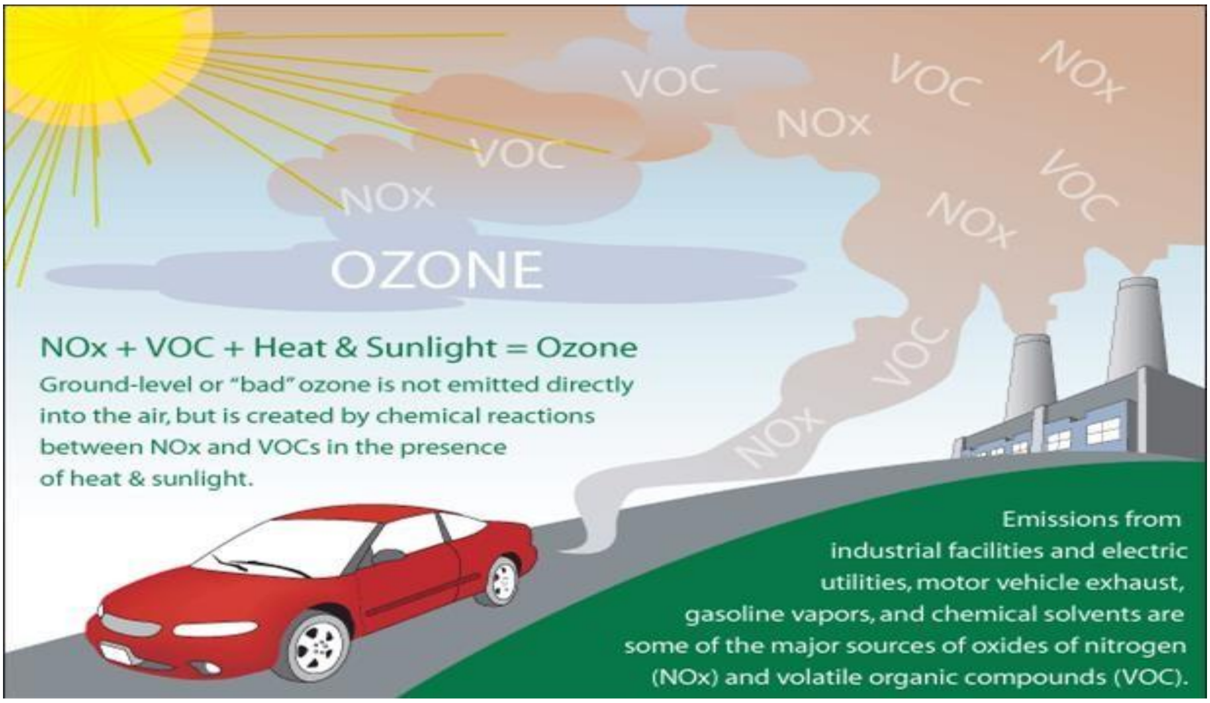


**Figure 13: Formation of ground-level ozone or $O_3$** (Image ©: USEPA)

**Recommendations:**

The study highlights the need for urgent policy interventions; strict implication of law including emission control measures; increased use of clean energy; strict implication of air (prevention & control of pollution) act of 1981; imposing heavy penalties for violating air pollution regulations; complete ban on vehicles older than 15 years from circulation; complete ban and implementation of strict penalties on manufacture, import, stocking, distribution, sell of single-use plastic products (including plastic bags, small plastic bottles, plastic plates, plastic straws, plastic cups, plastic sachets etc.); use of biodegradable or reusable alternatives to plastics whenever possible; promoting CNG operated or electric vehicles (as most of the CO in the ambient air comes from vehicle exhaust); plantation and increase of green cover in urban areas and public awareness campaigns to mitigate air pollution crisis of Motihari town. Individual actions can contribute to a larger positive impact on the environment and public health.

**Conclusion:**

The hazardous air quality index in Motihari town during winter often stems from a combination of intensified human activities and seasonal atmospheric conditions. Key causes include increased emissions from heating (e.g., coal, wood, or fossil fuels), vehicular exhaust, and output from construction sites, all of which release pollutants like PM2.5, PM10, nitrogen oxides, and sulfur dioxide. Cold weather exacerbates this by trapping pollutants under temperature inversions – where a layer of warm air prevents the dispersion of cooler, polluted air near the ground – leading to smog and prolonged exposure.

Winter's hazardous AQI is a vicious cycle of human-driven emissions and nature's atmospheric quirks, with ripple effects that hit health, economies, and the environment hard. Breaking it demands cleaner energy, smarter urban planning, and public awareness. The consequences are stark. Public health bears the brunt, with spikes in respiratory illnesses (e.g., asthma, bronchitis), cardiovascular strain, and even premature mortality, particularly among vulnerable groups like children and the elderly. Economically, productivity dips due to sick days, while healthcare costs soar. Environmentally, ecosystems suffer as pollutants settle on soil and water, disrupting plant life and wildlife. Socially, hazardous AQI restricts outdoor activity, eroding quality of life and straining urban infrastructure as mitigation measures – like traffic bans or shutdowns.

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