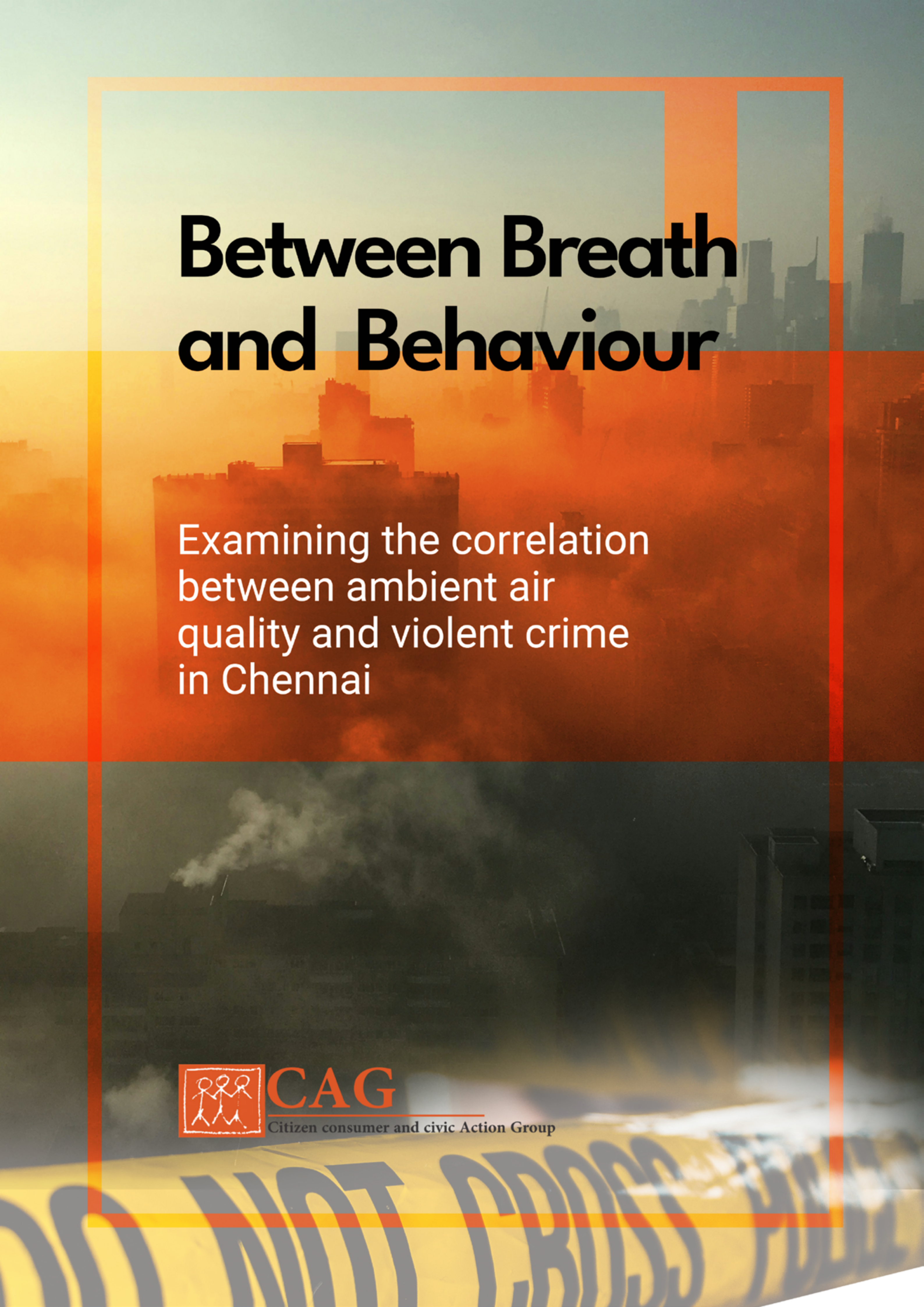

Between Breath and Behaviour

Examining the correlation between ambient air quality and violent crime in Chennai

CAG
Citizen consumer and civic Action Group

Author

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Acknowledgements

This study would not have been realised without the crucial air quality and violent crime data. Therefore, it is fitting to express gratitude to the individuals who played a key role in procuring this data.

The author extends sincere thanks to Mr. A. Udhayan IFS, former Chairperson of the Tamil Nadu Pollution Control Board, for his invaluable support in helping the researcher obtain the air quality data. Appreciation is also extended to Mr. R. Kannan, Member Secretary of the Tamil Nadu Pollution Control Board, for granting the necessary permissions to access air quality data from the Advanced Environmental Laboratory. Special acknowledgement is due to Mr. Sankarasubramanian, Deputy Director (Labs), for his insightful explanations on the distinctions between manual air quality monitoring and real-time continuous air quality monitoring. His insights have significantly shaped the direction of this study.

The author is profoundly grateful to Dr. J. Loganathan IPS, former Additional Commissioner of Police, Headquarters, Greater Chennai Police, for his openness to understanding the study and for granting the necessary permissions to access violent crime data from the Crime Records Bureau. Thanks are also extended to Mr. S. Seetharam, Inspector of Police, Crime Records Bureau, Greater Chennai Police, for his assistance in providing the required violent crime data. Thanks to Ms. Richa Shubhangi for designing this report.

Furthermore, the author would like to express gratitude to Mr. Vamsi Sankar Kapilavai and Mrs. S. Saroja for their critical review of the report. The communications team also deserves thanks for their diligent work in editing the report. This acknowledgment underscores the collaborative effort that has made this study possible, and the author extends heartfelt thanks to all involved.

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Suggested citation

Shankar Prakash, A. 2023. "Between breath and behaviour: Examining the correlation between ambient air quality and violent crime in Chennai | CAG". cag.org.in.

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CAG is a 38-year-old non-profit and non-political organisation that works towards protecting citizens' rights in consumer, civic and environmental issues and promoting good governance processes including transparency, accountability and participatory decision-making.

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EXECUTIVE SUMMARY

This study examined the relationship between air quality and violent crime in various localities in Chennai, India, using data from the Tamil Nadu Pollution Control Board and the Greater Chennai Police. The analysis focused on four key air pollutants: Nitrogen Dioxide, Sulphur Dioxide, Particulate Matters ($PM_{2.5}$ and PM_{10}) and their correlation with violent crimes such as murder, attempted murder, grievous hurt, robbery and dacoity.

Air quality has a significant impact on public health, affecting respiratory and cardiovascular systems and leading to a range of health issues. Poor air quality can also indirectly influence social behaviours, including crime rates, by affecting mental health. Understanding the relationship between air quality and violent crime is complex and involves considering various factors.

Key findings from the study include:

Air quality: In most monitoring stations, NO_2 and SO_2 levels are within the National Ambient Air Quality Standards. However, PM_{10} and $PM_{2.5}$ levels fluctuate significantly, likely due to factors such as vehicular traffic and dust from construction and infrastructure development activities.

Murder and Attempted Murder: A significant correlation was observed between these violent crimes and air pollutants in certain localities. However, the strength of correlation was either very weak or weak, suggesting other factors may also play a significant role.

Robbery: A significant but very weak or weak correlation was observed with NO_2, SO_2, and PM_{10}.

Grievous Hurt and Dacoity: No significant relationship was observed between these violent crimes and air quality.

Overall Violent Crime: A significant but very weak correlation was observed between NO_2, SO_2, and PM_{10} and violent crime. No significant correlation was observed between $PM_{2.5}$ and violent crime.

It's important to note that while the study found statistical correlations between air quality and violent crime, it did not establish a causal relationship. The observed associations may be influenced by various confounding factors and complex interactions between environmental, social, and individual factors. Therefore, further research is needed to understand the causation by factoring in various human physiological and socio-environmental factors.

While the study provides a compelling starting point, it underscores the need for further research in this area to fully understand the complex interplay between air quality, public health, and violent crime. This would not only enhance our understanding of the relationships between these factors but also inform the development of effective strategies for environmental management and violent crime prevention in Chennai.

1. INTRODUCTION

Air quality has become a global issue of concern, particularly in developing countries like India.

Since the liberalisation policies of the 1990s, India has experienced significant economic growth, rapid urbanisation, industrialisation, and infrastructure development. However, with the rapid expansion of cities, maintaining air quality has emerged as one of the most significant environmental challenges. Efforts are underway to improve both the ambient air quality in urban areas and indoor air quality in rural areas (NRDC 2019; Jain 2023). However, addressing issues related to ambient air quality requires a coordinated approach from all relevant stakeholders.

Air quality is assessed based on benchmarks set by the World Health Organisation (WHO) and national authorities such as India's Central Pollution Control Board (CPCB). These benchmarks mainly focus on pollutants like particulate matter ($PM_{2.5}$ and PM_{10}), ozone (O_3), nitrogen dioxide (NO_2), sulphur dioxide (SO_2), and carbon monoxide (CO). It's common to see differences between the standards set by WHO and CPCB.

For instance, the latest 24-hour standard for SO_2 set by WHO is 40, while CPCB's 24-hour standard for SO_2 is 80 (WHO 2021; CPCB 2009).

This discrepancy in standards can be attributed to various factors, including differing environmental conditions, technological capabilities, economic factors, and air pollution-related epidemiological studies (Gurjar 2021). Air pollution, often identified as a significant contributor to the deterioration of air quality, involves the release of harmful gases, dust, and smoke into the atmosphere.This contamination has profound and damaging effects on humans, animals, and plants.

It primarily consists of pollutants such as gases, particles, and biological molecules that pose a threat to human health and the environment. Amid these challenges, substantial evidence underscores the direct correlation between air pollution and public health. Exposure to polluted air has been linked to a variety of health problems, including respiratory and brain disorders and heart diseases (WHO 2023). Certain groups, such as children and the elderly, are particularly susceptible (UNEP 2018).

1.1 National Air Quality Monitoring Programme

The CPCB is leading a nationwide effort called the National Air Quality Monitoring Programme (NAMP). As of June 2023, this initiative comprises 931 manual air quality monitoring stations that track air quality in 398 cities and towns across 28 states and 7 Union Territories (CPCB 2023).

NAMP has several objectives, including

- assessing ambient air quality,
- ensuring compliance with air quality standards,
- pinpointing cities failing to meet these standards, and
- gathering information to develop pollution control and correction strategies.

It also seeks to understand natural processes that mitigate pollution, such as air dilution, dispersion, wind patterns, dry deposition, precipitation, and chemical transformations of pollutants.

NAMP monitors four key air pollutants (NO_2, SO_2, $PM_{2.5}$ and PM_{10}) at all locations and integrates meteorological data like wind speed, direction, relative humidity, and temperature with air quality data (CPCB 2021). The program monitors pollutants round-the-clock with different sampling frequencies, conducting gaseous pollutant sampling every 4 hours and particulate matter sampling every 8 hours, resulting in 104 observations annually. To maintain consistency in air quality data, the CPCB collaborates with State Pollution Control Boards, Pollution Control Committees, and the National Environmental Engineering Research Institute (NEERI). These agencies receive technical and financial support from the CPCB to operate air quality monitoring stations.

Due to the involvement of various personnel and equipment in the sampling and data analysis processes, there's a potential for variability and personal biases in the data. Therefore, it's crucial to consider these data as indicative rather than absolute (CPCB 2021).

1.2 National Clean Air Programme

In January 2019, the Ministry of Environment, Forest and Climate Change (MoEFCC) initiated the National Clean Air Programme (NCAP).

The primary objective of this programme is to enhance the air quality in 131 cities, which includes non-attainment cities and Million Plus Cities, across 24 States/UTs. This initiative encourages the participation of all relevant stakeholders including pollution control boards and local bodies.

The programme aims to achieve a reduction in PM_{10} concentrations up to 40% or meet the National Ambient Air Quality Standards (NAAQS) by 2025-2026. Under the NCAP, 82 cities have been assigned an annual target of reducing PM_{10} levels by 3-15%. Additionally, 49 cities that fall under the XV Finance Commission air quality grant have been set an annual target of reducing the average annual PM_{10} concentrations by 15%. While both programmes aim to improve air quality in India, NAMP focuses on monitoring air quality across the country, while NCAP aims to reduce particulate matter concentrations in the atmosphere (MoEFCC 2023).

1.3 Air quality and health

The link between the quality of air and health of the public is a significant and widely researched topic. The detrimental effects on human health are often associated with poor air quality, typically marked by high levels of pollutants in the air.

This correlation has been investigated in countless scientific research, and the findings repeatedly highlight the necessity to tackle air pollution for the global population's health. For instance, as per a study by the Lancet Commission on pollution and health, air pollution was the foremost environmental contributor to disease and early death globally in 2019, causing 6.7 million fatalities.In the same year, over 1.67 million premature deaths in India were attributed to air pollution, accounting for 25% of the global total (Fuller et al. 2022; Pandey et al. 2021).

One of the most well-documented associations between air quality and public health is its impact on respiratory health. High levels of pollutants like fine particuwlate matter ($PM_{2..5}$) and ground-level ozone are linked to an increased risk of respiratory conditions, including asthma, and chronic obstructive pulmonary disease (Ojha et al. 2022). Poor air quality is not limited to its impact on the respiratory system.

Numerous studies have shown a strong connection between air pollution and cardiovascular health. One such research examining the global burden of disease suggests that air pollution is a major risk factor for heart disease and stroke (Feigin et al. 2016; Sajith Kumar, Sasidharan, and Bagepally 2023).

Another study discusses the direct and indirect mechanisms of particulate matter-induced cardiovascular dysfunction like myocardial infarction, the elevation of blood pressure, cardiac arrhythmias, atherosclerosis, and thrombosis (Ain and Qamar 2021).

Several studies have demonstrated NO_2, SO_2, and carbon monoxide are significant pollutants that affect human health.

Chen et al (2007) observed that exposure to NO_2 in high concentrations and confined spaces has led to severe harm, even fatalities, in humans. The interaction of NO_2 with the immune system in an ambient environment can potentially heighten the risk of infections in the respiratory tract. SO_2 plays a role in causing respiratory issues in both healthy individuals and those with pre-existing lung conditions. Studies involving controlled human exposure have shown that SO_2 can alter lung function, leading to increased resistance in the airways. Exposure to carbon monoxide, whether short-term or long-term, is linked with a heightened risk of negative events related to the heart and lungs, including death.

Numerous research studies have highlighted the link between air pollution and mental health.

A comprehensive systematic review by Zundel et al (2022) delved into this body of research and found that exposure to polluted air can result in alterations in the brain areas that regulate emotions. This could potentially heighten the risk of mental health disorders such as anxiety and depression. The review further elaborated on the biological mechanisms involved, noting an increase in inflammation and oxidative stress, as well as changes in neurotransmitters and neuromodulators, along with their metabolites.

These physiological changes were detected in several brain regions, with a particular emphasis on the hippocampus, prefrontal cortex (PFC), and amygdala. The study by Oudin et al (2018) combined data on daily air pollution concentrations, including respirable PM_{10}, O_3, and NO_2, with data on daily visits to the psychiatric emergency units. The analysis revealed that visits to the psychiatric emergency unit increased with rising PM_{10} levels during the warmer season. However, no clear associations were found between the number of visits and NO_2, O_3, or PM_{10} during the colder season.

The results suggest that ambient air particle concentrations may exacerbate underlying psychiatric disorders or increase mental distress, even in areas with comparatively low levels of air pollution.

A study conducted by Balakrishnan and Tsaneva (2023) investigates the influence of air pollution exposure on mental health in India, demonstrating that increased pollution levels significantly affect feelings of sadness, depression, cognitive challenges, and the ability to manage life's demands. The mental health consequences of air pollution exposure have significant economic ramifications, as poor mental health can lead to reduced workforce participation, increased use of healthcare services, and the perpetuation of poverty.

Countries in development like India are particularly susceptible to the negative effects of air pollution exposure due to their high pollution levels, substantial disease burdens, and insufficient social safety nets. Considering the large population, it's crucial to comprehend the effects of pollution exposure on mental health.

This understanding will aid in the creation of optimal environmental and social policies that consider both the physical and mental health costs of pollution exposure. Thus, these studies demonstrate that air pollution could have widespread effects on brain function and structure, underscoring the need for further research and public health interventions.

1.4 Air quality and violent crime

Aggression often plays a significant role in violent crime (Goldstein 1986; Siever 2008), and some of the earliest studies have sought to understand the connections between air pollution and physical aggression. For instance, Jones and Bogat (1978) explored the impact of irritant air pollution on human aggression. They discovered that exposure to second-hand smoke significantly heightened aggression in both angered and non-angered subjects compared to those exposed to clean air.

Another study aimed to differentiate between the direct and indirect effects of air pollution. Direct effects refer to physiological reactions to toxic substances, while indirect effects relate to the irritation, displeasure, and annoyance caused by inhaling polluted air.It's important to note that people often perceive pollution as both unpleasant and toxic, but these two characteristics don't always coincide. For example, carbon monoxide is odourless yet extremely harmful to human health, while substances like ammonium sulphide and butyric acid have a terrible smell but pose no real threat to respiratory health. Thus, the study suggests that a moderately unpleasant pollutant might also increase aggressive behaviour. However, an extremely unpleasant one could inhibit aggressive behaviour by triggering escape responses that are incompatible with aggression.This research underscores the complex relationship between environmental factors like air pollution and human behaviour (Rotton et al. 1979).

In line with above, in another study conducted by Rotton and Frey (1985), time-series data was used to demonstrate a correlation between air pollution, weather patterns and assaults on individuals.

The findings showed a positive correlation between daily temperatures and assaults, and a negative correlation with wind speed and humidity levels.

The study further revealed that violent incidents were often preceded by high temperatures and low wind conditions and were more frequent on dry days compared to humid ones. Interestingly, the study also found a tconnection between family disturbance complaints and subsequent assaults, suggesting that these complaints could potentially be used as predictors to mitigate physical violence. The conclusion drawn from the study was that there seems to be not just a correlation, but also a causal link between atmospheric conditions, including the presence of pollutants, and violent episodes.

Research has shown a significant correlation between childhood lead exposure, which can result in impulsivity, aggressivity, and low intelligence quotient, and an increased propensity for criminal behaviour in adulthood. The 1970 Clean Air Act's significant reduction in lead exposure, particularly the removal of lead from gasoline between 1975 and 1985, is associated with a decrease in violent crime rates in the late 1990s and early 2000s in the United States (Reyes 2015).

Ozone exposure has been linked not directly to crime, but to mood and emotional states that could be considered precursors or risk factors for violent criminal behaviour.

Short-term exposure to ozone can significantly impact stress, irritability, impulsivity, aggressivity, and loss of control in humans and various animals. These effects are mediated through hormonal (testosterone) and neuro-chemical (serotonin) pathways (Heyes 2015).

Cross-sectional studies have associated particulate matter with increased behavioural problems. A longitudinal study found that $PM_{2.5}$ exposure during adolescence was significantly associated with increased delinquent behaviour. This suggests that long-term $PM_{2.5}$ exposure may increase delinquent behaviour among urban adolescents, with the resulting neurotoxic effect exacerbated by psychosocial adversities (Younan 2017).

In another study, Burkhardt et al (2019) found a strong positive effect of increased air pollution on violent crimes, specifically assaults. Also, Lu et al (2018) proposed that air pollution can increase criminal and unethical behaviour by increasing anxiety.

An analysis of a 9-year panel of 9,360 U.S. cities found that air pollution including carbon monoxide, NO_2, SO_2, $PM_{2.5}$ and PM_{10} predicted murder, rape, assault, and burglary. In addition to studies measuring the effect of lead, ozone and $PM_{2.5}$, it was found that carbon monoxide emissions have little effect on the overall level of physical violence displayed by a criminal offender. However, both the offender's race and sex moderate the relationship between air pollution and victim injury. As carbon monoxide levels rise in a city, both black and male offenders are more likely to physically injure their victims in the United States (Cruz, 2022).

The concentration of ozone, fine dust, and nitrogen dioxide identified the significant impacts of air pollution on assault rates. Ozone is expected to induce more assaults both locally and regionally. Fine dust decreases assault rates in an area and its neighbouring areas. NO_2 yields positive effects on the surrounding areas' assault rates but not in the area of pollution itself (Eum and Kim 2021).

A divergence from the above-discussed studies, Bondy, Roth, and Sager (2018) found that elevated levels of air pollution have a positive and statistically significant impact on overall crime, particularly less severe crimes.

Indeed, the body of research reviewed in this study compellingly illustrates that the impact of air pollution extends beyond its well-known effects on respiratory, heart and mental health. A variety of studies have uncovered intricate relationships between different types of air pollutants and crime rates, encompassing both violent and less severe offences. Certain pollutants appear to amplify specific types of crime rates through mechanisms such as heightened impulsivity or anxiety. Conversely, other pollutants seem to exert minimal or no influence on these rates.

These findings highlight the complexity of these relationships and underscore the pressing need for additional research including various socio-environmental factors.

Further exploration into the physiological and social mechanisms that underpin these observed effects could provide valuable insights into our understanding of the multifaceted impacts of air pollution on society.

1.4.1 Why this study

Despite daily exposure to pollutants such as particulate matter, the broader community often overlooks their impact on both physical and mental health. Interestingly, the majority of the population shows a keen interest in violent crimes, which are widely considered newsworthy and binge-worthy. This study aims to leverage this existing interest in violent crime to raise awareness about air pollution.

While there is a growing interest in the relationship between air quality and violent crime, there remains a significant gap in the literature, particularly concerning the Global South. This is especially true for countries like India, where many cities suffer from severe air quality deterioration (IANS 2023).

Both air quality and crime rates are influenced by various factors, including environmental, socio-economic, and cultural aspects specific to each region. Most of the research exploring this lesser-known relationship has been conducted in the Global North, highlighting the need for studies focused on the Global South.

This study is an attempt to explore this under-researched intersection of air quality and violent crime.The findings of this study could potentially draw significant attention from Chennai's population towards air quality issues, thereby initiating actions to mitigate them. By understanding the correlation between air quality and violent crime, we can not only address environmental concerns but also contribute to societal well-being.

1.5 Scope of the study

This study is concentrated on the geographical region of Chennai city, with the primary objective being to analyse data pertaining to ambient air quality (hereafter air quality) indices and the incidence of violent crime from January 2015 to December 2022. The analysis will encompass this specific time frame, aiming to identify any discernible trends and potential correlations that may exist between air quality and violent crime.

For the purpose of this study, air quality was measured based on indices that include the following pollutants: $NO_{2,}$ $SO_{2,}$ $PM_{2..5}$ and PM_{10}. Violent crime is defined as cases registered under the offences prescribed by the Indian Penal Code (IPC), such as murder, attempt to murder, grievous hurt, robbery, and dacoity. Although there is no specific offence classified as 'murder for gain' under the IPC, the police categorise certain offences under this heading. This category includes offences registered as murder.

The data has been analysed to determine if there are any statistical relationships between the variables. It is crucial to understand that while this study can identify and establish these statistical relationships, it cannot definitively ascertain causality. In other words, while we might observe a correlation between poor air quality and an increase in violent crime, this does not necessarily mean that one causes the other. However, the findings of this study can provide valuable insights that could be instrumental in guiding further research in this field.

2. CHENNAI: A CITY PROFILE

Chennai, once known as Madras, is the capital city of Tamil Nadu. It holds a significant position as a cultural, economic, and educational nucleus in the southern part of the country. As per the 2011 Indian Census, Chennai was home to approximately 4.54 million people residing in about 1.15 million households.

The city's population is currently estimated to be around 8.9 million, ranking it as the fourth largest city in India in terms of population. The governance of this bustling city is in the hands of the Greater Chennai Corporation (GCC), which is the oldest municipal institution in India.In 2011, the city expanded its jurisdictional area from 174 km^2 to 426 km^2. This jurisdiction includes three revenue districts within Chennai and portions of Kanchipuram and Tiruvallur (Murugesan and Alagesan 2021).

The GCC plays a pivotal role in managing approximately 15,000 licensed industries and factories within the city limits. These industries contribute significantly to the state's income, with the GCC alone accounting for 11% of it (GCC 2023). In terms of transportation, Chennai had a substantial number of registered vehicles as of 2020.

The city had around 5,70,000 commercial vehicles and about 5.78 million non-commercial vehicles plying its roads (MoRTH 2020). This extensive vehicular movement, coupled with industrial activities, inevitably impacts the city's air quality.

However, Chennai's air quality typically falls within the permissible limit set by the NAAQS, barring certain days during Bhogi and Diwali festivals when pollution levels tend to spike. The NAMP keeps a close watch on air quality, monitoring pollutants such as NO_2, SO_2, $PM_{2.5}$ and PM_{10}. To mitigate the impact on air quality, several measures are being implemented with support from CPCB and Tamil Nadu Pollution Control Board (TNPCB), GCC and other line departments.

These include enforcing emission norms, promoting public transportation to reduce vehicular pollution, increasing green spaces for better air quality, afforestation–Miyawaki forests for carbon sequestration, end-to-end paving of roads to reduce dust emissions, promoting battery-operated vehicles for a cleaner environment, and procurement of Mechanical Street Sweepers and water sprinklers to suppress dust (Government of Tamil Nadu 2023).On the crime front, Chennai recorded 1198 cases of violent crime in 2021 according to the latest Crime Review Tamil Nadu statistics published by State Crime Records Bureau (SCRB).These crimes included murder, attempt to murder, grievous hurt, robbery and dacoity (SCRB 2022).

However, it's important to note that these figures can fluctuate from year to year. The Greater Chennai Police (GCP) is dedicated to maintaining law and order in the city and works tirelessly to enhance safety for its residents.

3. METHODS

The study aims to explore the potential correlation between air quality and instances of violent crime. To gain a comprehensive understanding of the situation in Chennai city, it was initially decided to analyse data spanning at least 25 years. This necessitated the acquisition of air quality and violent crime data from two key sources: TNPCB and GCP.

A formal request for the past 25 years' data was submitted to the Member Secretary of TNPCB and the Commissioner of GCP. While the 'Crime Review Tamil Nadu Statistics' from the SCRB provides macro-level, city-wise violent crime data through the Tamil Nadu police website, it unfortunately does not include micro-level data at the police station level in the public domain.

As a result, a specific request must be made to the Commissioner of GCP to obtain these police station-wise data. The researcher had the opportunity to meet with these officials, including the Additional Commissioner of Police at GCP, to provide a detailed explanation about the study's objectives and its significance.

These meetings were fruitful, resulting in the granting of necessary permissions to access and utilise the data for the study. However, these two agencies do not have data for 25 years, but they assured to provide whatever data is available with them for this study. This marked a crucial step forward in this research endeavour, paving the way for an analysis of trends and patterns in air quality and violent crime within Chennai city.

3.1 Data and its treatment

The TNPCB has provided data spanning various periods: April to December 2015, April to December 2016, and January 2017 to December 2022. This data was collected from five manual air quality monitoring stations (AQMS) located in Anna Nagar, Thiagaraya Nagar, Adyar, Kilpauk, and Nungambakkam. The parameters included in this data are NO_2, SO_2, $PM_{2.5}$ and PM_{10}. These data files, which total about 1500 pages, were image-based scanned reports produced as part of the NAMP. It's a well-known challenge to extract data from scanned PDF files due to their non-editable nature. The reports grouped the data for NO_2, SO_2 and PM_{10} together, while $PM_{2.5}$ data was reported separately. This necessitated the researcher to calculate the monthly mean for $PM_{2.5}$ (refer to Figure 1). This process was crucial for ensuring the accuracy and consistency of the data analysis.

Sl. No.	Sampling Location, Type and Code	Month and Year	Para-meters (µg/m³)	No. of Observations			24 Hours. (µg/m³)			
				Days	4 hrs	8 hrs	Avg	Min	Max	Std. Dev
1	Anna Nagar Residential 765	January 2017	SO_2	5	30	--	9.9	8.9	10.6	0.7
			NO_2	5	30	--	15.9	14.4	17.6	1.4
			PM_{10}	5	--	15	96	73	119	18

Reporting of NO_2, SO_2 and PM_{10}

Sl. No	Date	Name of the Station	$PM_{2.5}$ (<2.5µ) (µg/m³)
1	02.01.2018	Anna Nagar	25
2	03.01.2018	Adyar	23
3	05.01.2018	Anna Nagar	43
4	09.01.2018	Adyar	13
5	18.01.2018	Anna Nagar	51
6	19.01.2018	Adyar	13
7	22.01.2018	Anna Nagar	51

Reporting of $PM_{2.5}$

Figure 1: Reporting of air quality by TNPCB

The researcher employed the Microsoft Snipping Tool and the 'Data from Picture' feature in Microsoft Excel to convert the scanned data into a format suitable for analysis. The data was organised based on each monitoring station and parameter, with the 24-hour mean for each month being considered. To ensure accuracy, meticulous verification was performed during the data transformation process to prevent any potential errors.

AQMS	Month and Year	Parameters	Mean (µg/m³)
Anna Nagar	January 2017	SO_2	9.9
		NO_2	15.9
		PM_{10}	96.0
		$PM_{2.5}$	49.3

Table 1: Transformation of TNPCB air quality data for analysis

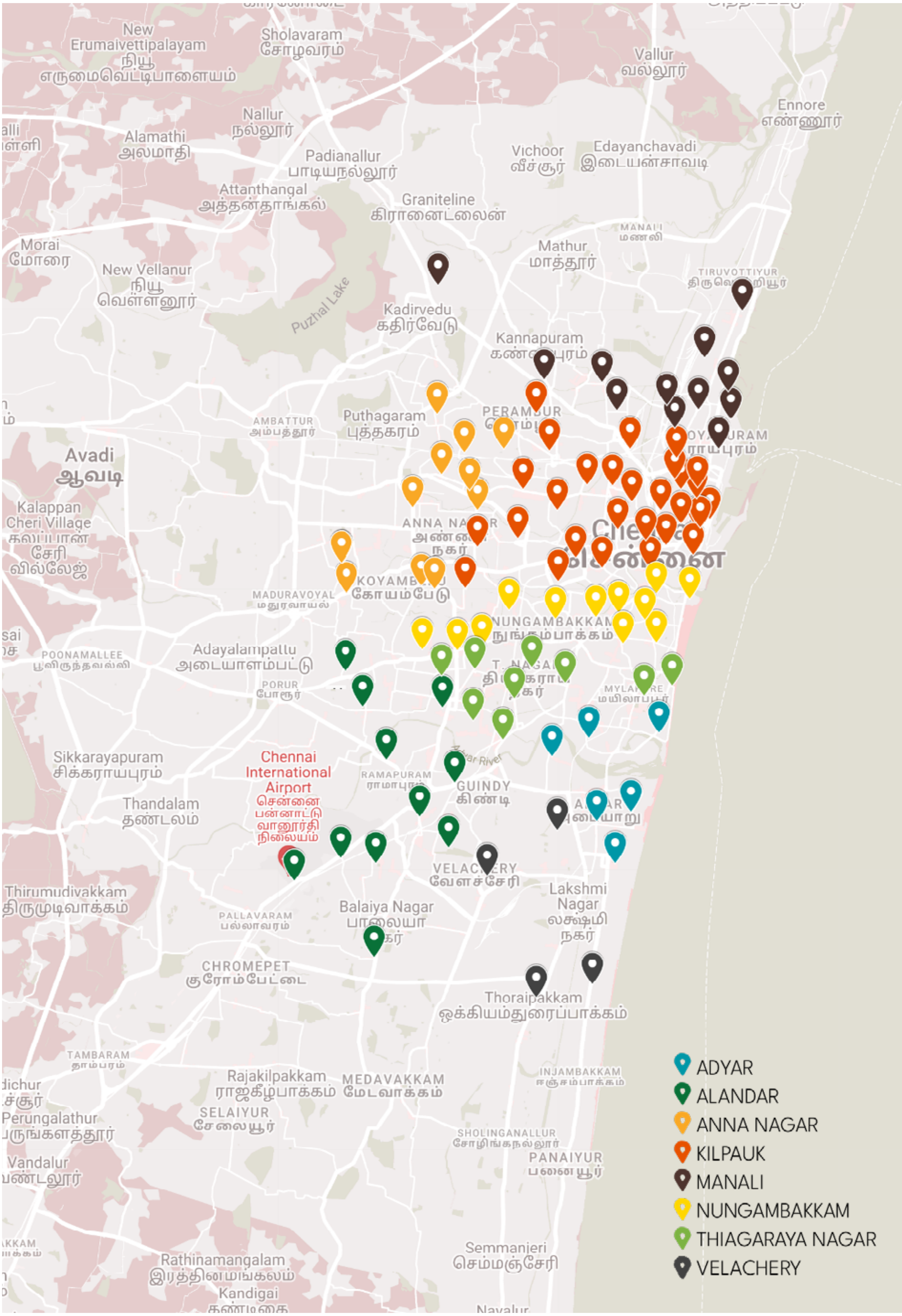
Please refer to Table 1 for a detailed view of how the TNPCB data was transformed as mentioned in Figure 1.

While the Tamil Nadu Pollution Control Board (TNPCB) provides data from only five manual air quality monitoring stations, the extensive geography of Chennai makes it challenging to cluster police stations within these five localities. The interpretation of findings would be more accurate with a higher number of monitoring stations. Therefore, in addition to the data provided by the TNPCB, the study also incorporated 24 - hour mean data from three continuous monitoring stations in Alandur, Velachery, and Manali, managed by the CPCB.

Data on violent crimes, categorised under headings such as murder, attempt to murder, grievous hurt, murder for gain, robbery, and dacoity, were obtained from the GCP for the period between January 2013 and May 2023.

AQMS	Police Station		
Adyar	E4 Abiramapuram E5 Foreshore Estate	J2 Adyar J4 Kotturpuram	J5 Sasthri Nagar J6 Thiurvanmiyur
Alandur	J3 Guindy R10 M.G R.Nagar R11 Royala Nagar R9 Valasaravakkam	S1 St.Thomas Mount S2 Airport S3 Meenambakkam S4 Nandhambakkam	S7 Madipakkam S8 Adambakkam S9 Palavanthangal
Anna Nagar	K10 Koyambedu K11 CMBT K4 Anna Nagar K5 Peravallur	K7 ICF T4 Maduravayol V1 Villivakkam V3 JJ Nagar	V4 Rajamangalam V5 Thirumangalam V6 Kolathur V7 Nolambur
Kilpauk	B1 North Beach B2 Esplanade B3 Fort B4 High court B5 Harbour C1 Flower Bazaar C2 Elephant Gate C3 Seven Wells C4 G.G Hospital OP C5 Kothavalchavadi	F1 Chindatripet F2 Egmore G1 Vepery G2 Periyamedu G3 Kilpauk G5 Sec.Colony G7 Chetpet H1 Washermenpet K1 Sembium K2 Ayanavaram	K3 Aminjikarai K6 T.P. Chatram K8 Arumbakkam K9 TVK Nagar N3 Muthial pet P1 Pulianthope P2 Otteri P3 Vyasarpadi P4 Basin Bridge
Manali	H3 Tondiyarpet H4 Korukkupet H5 New Washermenpet H6 RK Nagar	H8 Thiruvottiyur M1 Madhavaram M3 Puzhal N1 Royapuram	N2 Kasimedu N4 Fishing Harbour P5 MKB Nagar P6 Kodungaiyur
Nungambakkam	D1 Triplicane D2 Annasalai D3 Ice House D4 Zambazzar	D6 Anna Square E2 Royapettah F3 Nungambakkam F4 Thousand lights	F5 Choolaimedu R2 Kodambakkam R5 Virugambakkam R8 Vadapalani
Thiagaraya Nagar	D5 Marina E1 Mylapore E3 Teynampet	J1 Saidapet R1 Mambalam R3 Ashok Nagar	R4 S.P.Angadi R6 Kumaran Nagar R7 K.K Nagar
Velachery	J13 Taramani J7 Velachery	J8 Neelankarai	J9 Thoraipakkam

Table 2: Police stations clustered with air quality monitoring stations



Map of Chennai Police stations clustered with air quality monitoring stations

Fortunately, all this data was maintained in Microsoft Excel format by the Crime Records Bureau of GCP, which greatly facilitated its analysis. Consequently, the data sources from TNPCB, CPCB, and GCP were designated as master data files for this study. The analysis then focused on violent crimes registered at 95 police stations, excluding all-women police stations and the Central Crime Branch. It's important to note that GCP underwent a trifurcation in 2022 (Government of Tamil Nadu 2022), so only violent crimes registered under the current police stations with GCP were considered.

The next critical step in the analysis involved clustering the 95 police stations to the eight air quality monitoring stations. The GIS coordinates (latitude and longitude in decimal degrees) for all police and air quality monitoring stations were collected. Utilising ArcGIS Pro's proximity analysis functionality and near tool geoprocessing, police stations were clustered to air quality monitoring stations based on their nearest distance in decimal degrees (see Table 2). This resulted in a formulated dataset of violent crimes registered at police stations clustered to their nearest air quality monitoring station.

Month and Year	AQMS	Police Station	Murder	Attempt to Murder	Grievous Hurt	Murder for Gain	Robbery	Dacoity
January 2015	Adyar	E4 Abiramapuram	0	0	0	0	0	0
		E5 Foreshore Estate	0	0	0	0	0	0
		J2 Adyar	0	0	0	0	0	0
		J4 Kotturpuram	0	0	0	0	0	0
		J5 Sasthri Nagar	0	0	0	0	0	0
		J6 Thiurvanmiyur	0	0	0	0	0	0

Table 3: Transformation of GCP violent crime data for analysis

The violent crimes registered each month from 2015 to 2022 under the jurisdiction of the police stations within the air quality monitoring station were computed for final analysis, as depicted in Table 3.

3.2 Data analysis

The analysis of air quality and violent crime data was conducted in several stages. Initially, the raw data from the TNPCB and GCP datasets were transformed and cleaned to remove any inconsistencies or missing values. By inconsistencies, we refer to any discrepancies between the master data (i.e., TNPCB and GCP) and the computed data used for analysis, as illustrated in Table 4. The initial analysis of the air quality and violent crime data was carried out using Microsoft Excel. This allowed for a preliminary examination of the data and identification of any noticeable trends or patterns.

Following this, a correlation analysis was conducted to assess the strength and direction of the relationship between air quality indices and violent crime rates. Due to the non-linearity and non-normal distribution of the data, as well as the presence of outliers, Spearman's correlation coefficient was used. This non-parametric measure provides a robust assessment of the relationship between air quality and violent crime, even in the presence of these data characteristics.

ρ Value	Interpretation of the relationship
.00 - .19	Very weak
.20 - .39	Weak
.40 - .59	Moderate
.60 - .79	Strong
.80 - 1.0	Very strong

Table 4. Interpreting Spearman's Correlation Coefficient

The strength of relationship between air quality and violent crime will be interpreted based on the ρ value as described in Table 4.

Finally, IBM SPSS Statistics was used to run the correlation analysis. This advanced statistical software package allowed for a more detailed and rigorous examination of the relationships between air quality and violent crime.

AQMS	Year	Month	SO_2	NO_2	PM_{10}	$PM_{2.5}$	Murder	Attempt to Murder	Grievous Hurt	Robbery	Dacoity	Violent Crime
			(μg/m³)									
Adyar	2015	January	9.3	14.0	39.0	24.0	0	0	0	0	0	0
		February	8.7	12.8	60.0	16.0	0	1	0	0	0	1
		March	8.5	12.0	45.0	23.2	0	1	0	0	0	1
		April	13.8	17.6	37	17.4	0	0	0	1	0	1
		May	10.6	14.6	45.0	17.8	0	0	0	0	0	0
		June	10.5	14.8	48.0	12.1	0	1	0	0	1	2
		July	9.5	13.5	42.0	12.3	1	1	0	1	0	3
		August	9.8	13.8	47.0	12.2	0	2	0	0	0	2
		September	14.4	16.0	44.0	11.7	0	1	1	0	0	2
		October	10.1	12.2	46.0	16.2	0	0	0	0	0	0
		November	11.2	14.1	32.0	10.3	0	1	0	0	0	1
		December	12.8	14.2	66.0	33.0	1	1	1	0	0	3

Table 5. Computation of air quality and violent crime data for analysis

3.3 Limitations

This study does have certain limitations that need to be acknowledged. Air quality is influenced by a multitude of factors. Industrial activities in and around the city, for instance, can degrade air quality through the emission of pollutants such as particulate matter and SO_2. Similarly, heavy vehicular traffic, particularly during peak hours, can lead to increased emissions of NO_2 and particulate matter.

Meteorological conditions, including weather patterns, wind speed, and temperature, can also affect the dispersion and concentration of pollutants. Therefore, such meteorological conditions were not considered during data analysis.

One significant limitation of this study is that a statistical correlation does not necessarily imply causation.

While we can identify statistical relationships, establishing causality requires further research that includes meteorological variables and duration of exposure to polluted air. Moreover, determining the presence of air pollutants in the human body necessitates direct human testing. This involves analysing blood or tissue samples under strict ethical guidelines. These confounding variables were not accounted for in our analysis.

During the process of analysing air quality data, there were numerous instances where measurements for NO_2, SO_2, $PM_{2.5}$, and PM_{10} were missing. For instance, data for PM_{10} was only available from 2020 onwards for the locations Alandur, Manali, and Velachery. Similarly, for Nungambakkam and Thiagaraya Nagar, data for $PM_{2.5}$ was only available from 2017 onwards. In situations where only a few data points were missing, the analysis utilised data from the same month of the previous year. To illustrate, if the NO_2 data for Adyar in January 2015 was absent, the analysis would incorporate the mean NO_2 value from January 2016 instead.

Furthermore, due to the involvement of various personnel from TNPCB and GCP in the collection and compilation of air quality and violent crime data, there is potential for variability and personal biases in the data. Therefore, it's crucial to interpret these data as indicative rather than absolute.

4. FINDINGS

As previously discussed, data received from the TNPCB and the GCP were analysed to understand the air quality and violent crime situation in Chennai city. Initially, an analysis of the presence of ambient air pollutants was conducted for each monitoring station. Subsequently, the cumulative violent crimes reported at police stations, clustered according to air quality monitoring stations, were examined.

It has already been established that pollutants such as NO2, SO2, PM10, and PM2.5 have a significant impact on human health. Before discussing the study results, it would be appropriate to review the NAAQS prescribed by the CPCB.

Sl. No.	Pollutant	Concentration in ambient air in industrial and residential areas Annual weighted average ($\mu g/m^3$)
1	SO_2	50
2	NO_2	40
3	PM_{10}	60
4	$PM_{2.5}$	40

Table 6: National ambient air quality standards

4.1 Air quality in Chennai city

The following results pertain to the air quality reported in Adyar, Alandur, Anna Nagar, Kilpauk, Manali, Nungambakkam, Thiagaraya Nagar and Velachery monitoring stations. The NAAQS prescribed by the CPCB will serve as the benchmark for measuring the annual average air quality in these localities. All the measures in the figures indicate $\mu g/m^3$.

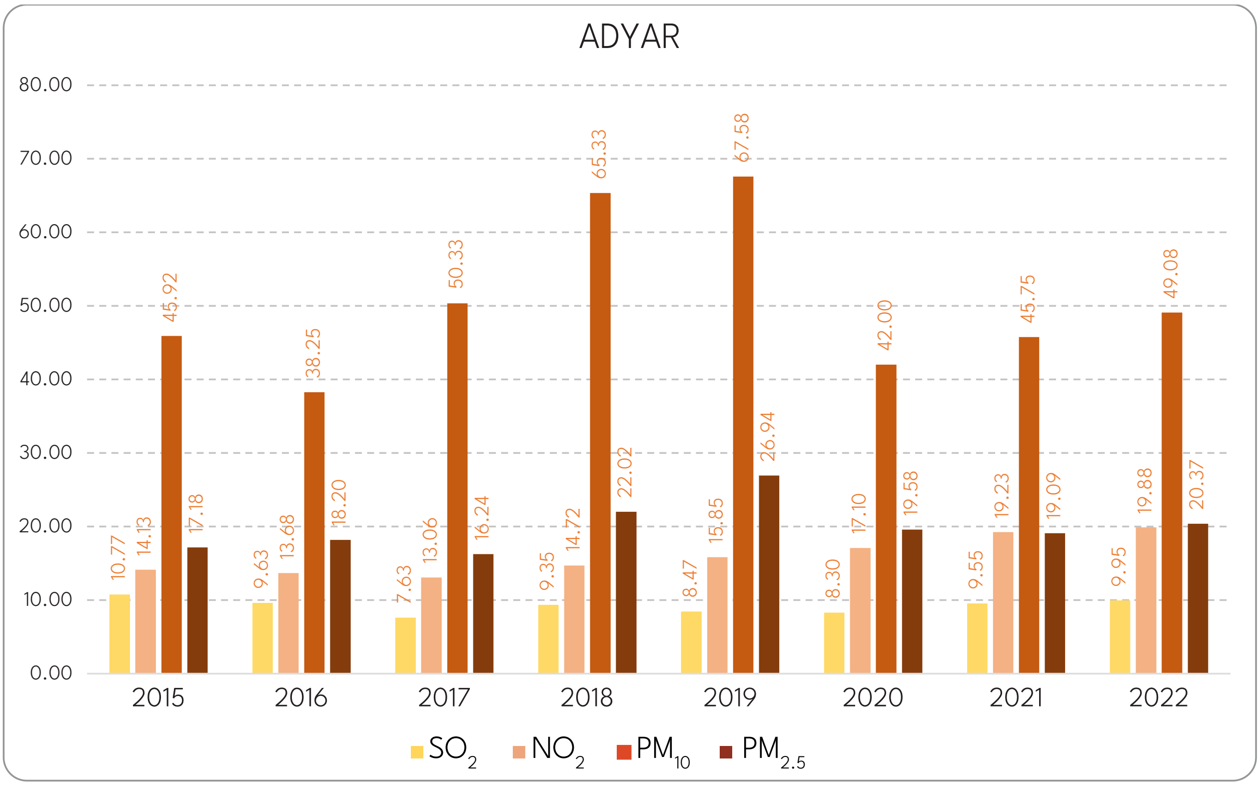


Figure 2. Air quality reported in Adyar between 2015 and 2022

Adyar is a large neighbourhood in South Chennai, renowned for its blend of residential areas and its proximity to Guindy National Park, several renowned state and central higher education institutions, and Information Technology (IT) parks. As a result, this locality experiences high vehicular traffic.

The levels of SO_2 and NO_2 in the ambient air are well within the limits prescribed by the NAAQS. For instance, over the observed eight-year period, the presence of SO_2 appears to have remained relatively stable, while there has been a gradual increase in NO_2 levels over the last five years, from 14.13 µg/m^3 in 2015 to 19.88 µg/m^3 in 2022.

Although $PM_{2.5}$ levels are within the prescribed limit, fluctuations have been observed in PM_{10} levels. For example, in 2018 (65.33 µg/m^3) and 2019 (67.78 µg/m^3), it exceeded the NAAQS (see Figure 2).

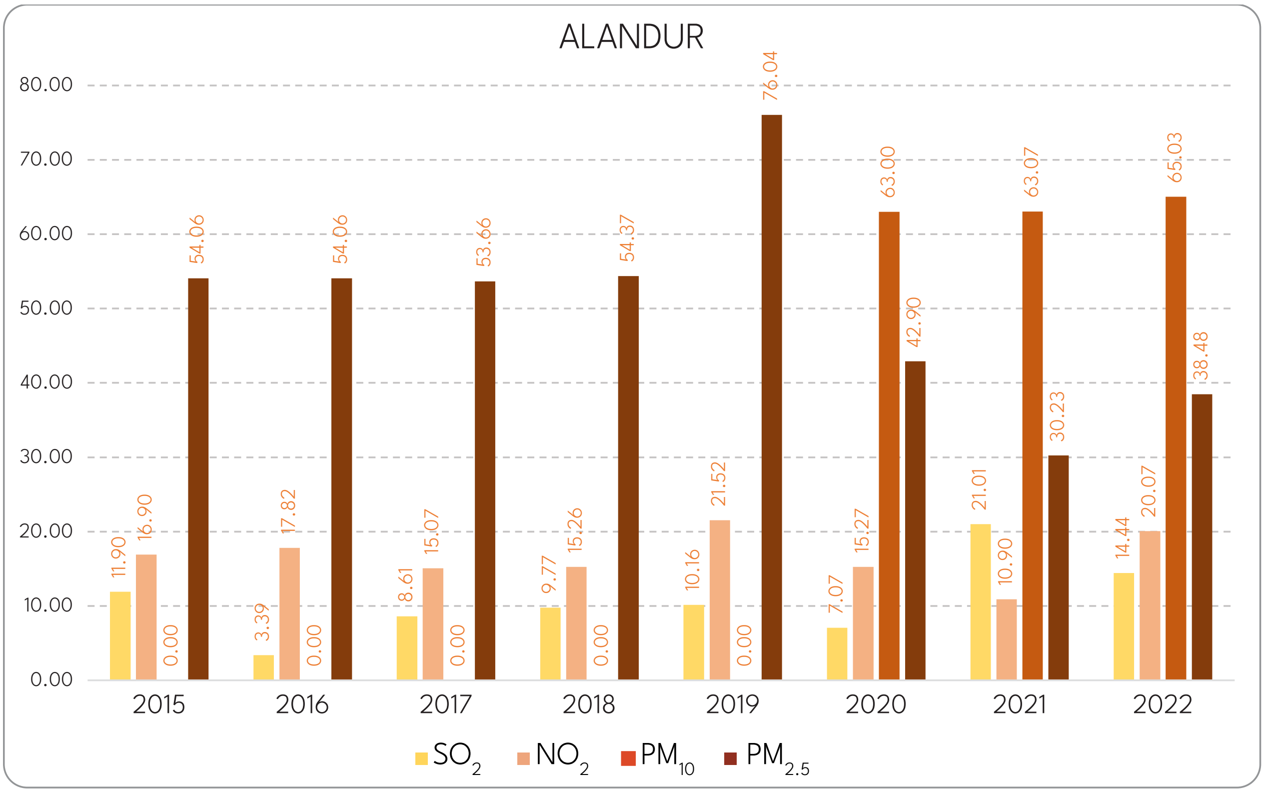


Figure 3. Air quality reported in Alandur between 2015 and 2022

The Alandur air quality monitoring station serves a variety of localities, encompassing the airport, Guindy industrial estate, IT parks, higher education institutions, and Micro, Small and Medium Enterprises (MSMEs). This region is a mix of industrial sectors and densely populated residential areas, leading to emissions from both vehicular traffic and industrial operations.

Compared to Adyar, Alandur has higher levels of SO_2 and NO_2. For instance, the highest presence of SO_2 (21.01 $\mu g/m^3$) and NO_2 (21.52 $\mu g/m^3$) was observed in 2021 and 2019 respectively (see Figure 3). Regarding PM_{10}, data is only available from 2020 onwards. The presence of PM_{10} in 2020 (65.03 $\mu g/m^3$), 2021 (63.07 $\mu g/m^3$), and 2022 (63.00 $\mu g/m^3$) exceeded the NAAQS.

Although $PM_{2.5}$ was reported to be consistently above the NAAQS between 2017 and 2020, it was within the limit in 2021 (30.23 $\mu g/m^3$) and 2022 (38.48 $\mu g/m^3$).

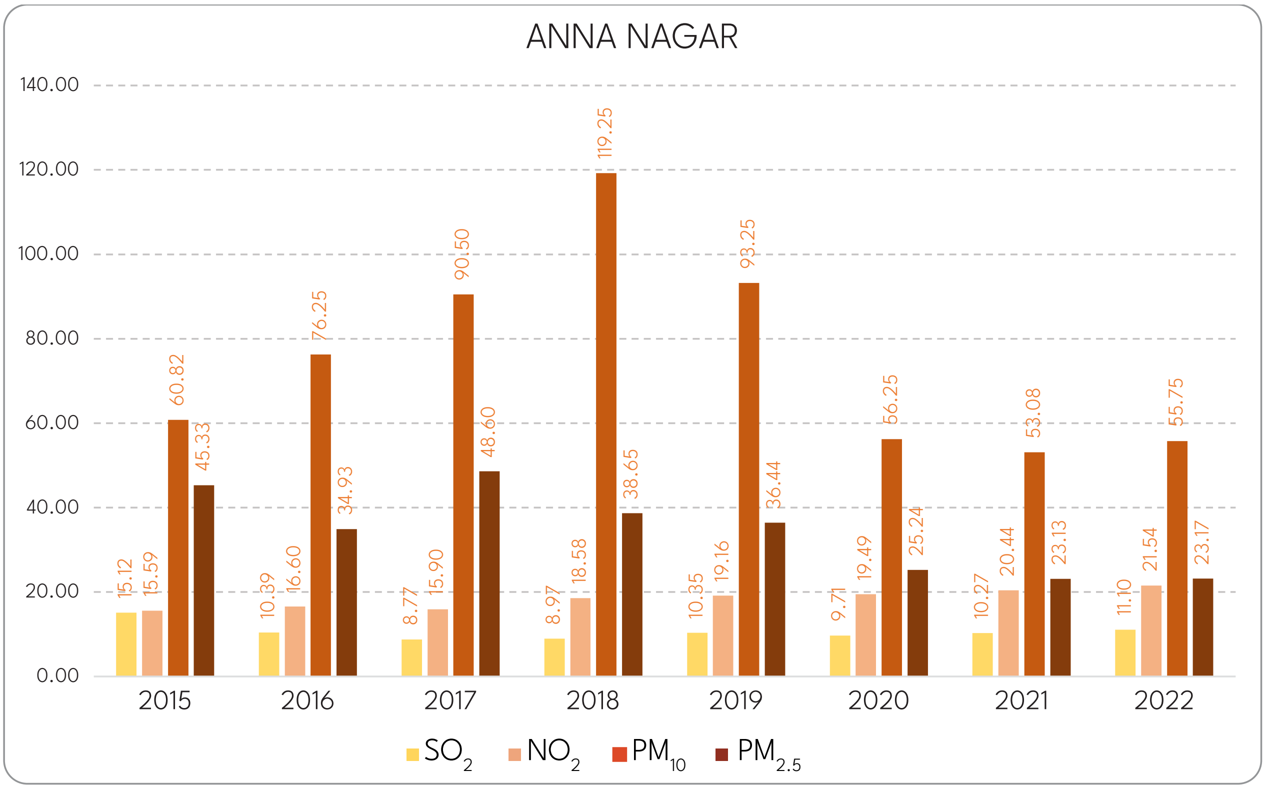


Figure 4: Air quality reported in Anna Nagar between 2015 and 2022

Anna Nagar is a diverse area that hosts the city's largest Mofussil bus terminus, the largest vegetable and fruit market, a logistics hub for various transportations, residential areas, shopping malls, the Integral Coach Factory, and industries specialising in granite, tiles, and ceramics. It also houses several water bodies and the Ambattur and Small Industries Development Corporation (SIDCO) industrial estates. As such, emissions in this area stem not only from vehicular traffic but also from industrial activities.

The emissions of SO_2 and NO_2 in Anna Nagar are within the standards. However, PM_{10} levels reached a high of 119.25 µg/m³ in 2018, before reducing to 55.75 µg/m³ in 2022. Although $PM_{2.5}$ levels exceeded the standards in 2015 (48.60 µg/m³) and 2017 (45.33 µg/m³), they have remained well within the standards for the last three years (as shown in Figure 4).

Comparatively, Anna Nagar, with its larger number of industries, exhibits different air quality characteristics than Alandur. This difference is particularly noticeable in the levels of NO_2 and PM_{10}. However, despite having fewer industries, Alandur records higher emissions of SO_2 and $PM_{2.5}$ compared to Anna Nagar. These variations in air quality can be attributed to the difference in type of industrial activities, traffic patterns and ongoing infrastructure projects in each area.

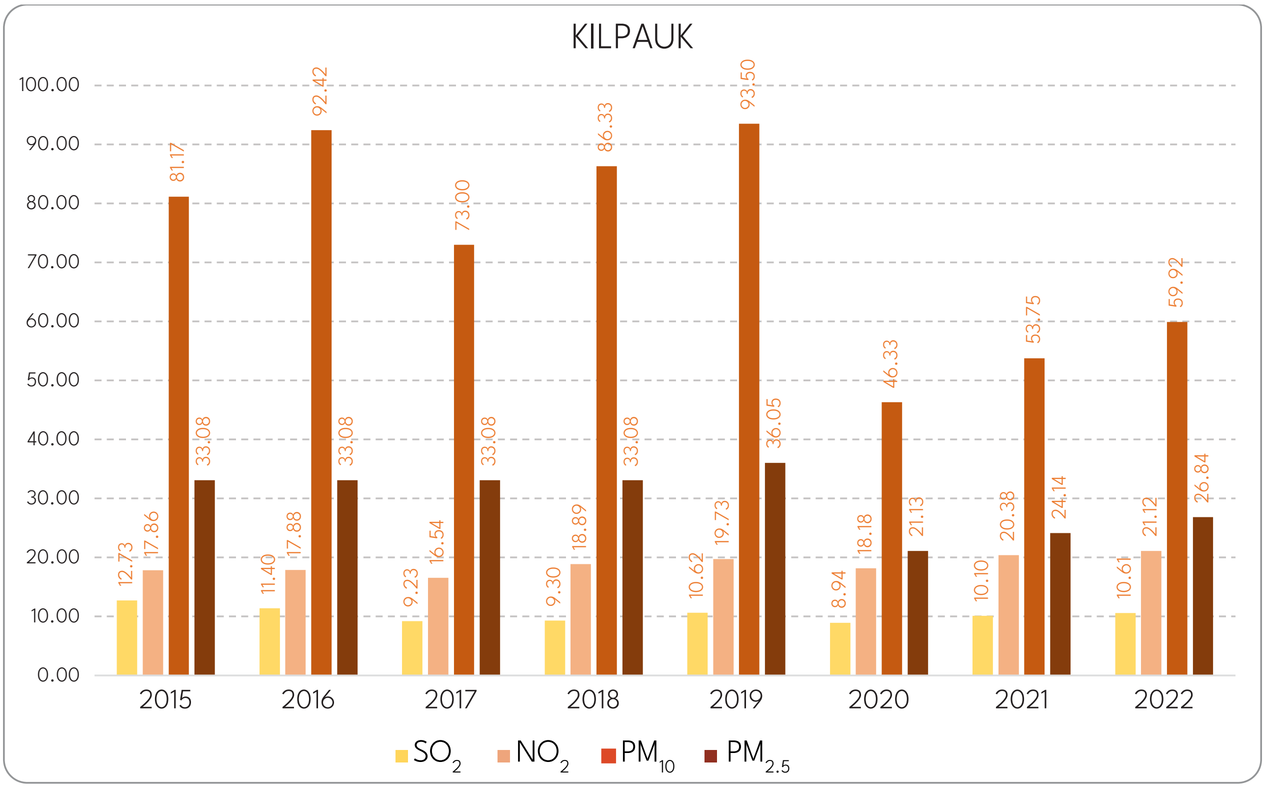


Figure 5: Air quality reported in Kilpauk between 2015 and 2022

The Kilpauk air quality monitoring station caters to a business district, a densely populated commercial area, small-scale vendors, a harbour and port, the High Court of Madras, a beach, the Secretariat of Government of Tamil Nadu, the majority of government offices, the central railway station, and a few manufacturing industries, unlike Alandur and Anna Nagar.

During the observed years, the levels of NO_2, SO_2, $PM_{2.5}$ were well within the limits set by the NAAQS. However, PM_{10} exceeded the standard in 2019, reaching 93.50 µg/m^3, but it considerably reduced to 59.92 µg/m^3 in 2022, which is almost at the cap set by the NAAQS (60 µg/m^3).

For $PM_{2.5}$, the peak level was recorded in 2019 at 36.05 µg/m^3, and it considerably reduced to 26.84 µg/m^3 in 2022.

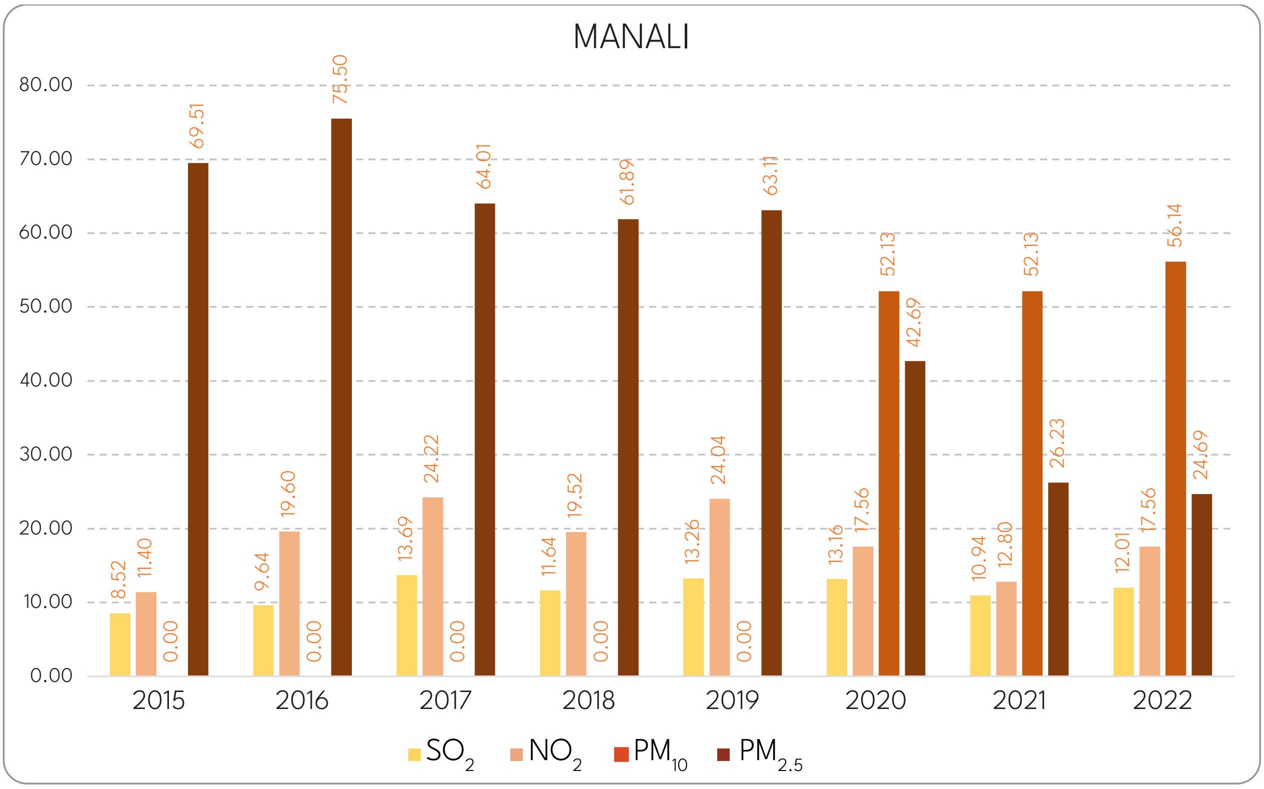


Figure 6: Air quality reported in Manali between 2015 and 2022

The Manali air quality station is situated in a locality that houses several manufacturing industries and oil refineries, incinerators, several water bodies, heavy goods vehicle movements, fishing harbours, one of the largest solid waste dump yards, and a geographically dispersed residential area.

The emissions of SO_2 and NO_2 here are within the prescribed standards. PM10 data is only available from 2020, and in 2022 it was reported to be 56.14 µg/m³. As for $PM_{2.5}$, there has been a decreasing trend from 2016 (75.50 µg/m³) to 2022 (24.69 µg/m³), which is the lowest level in the observed eight years.

When compared to Alandur and Anna Nagar, Manali recorded high NO_2 emissions in 2017 (24.22 µg/m³) and 2019 (24.04 µg/m³), which are the highest levels based on the observed eight years.

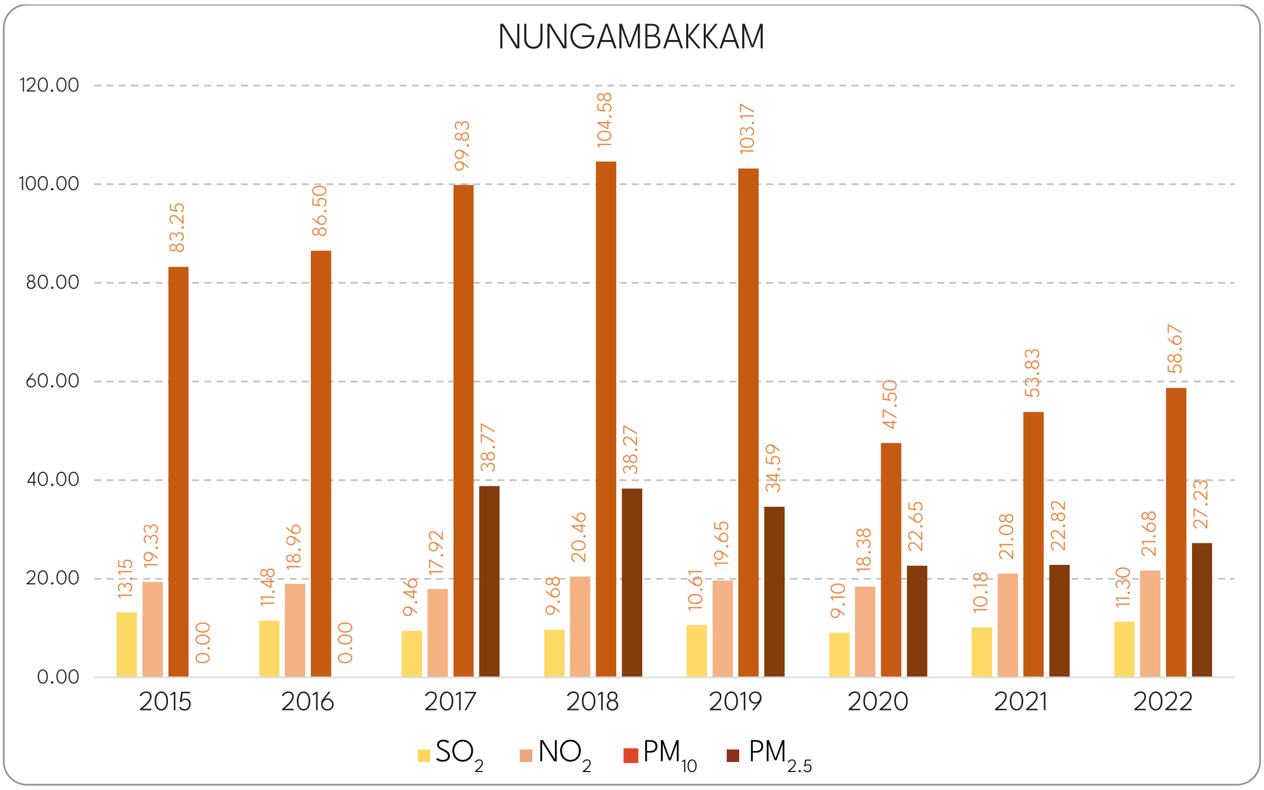


Figure 7: Air quality reported in Nungambakkam between 2015 and 2022

The Nungambakkam air quality monitoring station is located in a locality that comprises small-scale businesses, a few IT companies, several higher educational institutions, shopping malls, government offices, part of Marina beach, and a densely populated residential area. This area is the core of Chennai city and has fewer manufacturing industries compared to Alandur and Anna Nagar.

The emissions of SO_2 and NO_2 in this area are within the limits set by the NAAQS. However, NO_2 recorded an all-time high in the observed eight years during 2021 (21.08 µg/m^3) and 2022 (21.68 µg/m^3), although still within the prescribed standard. The highest presence of PM_{10} was observed in 2018 (104.58 µg/m^3), which reduced to 58.67 µg/m^3 in 2022. $PM_{2.5}$ data is only available from 2017 onwards. Compared to 2020 (22.65 µg/m^3) and 2021 (22.82 µg/m3), there was a slight increase in the presence of $PM_{2.5}$ in 2022 (27.23 µg/m^3).

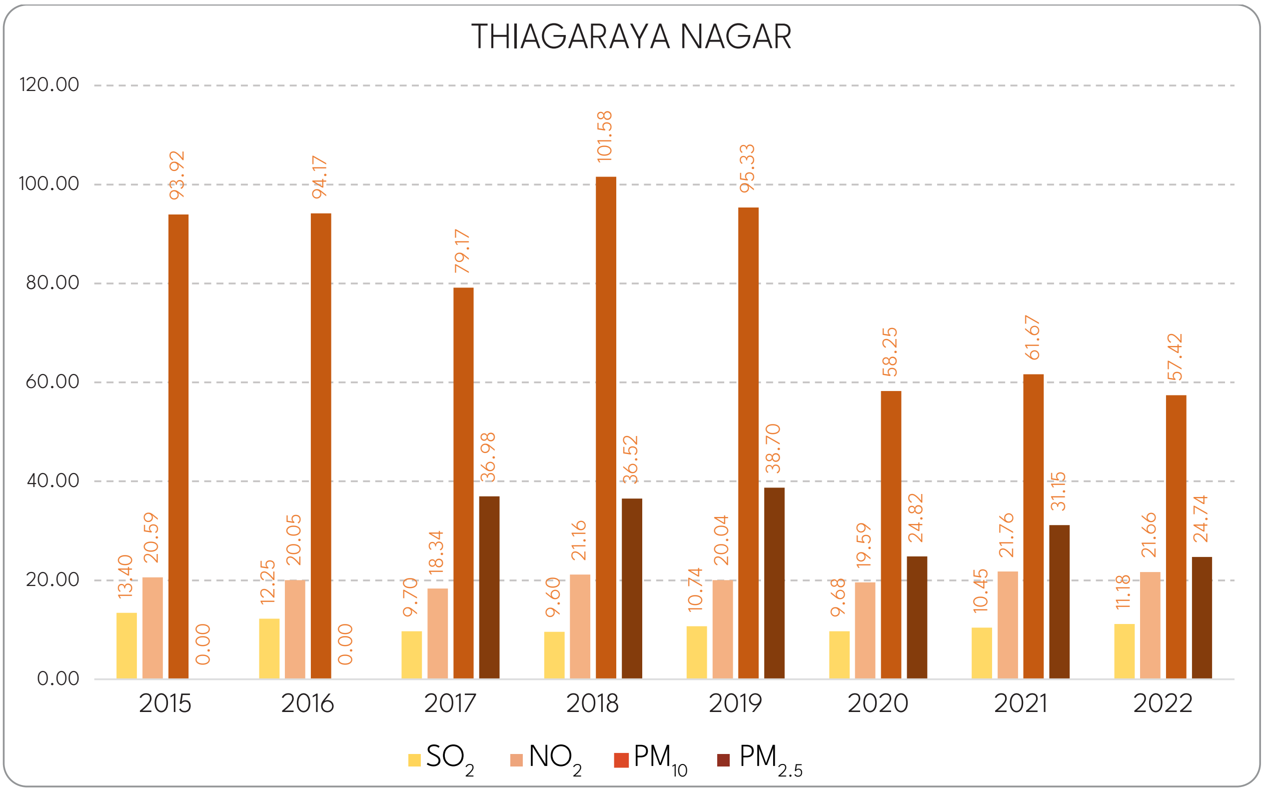


Figure 8: Air quality reported in Thiagaraya Nagar between 2015 and 2022

Thiagaraya Nagar, geographically, encompasses a portion of Marina beach, several higher education institutions, densely populated residential areas, and small-scale businesses, creating a blend of commercial and residential areas. This mix, along with high vehicular traffic, contributes to the area's air quality.

Over the past eight years, the presence of SO_2, NO_2, and $PM_{2.5}$ in the ambient air has remained within the limits set by the NAAQS. Given the area's vehicular movement, the presence of PM_{10} is almost on par with the NAAQS prescription. For instance, it reached its peak in 2018 at 101.58 µg/m^3 and was relatively within the NAAQS limit of 60 µg/m^3 last year, at 57.42 µg/m^3.

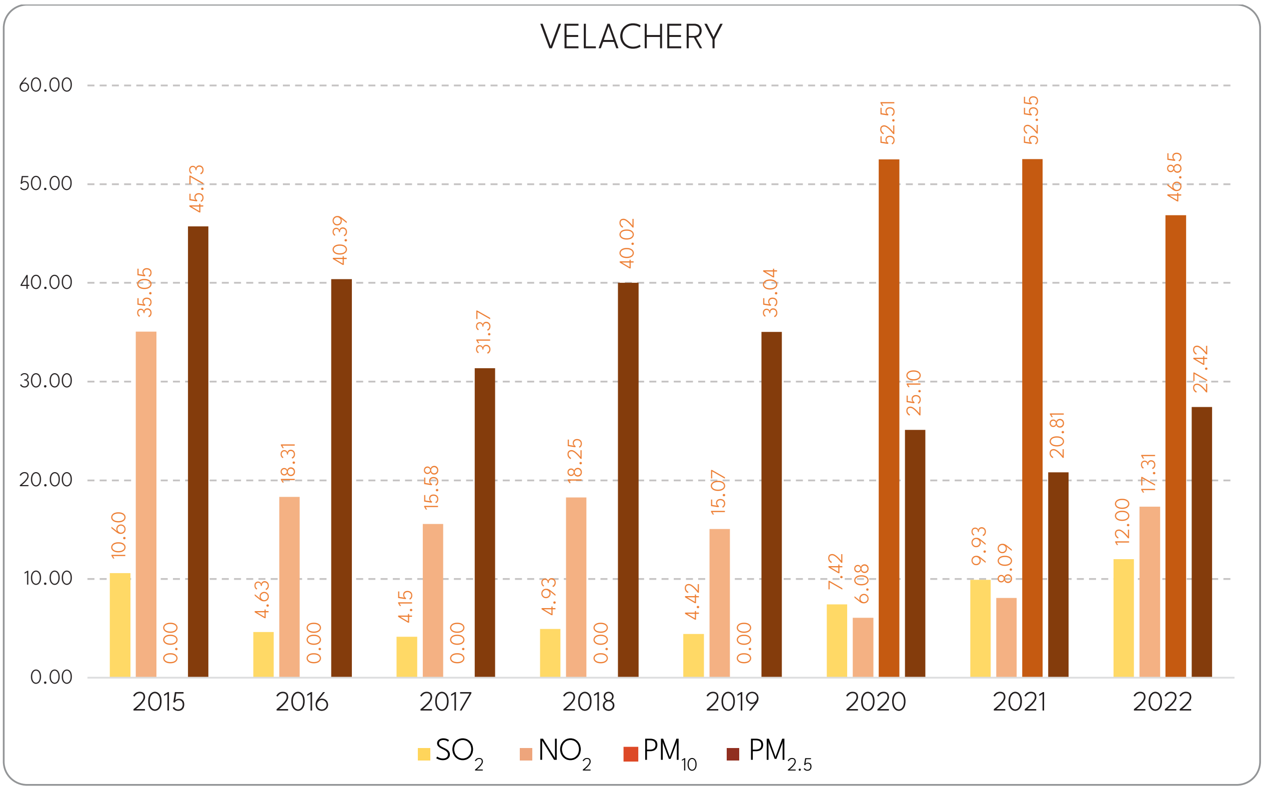


Figure 9: Air quality reported in Velachery between 2015 and 2022

Velachery, located in South Chennai, is a bustling commercial and residential area. The locality houses an incinerator, one of the city's largest solid waste dump yards, the IT hub of Chennai, several higher educational institutions, shopping malls, Neelankarai beach, a few water bodies, and marshland. As it is an IT hub, it has significantly high vehicular traffic.

Over the years, the presence of SO_2, NO_2, and PM_{10} (for PM_{10} data available from 2020 onwards) in the ambient air has remained within the limits set by the NAAQS. However, fluctuations have been observed in $PM_{2.5}$ levels. Although $PM_{2.5}$ levels were above the standards in 2015, at 45.73 µg/m3, they were within the prescribed limit in 2022, at 27.42 µg/m^3.

Year	Number of instances where the air quality monitoring system was not functioning	Percent
2015	5	3.7
2016	16	11.6
2017	6	4.3
2018	17	12.3
2019	22	15.9
2020	36	26.2
2021	26	18.8
2022	10	7.2
Total	138	100.0

Table 7: Yearly instances of no data being recorded in the AQMS

In addition to the air quality status mentioned above, there have been several instances where the AQMS has not functioned due to various reasons. These include instrument failure, power failure, during rainfall, and during COVID-19 lockdowns.

According to the data provided by the TNPCB, there were 22 instances in 2019, 36 instances in 2020, and 26 instances in 2021 where air quality data was not recorded. The higher number of instances in 2020 can be attributed to the COVID-19 lockdown.

However, there has been a significant reduction in such instances from 26 in 2021 to 10 in 2022. This improvement is commendable and shows that the TNPCB has effectively managed to reduce the instances of data not being recorded in their AQMS (see Table 7).

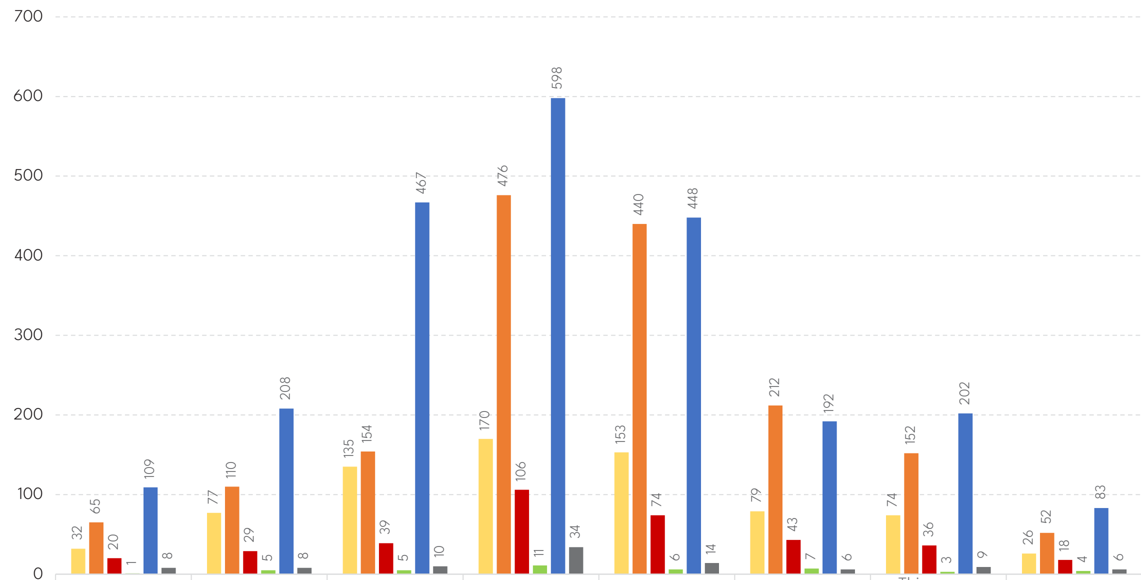
The above findings can be interpreted in the context of existing literature. Thus, literature reviewed in this study indicates that pollutants such as NO_2, SO_2, $PM_{2.5}$ and PM_{10} significantly impact human respiratory and cardiovascular health (Ojha et al. 2022; Feigin et al. 2016; Sajith Kumar, Sasidharan, and Bagepally 2023; Chen et al. 2007).

Additionally, air polluwtants including SO_2 and PM_{10} have been linked to mental health issues (Oudin et al. 2018; Zundel et al. 2022; Balakrishnan and Tsaneva 2023).

Also, this study's above findings reveal considerable fluctuations in PM_{10} and $PM_{2.5}$ levels, sometimes exceeding the NAAQS. Consequently, residents and individuals in these localities who interact with the environment may potentially develop respiratory, cardiovascular, and mental health problems. However, it's important to note that the effects of these pollutants can vary among individuals, depending on factors such as age and existing medical conditions (WHO 2023; UNEP 2018; Manisalidis 2020).

4.2 Air quality and violent crime in Chennai city

Violent crimes registered under 95 police stations have been clustered into eight air quality monitoring stations for analysis. The focus of this discussion is on violent crimes categorised as murder, attempt to murder, murder for gain, grievous hurt, robbery, and dacoity. However, it's important to note that many factors contribute to crime rates, and air quality is just one aspect. Socioeconomic factors, law enforcement practices, population density, and many other variables also play significant roles. Therefore, while this analysis can provide insights, it should be considered as part of a broader, multifaceted approach to understanding and addressing air pollution and violent crime.



	Adyar	Alandur	Anna Nagar	Kilpauk	Manali	Nungambakkam	Thiagaraya Nagar	Velachery
Murder	32	77	135	170	153	79	74	26
Attempt to Murder	65	110	154	476	440	212	152	52
Grievous Hurt	20	29	39	106	74	43	36	18
Murde for Gain	1	5	5	11	6	7	3	4
Robbery	109	208	467	598	448	192	202	83
Dacoity	8	8	10	34	14	6	9	6

Figure 10: Air quality monitoring station wise violent crime registered between 2015 and 2022

Murder, being the most extreme violent crime against a human, was most frequently registered in Kilpauk (170 cases), followed by Manali (153 cases) and Anna Nagar (135 cases). The lowest numbers were reported in Adyar (32 cases) and Velachery (26 cases).

In terms of attempted murder, Kilpauk again topped the list with 476 cases, followed by Manali with 440 cases and Nungambakkam with 212 cases. Adyar and Velachery reported the lowest numbers, with 65 and 52 cases respectively.

Grievous hurt was also most common in Kilpauk (106 cases) and Manali (74 cases). For murder for gain, the highest numbers were reported in Kilpauk (11 cases) and Nungambakkam (7 cases).

Robbery cases were most frequently registered in Kilpauk (598 cases) and Anna Nagar (467 cases). Dacoity was highest in Kilpauk (34 cases) and Manali (14 cases), and lowest in Nungambakkam (6 cases) and Velachery (6 cases).

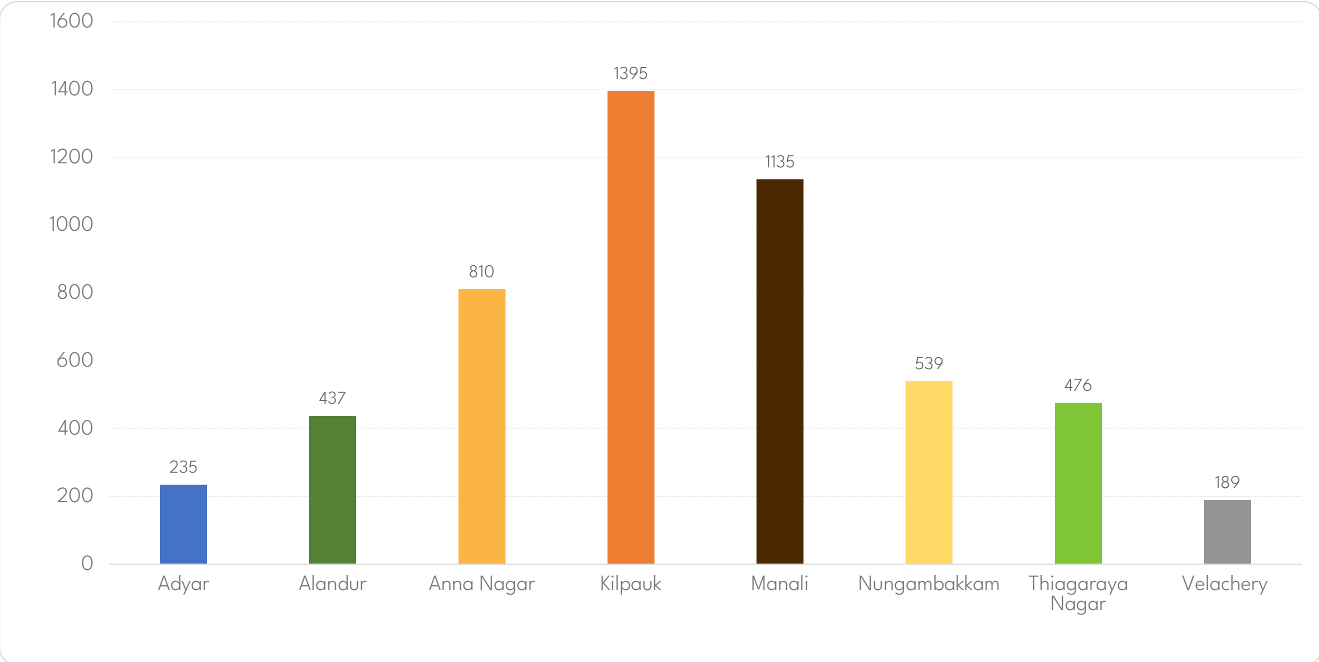


Figure 11: Air quality monitoring station-wise overall violent crime reported between 2015 and 2022

Between 2015 and 2022, the sum of violent crimes reported varied across different localities. Kilpauk registered the highest number of violent crimes (1395), followed by Manali (1135) and Anna Nagar (810). On the other hand, Alandur (437), Adyar (235), and Velachery (189) registered the fewest violent crimes.

The high number of violent crimes in Kilpauk may be attributed to the larger number of police stations (29) clustered around this air quality monitoring station. However, this trend of “more police stations leading to higher registration of cases” does not hold true for Manali, Anna Nagar, and Nungambakkam. These monitoring stations each have 12 police stations clustered around them, yet the number of violent crime cases registered varies. For instance, Manali registered 1135 cases, whereas Nungambakkam registered only 539 cases. These figures highlight the complexity of crime rates and their relationship with various factors, including the air quality monitoring station cluster, number and distribution of police stations.

Sl. No.	AQMS	Annual average of NO_2, SO_2, PM_{10} and $PM_{2.5}$ (μg/m³)	Violent crime
1	Thiagaraya Nagar	35.90	476
2	Alandur	35.39	437
3	Nungambakkam	35.17	539
4	Anna Nagar	34.77	810
5	Manali	34.22	1135
6	Kilpauk	33.14	1395
7	Velachery	26.96	189
8	Adyar	23.91	235

Table 8: Combination of air quality and violent crime registered between 2015 and 2022

While the absolute numbers of annual average NO_2, SO_2, PM_{10} and $PM_{2.5}$ levels combined with the sum of violent crimes as reported provide a snapshot of the situation, they may not clearly demonstrate a direct connection between air quality and violent crime in Chennai city.

4.3 Correlation between air quality and violent crime

To determine the relationship between air pollutants such as NO_2, SO_2, PM_{10} and $PM_{2.5}$ and violent crime, we used Spearman's correlation coefficient. This statistical method helps to identify the strength and direction of the relationship between these variables.

From Table 9, it can be inferred that there is a significant correlation (i.e., $\rho < .01$) between violent crimes such as murder and attempted murder and air pollutants like NO_2, SO_2, PM_{10} and $PM_{2.5}$ This suggests that an increase in the presence of these air pollutants is associated with an increase in these types of violent crimes. However, the correlation is either very weak or weak.

Variables	Correlations (ρ)										
	M	SD	1	2	3	4	5	6	7	8	9
1. SO_2	10.16	4.47	–								
2. NO_2	18.12	6.66	.30**	–							
3. PM_{10}	52.78	38.10	.28**	.16**	–						
4. $PM_{2.5}$	33.60	21.81	-.10**	.05	-.17**	–					
5. Murder	1.03	1.19	.16**	.14**	.15**	.09**	–				
6. Attempt to murder	2.16	2.35	.23**	.19**	.13**	.10**	.28**	–			
7. Grievous hurt	.48	.79	.06	.07	.06	.00	.16**	.25**	–		
8. Robbery	3.00	3.64	.10**	.22**	.09**	.02	.27**	.34**	.21**	–	
9. Dacoity	.12	.54	-.03	-.01	-.02	-.03	.05	.08*	.10**	.10**	–

Table 9: Air quality and violent crime headwise descriptive statistics and correlation

In terms of robbery, a significant but very weak or weak correlation is observed with NO_2, SO_2, PM_{10}. No significant relationship is observed between grievous hurt, dacoity, and air quality.

Variables	Correlations (ρ)						
	M	SD	1	2	3	4	5
1. SO_2	10.16	4.47	–				
2. NO_2	18.12	6.66	.129**	–			
3. PM_{10}	52.78	38.10	.160**	.026	–		
4. $PM_{2.5}$	33.60	21.81	.016	.122**	-.307**	–	
5. Violent crime	6.79	6.06	.125**	.131**	.132**	.050	–

**Correlation is significant at the 0.01 level (2-tailed).

Table 10: Air quality and violent crime descriptive statistics and correlation

Table 10 explores the relationship between NO_2, SO_2, PM_{10}, and $PM_{2.5}$ and overall violent crime registered between 2015 and 2018. A significant but very weak correlation is observed between NO_2, SO_2, PM_{10} and violent crime. No significant correlation is observed between $PM_{2.5}$ and violent crime.

As previously discussed, it's crucial to distinguish between correlation and causation. While this study demonstrates significant correlations between air quality and violent crime, it does not definitively establish a causal relationship. The associations observed may be influenced by various confounding factors and complex interactions between environmental, social, and individual factors.

Understanding causality would require conducting controlled experiments or longitudinal studies that account for these complexities. These could involve tracking changes in air quality and violent crime rates over time in specific locations while controlling for potential confounding factors such as socioeconomic status, population density, law enforcement practices, and other environmental factors. Moreover, individual physiological responses to air pollution can vary widely, depending on factors such as age, and health status. Therefore, even if a general correlation between air quality and violent crime is observed, the specific impacts on individuals could vary greatly.

While these findings provide a compelling starting point, they should be seen as a stepping stone for further research in this area. Future studies could build on this work by exploring the potential mechanisms underlying the observed correlations, conducting more granular analyses, and employing more rigorous experimental designs to test for causality. This would not only enhance our understanding of the relationships between air quality and violent crime but also inform the development of effective strategies and policies for crime prevention and environmental management.

5. RECOMMENDATIONS

Based on the findings of this study, several recommendations have been formulated for the TNPCB and the GCP. These recommendations are made with the good faith of improving air quality and controlling violent crimes.

1. Most monitoring stations report levels of NO_2 and SO_2 in ambient air within the limits prescribed by the NAAQS. However, significant fluctuations have been observed in PM_{10} and $PM_{2.5}$ levels, likely due to vehicular traffic, construction activities, and infrastructural development works such as expansion of Chennai metro rail, relaying of roads etc. The TNPCB, in consultation with relevant government departments, should monitor these situations to minimise the presence of PM_{10} and $PM_{2.5}$ in Chennai.

2. In the Adyar locality, there has been a gradual increase in NO_2 levels over the last five years. Steps should be taken to understand this phenomenon and implement remedial measures.

3. In the Alandur locality, PM_{10} levels have exceeded the NAAQS, and in Kilpauk, Manali, Nungambakkam, and Thiagaraya Nagar localities, PM_{10} levels are close to the NAAQS limit. Concerted efforts are required to reduce PM_{10} presence in these localities.

4. Considering the geographical extent of Chennai city (426 km^2), the current eight manual air quality monitoring stations are insufficient for reliable air quality measurement. Steps should be taken to increase the number of AQMS.

5. According to the information available on the CPCB website, Chennai is equipped with 11 manual ambient AQMS. However, the data from these stations is separately maintained by the CPCB and the TNPCB. To enhance transparency and accessibility, it would be beneficial if the historical manual ambient air quality data collected by the CPCB and TNPCB were made publicly available. This could be done in a manner similar to the continuous air quality data that is currently accessible through the Central Control Room for Air Quality Management portal.

This can be achieved once TNPCB develops a data management and sharing policy. Such a measure would not only benefit researchers who rely on this data for their studies but also the general public who have an interest in understanding the quality of the air they breathe. This initiative could lead to increased awareness and more informed decision-making regarding air quality management at both the individual and community levels.

6. Robbery is the most frequently registered violent crime in all the police stations clustered to the AQMS. The second most common violent crime is attempted murder, except in Nungambakkam where it is more prevalent than robbery. Therefore, police should formulate crime prevention strategies to control these crimes.

7. There are 29 police stations clustered to the Kilpauk AQMS, which have registered 170 murders. Despite Manali and Anna Nagar having fewer clustered police stations (12 each), they reported 153 and 135 murders respectively. Nungambakkam, Alandur, and Thiagaraya Nagar, with 12, 11, and 9 clustered police stations respectively, registered 79, 77, and 74 murders (see Table 2 for list of police stations clustered to AQMS). Serious retrospection is required to reduce the occurrence of murder in these localities.

8. As noted elsewhere in the report, macro-level violent crime data, categorised by city, is readily available on the Tamil Nadu police website. However, obtaining micro-level data, specifically police-station-wise violent crime statistics, requires a direct request to the Commissioner of GCP. To enhance transparency and ease of access to this data, it would be beneficial to initiate measures to create an online dashboard. This dashboard would make police station-wise crime data publicly available. Such a resource would greatly assist researchers and the general public in understanding the local crime situation. Furthermore, it would aid in the prevention and control of crime at a micro level, as it would provide valuable insights into crime patterns and trends. This, in turn, could inform more effective, targeted strategies for crime reduction.

9. The Spearman's correlation coefficient indicates a very weak or weak correlation between NO_2, SO_2, PM_{10} levels and violent crimes. This study statistically demonstrates a correlation between ambient air quality and violent crimes, except for $PM_{2.5}$. This calls for raising awareness about the potential health and safety risks associated with poor air quality and advocating for cleaner air.

10. One of the primary goals of this study is to raise public awareness about the importance of maintaining good air quality at the city level. Public engagement in discussions about air quality and its potential impact on safety can lead to more informed choices and support for policies aimed at improving air quality, especially those aimed at reducing emissions from vehicular traffic.

11. To build on this study and gain a deeper understanding of the complex relationships between air quality and violent crime, it is recommended that future research should be carried out. This could include conducting longitudinal studies to investigate the long-term effects of air quality on crime rates, considering variations across seasons and years. It could also involve examining community-level data at smaller spatial scales to identify localised effects and potential hotspots.

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