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Does Vehicular Growth Affect Dhaka's Air Quality? Evidence From Time-Series Analysis

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Abstract
Air pollution in Dhaka, one of the most densely populated and traffic-congested cities in the world, has reached alarming levels, with vehicular emissions identified as a major contributor. This study examines the relationship between vehicular growth and air quality using time-series data from 2013 to 2023. Applying Autoregressive Distributed Lag (ARDL), Vector Error Correction Model (VECM), and Seasonal ARIMA with Exogenous Regressors (SARIMAX), it investigates both short-run and long-run effects of vehicle registration trends on Dhaka's Air Quality Index (AQI). Findings indicate that motor vehicles and cargo transport significantly deteriorate air quality in the long run, while seasonal variations influence pollution fluctuations. Winter months experience the worst air quality due to atmospheric stability and temperature inversions, whereas monsoons aid pollutant dispersion through rainfall. Notably, the rise in private vehicles did not directly correlate with worsening air quality, suggesting improvements in fuel efficiency and emission standards. However, the surge in motorcycles, especially after ridesharing services emerged, contributes heavily to hydrocarbon emissions. The study underscores the need for targeted policies, such as stricter emission norms, congestion pricing, and greater investment in sustainable public transport infrastructure.
Keywords: *Air Quality, Vehicles, Pollution, Urbanization, Emissions, Seasonality, Traffic.*

Highlights

- *Vehicle growth in Dhaka linked to long-term air quality decline.*
- *Cargo transport shows strong short-term impact on pollution levels.*
- *Seasonal variation is a key driver of air quality fluctuations.*
- *Rainfall improves air quality over time by dispersing pollutants.*
- *ARDL and VECM models confirm long-run and short-run pollution dynamics.*

1 INTRODUCTION

Air pollution causes significant environmental as well as health hazards. Unlike many other types of pollution, its impact is not local; rather in can spread to its immediate neighborhood as well as to far-off distance corner. Air pollution represents the most significant environmental health risk globally, driven by natural and anthropogenic sources, including emissions from industrial processes, vehicles, biomass burning, and re-suspension of dust in arid areas (Samiul & Auvee, 2019; (Hossain et al., 2023) (Rahman et al., 2023). Historically, air pollution is higher in industrial areas and in urban agglomerates where automobile emissions are rampant. Dhaka, the capital city of Bangladesh, is one of the most populated cities in the world and infamously known for severe traffic congestion and airborne pollution. Dhaka city is divided into two administrative city corporations, (i) Dhaka South City Corporation (DSCC) and (ii) Dhaka North City Corporation (DNCC). There are 25 Thanas and 75 Wards in DNCC. Correspondingly, there are 28 Thanas and 54 Wards in DSCC(Figure 1). According to Census 2022 data collected by the Bangladesh Bureau of Statistics, the population densities of DSCC and DNCC are 30,531 and 39,406 persons per square kilometer respectively (BBS, 2024). These numbers themselves speak of the magnitude of the congestion problem in Dhaka city and its potential nexus to air pollution; it may deeply realize further given Bangladesh's overall population density is 1,119 persons per square kilometer. It suggests the Bangladesh economy is highly concentrated and dependent on Dhaka city, and opportunities and facilities in other urban cities are significantly deemed in comparison to it. Hence, it is of no surprise that Dhaka houses 26% of all registered vehicles in Bangladesh, which further exacerbate problems of traffic congestion and air pollution. The city of Dhaka has only 3,000 kilometers of roads to serve over 4.5 million people who are registered as vehicle owners.

Around 7% of Dhaka's built-up area has a short road network, which is completely insufficient to support the increasing vehicle population. The main means of public transport are buses and minibuses along with cars and ridesharing services, autorickshaws, and non-motorized cycle rickshaws.

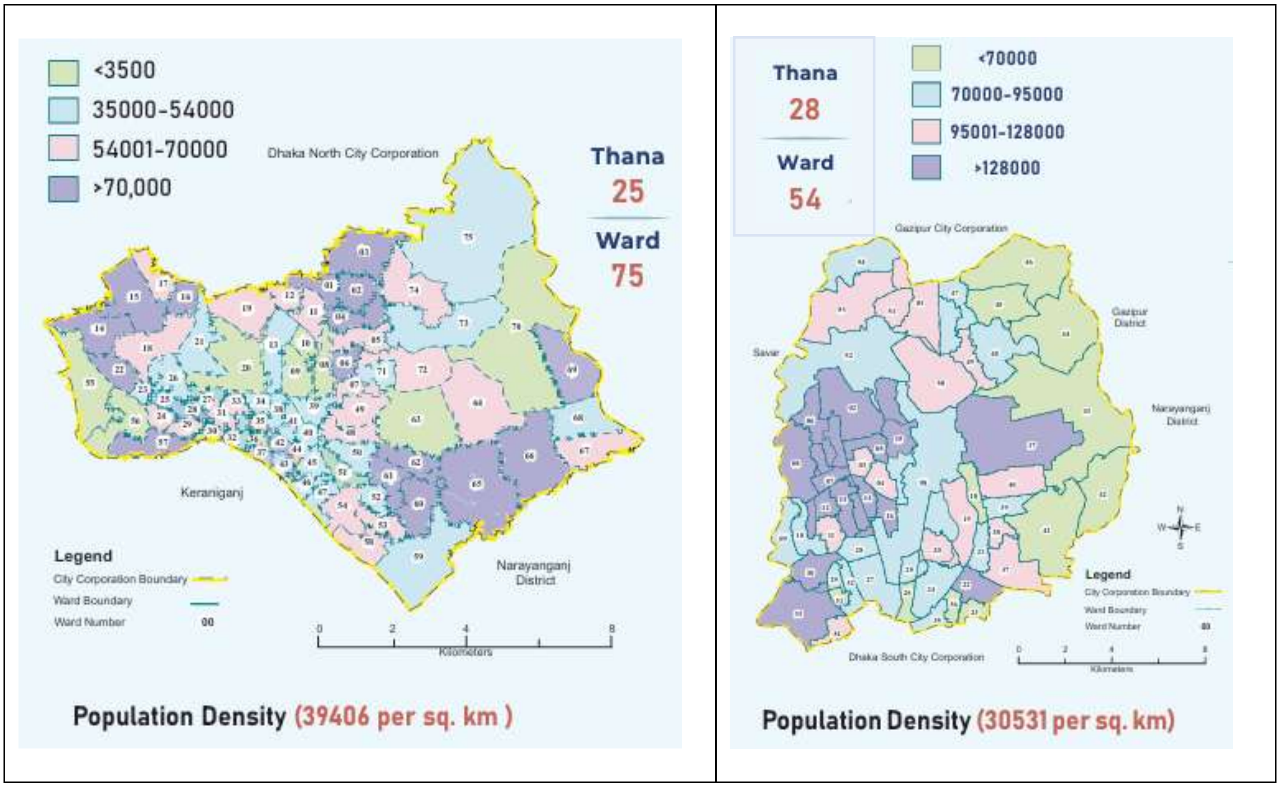

Figure 1: Population Map by Dhaka North and South City Corporation
Source: BBS, 2025

The latest data published by the Bangladesh Road Transport Authority (BRTA) for the quantity of motorized public transport vehicles registered in Dhaka, there are 42,537 buses and 10,240 minibuses as of December 2024, which is only 2.5 percent of the total number of motorized vehicles. On the other hand, private vehicles such as cars and motorcycles make up 15.85% and 54.10% of registered vehicles, respectively (BRTA, 2025). Despite the introduction of public transit options such as the metro rail, vehicular emissions continue to rise due to an increasing number of motor vehicles. Moreover, studies indicate that while buses constitute only 10% of road vehicles, they transport approximately 75% of commuters highlighting a stark imbalance in transport efficiency.

At the same time, Dhaka is one of the most polluted cities in the world, with a PM2.5 concentration of 97.1 $\mu g/m^3$ annually (Islam et al., 2021). The disaggregation of the air pollution sources in Dhaka reveals that emissions from vehicles are responsible for 58% of total air pollution; brick kilns account for another 15%; lead, biomass burning, sea salt and dust contribute to 15% and 10%, respectively(DoE & MoEFCC, 2020) . Increased registered vehicles with ineffective traffic control measures and lack of public transport are further worsening air quality. The number of motor vehicles in Dhaka increases every year by roughly 5%, which contributes to heightened traffic congestion and worsens the air quality (Azad et al., 2022). PM2.5 and PM10 levels exceed standards in the dry season and drop below them in the rainy season (Maksimul Islam et al., 2015; McCarty & Kaza, 2015). Rain reduces pollutants via wet deposition during monsoon, while relative humidity worsens air quality in winter but improves it during monsoon (Zarin & Esraz-Ul-Zannat, 2023). Considering that PM2.5 and PM10 pollution is associated with such adverse health conditions as respiratory infections, heart diseases, and cancer (M. L. Hossain et al., 2023), the concern on emissions from vehicles is greatly needed.

Local meteorological features are affecting Dhaka's air quality index. The concentration of pollutants and the dispersion are affected by the seasonal variation, temperature, solar radiation, and relative humidity(Hernandez et al., 2017) . For instance, all these variables jointly lead to higher pollution during winters due to the stability of the atmosphere and the presence of temperature inversions(Gramsch et al., 2014; Largeron & Staquet, 2016). In contrast, rainfall during monsoon seasons helps to reduce pollution through wet deposition, whereas high solar radiation intensifies photochemical reactions, producing secondary pollutants like ground-level ozone (Rathnayaka & Hewapathirana, n.d.). Given these complexities, it is imperative to examine the causal relationship between the number of registered vehicles and air pollution levels in Dhaka.

This study aims to analyze the extent to which the increasing number of registered vehicles contributes to air pollution in Dhaka city. By assessing vehicle registration trends, traffic congestion patterns, and air quality data, this research seeks to examine both short-run and long-run causal relationships between vehicular density and pollution levels. Understanding these dynamics is crucial for formulating evidence-based policies to mitigate air pollution and promote sustainable urban mobility solutions in Dhaka.

2 LITERATURE REVIEW

Pollution is a global concern, as well as a national concern, with its major focus being air pollution. This is further accentuated within major cities, which are characterized by high levels of industry and population (B. Sun et al., 2023) . The sources of air pollution are diverse and can be classified as biological or anthropogenic. Some of these sources are vegetative emissions, biomass for oceans, volcanic eruptions, and the combustion of liquid and solid fuels for power and other industries. Important additional sources include construction activities, quarries, cement plants, smelting works, and desert dust storms(Mallik & Islam, 2017). The physical geography and weather patterns of a city intensify pollution, making matters worse for public health and the environment (Begum et al., 2011). Among these factors, vehicular emissions are one of the strongest pollutants in the metropolitan cities. In many Asian urban cities, motor cars are the key source of worsening air quality(Bose, 2007).

The dependency on private cars is one of the main causes of the emission of airborne pollutants from the transport industry's operations, particularly in emerging economies(Kii & Hanaoka, 2003). The increase in private vehicles in many Asian countries corresponds with the decline in air quality. Hence, many Asian megacities are experiencing poor air quality index (AQI)(MOHAMAD & KIGGUNDU, 2007). Due to the rise in overall urban populations due to economic growth, which facilitates personal vehicle ownership, there has also been a rise in traffic jams. This traffic increases the emissions of nitrogen oxides, particulate matter (PM2.5), carbon monoxide, and other substances that are detrimental to the air(Colvile et al., 2001). The dramatic increase of automobile ownership during the last two decades in China has forced major cities, including Beijing, to take strict limitations on the number of vehicles to control the deteriorating AQI(B. Sun et al., 2023). Gasoline and diesel engines continue to release harmful emissions, which contribute to the already terrible smog and serious health concerns for people living in cities pertaining to respiratory issues (Vohra et al., 2015).

Poor planning of a city combined with the emissions produced by vehicles leads to the concentration of pollutants in a given region, especially at peak hours. Such situations lead to the entrapment of perilous gases in the atmosphere, which results in lowering the visibility and causing an increase in health problems (Hasan et al., 2023). In Bangkok, for instance, the growing number of private cars has significantly increased the AQI because people prefer to use personal cars over public transport despite its availability (González et al., 2021; Kenworthy, 2018). This problem is even greater in megacities of South Asia, particularly in New Delhi, Mumbai, and Dhaka. These cities are bearing the brunt of unchecked pollution that is escalating due to increased car ownership and a lack of adequate public transportation arrangements (Jabbar et al., 2022). New Delhi, which is regarded as one of the most polluted cities in the world, has alarmingly high AQI, and its main source of pollution in the city is vehicular emissions(Ma et al., 2021). In New Delhi, the levels of NOx pollution and PM2.5 pollution are at their peak around the hours of heavy traffic. This is ever so indicative that there is a strong reliance on private cars, which in turn impacts the air in a negative manner (Vohra et al., 2015). In Delhi's odd-even vehicle rationing scheme has provided temporary relief; however, it did not work in Mexico back in 1993 (C. Sun et al., 2019) . Hence, sustainable transport solutions are necessary for long-term improvements

In Dhaka, the air quality has worsened significantly due to the increase in motorcycles and cars, with PM2.5 concentration in the traffic jam areas often exceeding WHO standards(Md. M. Hossain, 2019). A comparison with less motorized pedestrian zones illustrates that private cars are a major source of air pollution and motorized traffic congestion in Dhaka (Md. M. Hossain, 2019). On the other hand, air quality studies in Chinese cities indicate that the increase in public bus transportation can reduce air pollution, indicating that investing in public transport facilities has the potential to remarkably improve air quality in urban places (C. Sun et al., 2019). In Bangladesh, primarily in Dhaka, the uncontrolled increase in motor vehicles has emerged as a serious issue of concern for the environment as the emissions from vehicles are one of the two major sources of the pollution in the capital city (Begum et al., 2011). In Dhaka, there has been a significant increase in the number of motorbike registrations since Uber and other ride-sharing companies started their operations in 2016. The combination of a large number of vehicles and heavy traffic for long periods of time results in considerable air pollution(Colvile et al., 2001). Consequently, pollution in Dhaka has increased dramatically, resulting in critical issues concerning the health and exposure of the populace along with the ecological balance (Hasan et al., 2023).

The social costs of excessive air pollution, together with emission toxicities, are staggering, creating a nexus of large poverty-stricken areas alongside regions with elevated mortality rates (Zhai & Wolff, 2021). Industrial clusters located in major metropolitan areas are also responsible for emission production with little regard to public health welfare. Overwhelmingly, the emission greatly disrupts the productivity and mortality rates in China due to vehicle pollution. It has been estimated that about twenty thousand people die each year as a result of vehicular emissions alongside several congested cities, which has triggered an acquisition of some extreme central planned health policies(Mofolasayo, 2023). Airborne pollution's share in the global CO_2 emission was captured at approximately 23% and is only expected to increase due to the growing rate of vehicles across the globe(Mofolasayo, 2023). The use of personal means of transportation is the most common in metropolitan areas, with the population already reaching beyond 700 million and being presumed to further increase. Developed countries will meet a vehicle-endorsed urban pollution emission crisis of 40% to 80% being contributed from emission-exacerbated vehicles(Ghose et al., 2004).

In summary, globally, emissions from vehicles are one of the main sources of air pollution and have resulted in adverse environmental and health effects. Its effects, however, differ in developed and developing countries. For instance, in London, despite stricter laws and policies in place, road transport is one of the main sources of air pollution. The issue is greater in urban areas where there is a greater number of cars. On the other hand, developing nations such as India, Bangladesh, and China deal with much worse air quality due to the increased number of private vehicles, poor public transport, lack of proper urban infrastructure, and non-compliance with traffic rules and regulations. The growing use of personal vehicles, coupled with inadequate urban development, worsens traffic and ultimately, pollution. The increase in the use of personal cars in urban zones, especially in developing countries, has led to a significant decline in air quality. Numerous efforts have been made to reduce the impact of emissions from vehicles through rationing the use of cars and increasing the use of public transport, but no sustainable optimal mix is yet to be sorted out. Both developed and developing countries need to emphasize long-term solutions like enhancing public transport systems, planning cities better, and using cleaner technologies. Though developed countries have taken steps to mitigate carbon emissions, developing countries still need effective regulations and greater infrastructure spending to contain pollution and public health issues. Reducing reliance on private vehicles, increasing investment in mass transportation, and better city planning are key components needed to combat the issue of air pollution. The implications of doing nothing go beyond health risks to people; they endanger nature and exacerbate the issues related to climate change.

3 DATA SOURCES AND METHODOLOGY

To examine the causal relationship between air pollution and the number of transportation vehicles in Dhaka, primary data were collected and compiled from three institutions. These are BRTA, Department of Environment (DoE), and Bangladesh Meteorological Department (BMD). With best of efforts, consistent and systematic data on all the climatic parameters, AQI and number of registered vehicles are compiled for the period of 2013 to 2023 a on monthly basis. In particular, monthly reports of registered motor vehicles from the BRTA are collected. In the absence of disaggregated vehicular emission data, in this study, the number of registered motor vehicles is used as an alternative proxy for it.

In addition, AQI is computed from the Department of Environment (DoE) data which measures air quality based on five major pollutants: Ozone (O3), Carbon Monoxide (CO), Sulfur Dioxide (SO2), Nitrogen Dioxide (NO2), and Particulate Matter (PM2.5 and PM10). The AQI values above 100 indicate unhealthy air quality, initially affecting sensitive groups and later the general population as values increase. The data is categorized into different levels of air quality, ranging from "Good" (0-50) to "Extremely Unhealthy" (301-500), providing a clear view of the air pollution levels and their potential impact on public health and the environment in Bangladesh.

Furthermore, data on key climatic parameters such as temperature, humidity, wind velocity, and rainfall are compiled from the dataset of Bangladesh Meteorological Department (BMD). These parameters are crucial for understanding urban pollution because weather conditions influence the concentration and distribution of pollutants in urban settings. Understanding these meteorological factors is crucial for interpreting how varying weather patterns influence air quality and the overall pollution levels in Bangladesh. In case of air quality and climatic parameters, daily data were initially collected. Later, daily data were converted into the monthly data by taking the averages.

3.1Methodology

Analyzing the dynamics of air pollution involves developing an appropriate statistical framework that addresses both sudden variations and overall relationships between the level of pollution and its determinants over a period of time. For such analysis, the Autoregressive Distributed Lag (ARDL) Model is appropriate, especially where there is mixed order integrated monthly time series data. This framework permits the estimation of relationships between air pollution and selected determinants such as registered vehicles, rainfall, and seasonality, whose effects are presumed to operate with a time lag.

The ARDL model is also useful for other time series analyses in which some of the variables are stationary (I(0)) while others are non-stationary (I(1)). ARDL differs from traditional cointegration approaches, such as the Johansen test, that require all variables to be integrated in the same order. Methods such as ARDL do not need all variables to be integrated in the same manner. This flexibility makes ARDL a preferred method for estimating the relationship between the AQI and the number of vehicles registered. The specific equations used in this particular study are systematically explained below -

Autoregressive Distributed Lag (ARDL) Model

The ARDL model is useful when the variables are a mix of stationary (I(0)) and non-stationary (I(1)) series. It allows the estimation of both short-term and long-term relationships.

$$\mathrm{AQI}_t = \alpha + \sum_{i=1}^{p} \beta_i\, \mathrm{AQI}_{t-i} + \sum_{j=0}^{q} \gamma_j\, \mathrm{Vehicles}_{t-j} + \sum_{k=0}^{q} \delta_k\, \mathrm{Rainfall}_{t-k} + \emptyset \mathrm{Seasonality}_t + \varepsilon_t \qquad (1)$$

As variables are found to be cointegrated, we express the long-run relationship as:

$$\mathrm{AQI}_t = \theta_0 + \theta_1 \mathrm{Vehicles}_t + \theta_2 \mathrm{Rainfall}_t + \theta_3 \mathrm{Seasonality}_t + u_t \qquad (2)$$

The Error Correction Model (ECM) for short-term adjustments used in this study is:

$$\Delta\mathrm{AQI}_t = \lambda(\mathrm{AQI}_{t-1} - \theta_0 - \theta_1 \mathrm{Vehicles}_{t-1} - \theta_2 \mathrm{Rainfall}_{t-1} - \theta_3 \mathrm{Seasonality}_{t-1} + \sum_{i=1}^{p-1} \beta_i\, \Delta\mathrm{AQI}_{t-i} + \sum_{j=0}^{q-1} \gamma_j\, \Delta\mathrm{Vehicles}_{t-j} + \sum_{k=0}^{q-1} \delta_k\, \Delta\mathrm{Rainfall}_{t-k} + \varepsilon_t \qquad (3)$$

where: λ is the speed of adjustment to long-run equilibrium and Δ represents first differences.

In order to check the long-term relationship, a Vector Error Correction Model (VECM) is also estimated. As all the abovementioned variables are integrated of order 1 (I(1)) and are cointegrated, the VECM is found to be appropriate.

Long-run equation:

$$\mathrm{AQI_t} = \theta_0 + \theta_1 \mathrm{Vehicles_t} + \theta_2 \mathrm{Rainfall_t} + \theta_3 \mathrm{Seasonality_t} + \mathrm{u_t} \quad (4)$$

The VECM representation:

$$\Delta \mathrm{AQI_t} = \lambda \mathrm{u_{t-1}} + \sum_{i=1}^{p-1} \beta_i \, \Delta \mathrm{AQI_{t-i}} + \sum_{j=0}^{q-1} \gamma_j \, \Delta \mathrm{Vehicles_{t-j}} + \sum_{k=0}^{q-1} \delta_k \, \Delta \mathrm{Rainfall_{t-k}} + \varepsilon_t \quad (5)$$

where, u_{t-1} is the error correction term derived from the long-run equation and λ is the speed of adjustment. In addition, in this study, a structural time series model (STSM) is attempted to identify whether AQI has an underlying trend and strong seasonal patterns. The STSM then decomposed into the following equation:

$$\mathrm{AQI_t} = \mu_t + S_t + \beta_1 \mathrm{Vehicles_t} + \beta_2 \mathrm{Rainfall_t} + \varepsilon_t \quad (6)$$

where, μ_t is the trend component; S_t is the seasonal component; β_1 and β_2 measure the impact of vehicles and rainfall.

The trend follows:

$$\mu_t = \mu_{t-1} + v_t, \quad v_t \sim N(0, \sigma_v^2) \quad (7)$$

The seasonal component follows:

$$S_t = -\sum_{i-1}^{s-1} S_{t-1} + \eta_t, \ \eta_t \sim N(0, \sigma_\eta^2) \quad (8)$$

Finally, a Seasonal ARIMA with Exogenous Regressors (SARIMAX) is conducted given potential autoregressive structure in AQI using the following equation.

$$\mathrm{AQI_t} = \emptyset_0 + \sum_{i=1}^{p} \emptyset_i \, \mathrm{AQI_{t-i}} + \sum_{j=1}^{q} \theta_j \, \varepsilon_{t-j} + \sum_{m=1}^{s} \gamma_m \, \mathrm{AQI_{t-m}} + \beta_1 \mathrm{Vehicles_t} + \beta_2 \, . \mathrm{Rainfall_t} + \beta_3 \, . \mathrm{Seasonality_t} + \varepsilon_t \quad (9)$$

Where: p, q, s are autoregressive, moving, and seasonal lags; γ_m captures seasonal effects and ε_t is the error term

4 Descriptive Analysis

In this section, a descriptive analysis of the key variables of the study is presented to better inform the readers about the raw data. According to the data, in the period from 2010 to 2014, registered private vehicles rose steadily; the percentage of new registrations of private vehicles began to decline after peaking at 9.26% in 2015 and then fell down to 4.42% (Table 1). Private vehicles include private cars, microbuses, and jeeps. At present, combinedly, 0.53 million registered private vehicles are in operation in Dhaka city. The Caveat is, that it doesn't include unregistered private vehicles, where is believed to be high in number, as well as vehicles commuting on the roads of Dhaka but registered elsewhere. These numbers alone make it clear just how much the region is contributing to PM2.5, NOx, and CO emissions. The increasing number of personal vehicles, coupled with the public's dependency on motorcycles due to cheap prices and convenient use, has led to a deterioration in the air quality. The slow growth in public transportation, which fell to 2.03% by 2024, paints a picture of low priority on sustainable transportation methods and increased reliance on personal vehicles, which only adds to the congestion and pollution. In this period, the growth of registered private motorcycles was significantly high. After ride-sharing companies received permission to operate in Bangladesh in 2016, the average growth rate of motorbikes was roughly 18% between 2018 and 2020. At present, more than 1.19 million motorbikes are registered in Dhaka alone. While they may serve the purpose of mobility, motorcycles are also one of the biggest sources of hydrocarbon emissions. On the other hand, cargo and delivery vans do show growth fluctuations, but their contribution to diesel emissions is quite high in areas of commerce.

Table 1: Number of Registered Vehicles by Types and its Growth Trend

Year	Private Vehicles*	Motorcycle	Public Vehicles**	Cargo and Delivery Van	Private Vehicles	Motorcycle	Public Vehicles	Cargo and Delivery Van
	Number of Vehicles				% Growth of Vehicles			
2010	222,549	210,879	26,813	49,643				
2011	239,254	245,586	29,015	61,268	7.51	16.46	8.21	23.42
2012	251,333	278,394	30,480	68,978	5.05	13.36	5.05	12.58
2013	263,968	304,724	31,646	77,347	5.03	9.46	3.83	12.13

2014	282,405	337,615	33,254	88,465	6.98	10.79	5.08	14.37
2015	308,567	384,373	36,078	98,303	9.26	13.85	8.49	11.12
2016	336,183	438,091	40,506	110,719	8.95	13.98	12.27	12.63
2017	365,624	513,342	44,175	128,044	8.76	17.18	9.06	15.65
2018	390,888	617,393	46,893	147,622	6.91	20.27	6.15	15.29
2019	414,593	716,645	50,030	160,177	6.06	16.08	6.69	8.50
2020	432,744	795,196	51,957	168,605	4.38	10.96	3.85	5.26
2021	458,570	895,006	53,356	180,116	5.97	12.55	2.69	6.83
2022	489,644	1,015,854	55,753	189,849	6.78	13.50	4.49	5.40
2023	511,055	1,106,257	57,762	195,062	4.37	8.90	3.60	2.75
2024	533,638	1,191,021	58,935	201,191	4.42	7.66	2.03	3.14

Source: Authors' Calculation Based on BRTA data; Note: *Car, Microbus and Jeep etc.; **Bus, Minibus, Human Hauler etc.

The data on the monthly average AQI of Dhaka City from 2013 to 2023 shows a specific cyclical occurrence (Figure 2). The period between December and February exhibits the most deterioration, while June to September sees the least pollution. The combination of temperature inversion decreased wind speeds, and dry conditions in winter severely increases air pollution. In winter, increased emissions from vehicles, industries, and construction activities combined with the inversion of temperature result in the aggravation of air quality (Alsowaidan et al., 2024).

On the contrary, the monsoon tremendously enhances air quality as the heavy rainfall along with strong winds helps to disperse the pollutants. The pre-monsoon period from March to May witnesses a gradual worsening of air quality leading up to the monsoons, and the post-monsoon months of October and November display deteriorating conditions post the rains. The variations throughout the seasons clearly showcase the meteorological parameters that directly impact air pollution and emphasize the need for strategic action during winter months when the destruction is at its peak.

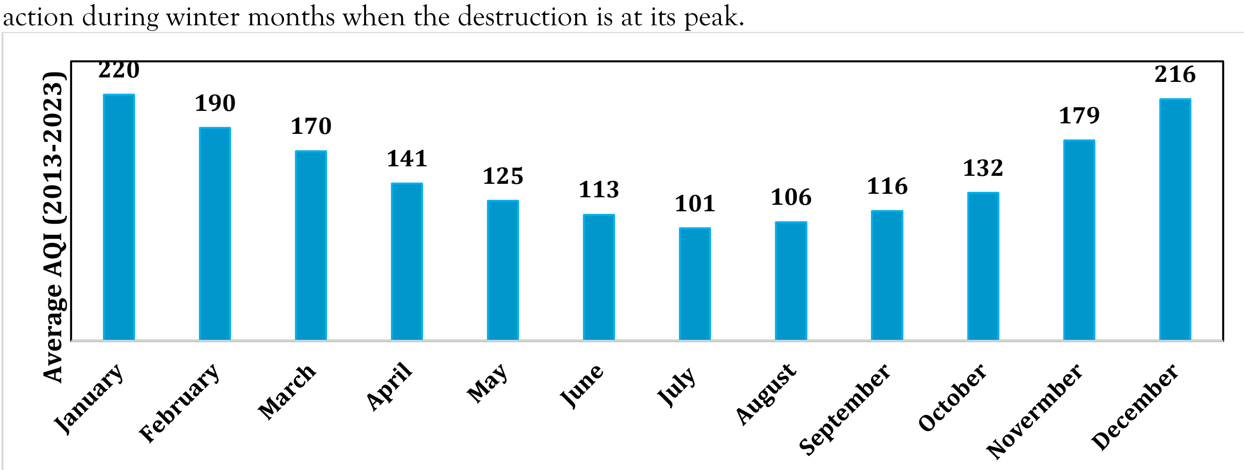

Figure 2: Monthly Average AQI of Dhaka City (2013-2023)

Source: Authors' estimation

A seasonal breakdown of AQI and its key determinants reveals substantial variations across different periods of the year. The average AQI is the highest at 201.31(Table 2), with a standard deviation of 25.5, suggesting severe air pollution. Private vehicle volume and cargo transport are also at their peak, indicating possible emissions-related air quality deterioration. Rainfall is minimal (0.15), which may contribute to stagnant atmospheric conditions and pollutant accumulation.

Table 2: Summary Statistics

Variables	Mean Values		
	Winter	Pre-monsoon	Monson
Air quality index	201	137	114
Private Vehicles (no.)	375891	371876	379522

Public Vehicles (no.)	44446	44024	44826
Motorcycles (no.)	613176	600414	624744
Cargo Vehicles (no.)	135127	133188	136878
Ln (Air quality index)	5.28	4.91	4.73
Ln (Private Vehicles)	12.81	12.80	12.82
Ln (Public Vehicles)	10.68	10.67	10.69
Ln (Motorcycles)	13.23	13.21	13.25
Ln (Cargo Vehicles)	11.76	11.75	11.78
Rainfall (mm)	0.15	0.22	0.19

Source: Authors' Calculation

In contrast, AQI declines significantly to an average of 137.08, showing improved air quality. Private and public vehicle volumes remain stable, but rainfall increases slightly (0.22), which may assist in pollutant dispersion.

In the Monsoon The lowest AQI is observed during this season, averaging 113.85, with increased rainfall (0.18) acting as a natural air purifier. Cargo transport remains consistent with other seasons, but increased precipitation likely helps reduce pollution levels.

4.1Results

To examine the determinants of air quality ('lnAQI'), this study has conducted three econometric approaches: (i) Autoregressive Distributed Lag (ARDL) model, (ii) Vector Error Correction Model (VECM), and (iii) ARIMA-SARIMA model. Each model was chosen to address different methodological considerations, including stationarity, long-run equilibrium relationships, and time-series dependencies.

A unit root test (ADF and KPSS) confirmed the presence of mixed integration orders ('I(0)' and 'I(1)'), justifying the use of ARDL and VECM for long-run and short-run dynamics. The Johansen cointegration test and ARDL Bounds test further established the existence of a cointegrating relationship among the variables.

4.2ARDL Model Results

The ARDL model, estimated with a lag structure (1,1,1,1,1,1,1), provided insights into both long-run and short-run relationships. The results indicate that the error correction term (ECM) coefficient was -0.582 ($p = 0.000$), suggesting that 58.2% of deviations from equilibrium are corrected within a month. Cargo transport (lncargo_v) had a significant positive short-run impact on AQI ($p = 0.067$), implying that an increase in cargo transport is associated with deteriorating air quality. Seasonality was a dominant long-term determinant of air quality ($p = 0.000$), reinforcing the need for seasonal interventions. Rainfall exhibited a marginally significant negative effect in the long run ($p = 0.073$), suggesting its role in improving air quality over time (Annex 1).

4.3Johansen Cointegration and VECM Results

The Johansen test confirmed the existence of at least one cointegrating relationship (Annex 2). VECM estimation provided further insight into long-run and short-run dynamics. The error correction term (ECM) was unexpectedly positive (0.505, $p = 0.000$), indicating potential structural instability or omitted variables. In the long run, motor vehicle presence ($\lambda = 2.38$, $p = 0.010$) was positively associated with air pollution, while rainfall (-0.38, $p = 0.008$) improved air quality (Annex 3). Private vehicle volume (-5.73, $p = 0.010$) had an unexpected negative coefficient, potentially due to shifts toward fuel-efficient or electric vehicles. Cargo transport did not show a significant long-term effect ($p = 0.828$), despite its short-term significance in the ARDL model.

4.4ARIMA-SARIMA Model Results

The ARIMA (1,1,1) with SARIMA (1,1,1,12) model provided insights into short-term dependencies and seasonal patterns. The findings indicate that cargo transport remained a significant contributor to deteriorating air quality ($p = 0.027$), while motor vehicle presence had a surprising negative effect ($p = 0.040$), potentially reflecting regulatory improvements (Annex 4). Seasonal components suggested a strong correction mechanism for past seasonal shocks.

5 DISCUSSION

This study investigates the determinants of air quality, measured as the log-transformed AQI, by using multiple econometric approaches, including ARDL, VECM, and ARIMA-SARIMA models. The findings highlight both short-run and long-run relationships between air pollution and key explanatory variables, including private vehicle volume, public vehicle volume, motor vehicle presence, cargo transport volume, rainfall, and seasonality.

5.1Long-Run Relationships and Equilibrium Adjustment

The Johansen cointegration test and the ARDL Bounds test confirm the existence of a long-run equilibrium relationship between air quality and the selected determinants. The VECM results provide further insight into this equilibrium adjustment. The error correction term (ECM) coefficient was found to be positive instead of the expected negative value, suggesting a possible instability in the model's adjustment toward equilibrium. This may indicate structural shifts in policy, fuel standards, or urban transport regulations over the study period.

Among the long-run coefficients, motor vehicle presence exhibited a statistically significant positive relationship with air pollution, aligning with expectations that greater motor vehicle use contributes to higher pollutant emissions. Meanwhile, rainfall was found to have a significant negative effect on air pollution, supporting the hypothesis that precipitation aids in dispersing airborne pollutants. Seasonality was highly significant, indicating that certain times of the year (e.g., dry or winter months) exacerbate pollution levels, possibly due to increased particulate matter accumulation and meteorological conditions that hinder pollutant dispersion.

Interestingly, the private vehicle volume variable displayed a counterintuitive negative coefficient in the VECM, implying that an increase in private vehicle numbers is associated with reduced pollution levels. This may be explained by improved vehicle emissions standards, a shift toward hybrid and electric vehicles, or behavioral changes such as increased telecommuting and carpooling. The statistical insignificance of public transport volume suggests that its role in air pollution is not straightforward and may depend on factors such as fleet composition, fuel type, and efficiency.

5.2Short-Run Dynamics and Immediate Impacts

The ARDL and VECM results highlight notable differences in the short-run effects of the explanatory variables. Cargo transport emerged as a key short-term driver of air pollution, with a statistically significant positive impact on AQI. This finding suggests that heavy-duty freight transport, particularly in urban corridors, contributes to increased emissions. Short-run coefficients for private and public vehicle volumes were not significant, implying that immediate variations in these variables do not strongly influence air pollution levels.

The ARIMA-SARIMA model further validates these short-run trends. The motor vehicle variable, which had a positive long-run relationship with AQI, surprisingly exhibited a negative short-run coefficient. This may suggest that the impact of new motor vehicle registrations or fluctuations in traffic density is offset by regulatory measures, periodic emission control programs, or improved fuel quality. Cargo transport remained a significant short-term contributor to pollution, reinforcing the need for targeted policy interventions to curb emissions from freight movement.

Rainfall did not show a significant short-run effect, which may be due to variations in the intensity and duration of precipitation across different time periods. However, its consistent long-run effect suggests that it plays a crucial role in pollutant dispersion over extended periods. Seasonality continued to be a dominant factor, with both ARDL and VECM models showing its strong association with air pollution, reinforcing the need for seasonal air quality management strategies.

6 Implications for Policy and Urban Planning

The results provide several important implications for policymakers and urban planners. First, the long-run significance of motor vehicles and cargo transport highlights the need for stricter emission regulations, enhanced vehicle efficiency standards, and improved public transport systems to reduce reliance on individual car ownership.

Second, the role of seasonality in air pollution underscores the necessity for season-specific interventions, such as stricter industrial controls during high-pollution periods, increased enforcement of vehicular emission standards, and targeted public health advisories. The significance of rainfall as a natural pollution mitigator suggests that urban planning should integrate green infrastructure solutions, such as increased tree cover and water bodies, to enhance air quality.

Third, the counterintuitive findings regarding private vehicle volume suggest that rather than blanket restrictions on private vehicles, policies should focus on promoting cleaner vehicle technologies and incentivizing fuel efficiency improvements. Given that public transport volume did not exhibit significant effects, further research is needed to assess the emissions profile of public transit fleets and optimize their environmental impact.

7 CONCLUSIONS

This study has investigated both short and long-run causal relationships between air pollution and the number of vehicles registered in Dhaka city, one of the most polluted and congested cities on the globe. The results show that motor vehicles and cargo trucks are primarily responsible for the short-term deterioration of the air quality. Depending on the season, pollution differs, with air pollution reaching its utmost value during winter when proclamations and other atmospheric disorders combine with the monsoon, which subsequently assists in the dilution of pollutants. The results of econometric analysis suggest that the growth in the number of motor vehicles is a strong driver of degrading air quality over a prolonged period of time, but in the short run, the impacts are more complex and are likely shaped by enforcement and vehicle emission standards regulations having a change in focus.

The study, too, finds something unexpected in regard to long-term relationships of the private vehicle volume; air pollution does not seem to have a direct correlation. Thus, the changes in fuel efficiency standards, the use of new technologies, and even altered commuting patterns are lessening the expected surge in pollutants. Simultaneously, though, there is the challenge of incessant increases in the number of motorcycles, as well as cargo transport, which are great sources of pollutant emissions.

Emissions from vehicles are a critical part of air pollution in Dhaka, which means policies must work on reforming the transportation system. Changes in emission standards, building new facilities for public transportation, and encouraging the electrification of public transport and implementing congestion pricing are some solutions that can help in controlling pollution. Moreover, such measures must also be in place during designated seasons, specifically the winter when the level of pollution is excessive.

The limitations of this particular study further inform about the need to investigate the impacts from the emissions of factories, the urban heat effect, as well as shifts in mobility as a consequence of policies. The impacts of other modes, such as walking, the creation of car-free areas, and urban landscaping on air pollution should also be studied more deeply. In order to make progress toward sustainable urban development in Dhaka, effective air pollution control needs an integrated approach, combining transportation engineering and planning, environmental management, and public health.

Limitations and Future Research Directions

Although the findings provide a robust assessment of air quality determinants, some limitations must be acknowledged. First, the positive error correction coefficient in the VECM suggests potential instability, indicating that structural breaks or omitted variables may influence the results. This requires further investigation. Second, while cargo transport consistently appeared as a significant determinant of air pollution, more granular data on fleet composition, fuel types, and freight corridors could enhance understanding of its precise impact. Third, the role of industrial emissions, urban topography, and meteorological variables beyond rainfall (e.g., wind speed, temperature inversions) should be examined to refine the air pollution modeling framework.

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***Authors' Contributions**

♦ Estiaque Bari led the conceptualization, econometric modeling, and writing of the initial draft.
♦ Antara Biswas contributed to the literature review and policy discussion.
♦ Sabrin Sultana handled data collection, visualization, report writing, interpretation of results and final editing.
♦ Tonmay Saha supported the data analysis.

All authors read and approved the final manuscript.

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Annex

Annex 1: ARDL Model Results

Variable	Long-Run Coefficient	Std. Error	p-value	Short-Run Coefficient	Std. Error	p-value
Ln (Air Quality Index)	-0.582	0.101	0.000	-	-	-

Ln (Private Vehicles)	1.64	3.39	0.630	-21.16	25.20	0.403
Ln (Public Vehicles)	-3.98	2.33	0.091	9.50	15.68	0.546
Ln (Motorcycles)	1.61	1.39	0.250	3.34	11.76	0.777
Ln (Cargo Vehicles)	-0.25	1.11	0.819	25.07	13.56	0.067
Rainfall	-0.31	0.17	0.073	0.08	0.08	0.344
Seasonality	-0.25	0.03	0.000	-0.04	0.02	0.136

Source: Authors estimation

Annex 2: Johansen Test for Cointegration

Rank	**Trace Statistic**	**5% Critical Value**	**Decision**
r = 0	124.24	94.15	Reject H_0 (Cointegration Exists)
r ≤ 1	94.15	68.52	Reject H_0
r ≤ 2	68.52	47.21	Reject H_0

Source: Authors estimation

Annex 3: Vector Error Correction Model (VECM) Long-Run Estimates

Variable	**Coefficient**	**Std. Error**	**p-value**
Ln (Air Quality Index)	1.000	-	-
Ln (Private Vehicles)	-5.73	2.21	0.010
Ln (Public Vehicles)	1.62	1.53	0.291
Ln (Motorcycles)	2.38	0.92	0.010
Ln (Cargo Vehicles)	-0.16	0.72	0.828
Rainfall	-0.38	0.14	0.008
Seasonality	0.51	0.02	0.000

Source: Authors estimation

Annex 4: ARIMA-SARIMA Estimates

Variable	**Coefficient**	**Std. Error**	**p-value**
Ln (Private Vehicles)	3.14	2.28	0.169
Ln (Public Vehicles)	-1.32	1.51	0.380
Ln (Motorcycles)	-2.63	1.27	0.040
Ln (Cargo Vehicles)	3.25	1.47	0.027
Rainfall	-0.039	0.091	0.667
Constant	0.0034	0.0012	0.008

Source: Authors estimation