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Impact of Vehicles of Different Fuel Types on Air Pollution: A Study on 24 Indian cities during 2016-2023

Yoga Panini K.[1], MSc. 2nd Year, Amity School of Economics, Amity University Kolkata

Debalina Saha, Assistant Professor, Amity School of Economics, Amity University Kolkata

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ABSTRACT

This study investigates how vehicles with different fuel types affect urban air pollution across 24 cities in low-, middle-, and high-income states in India during 2016 -2023. Using a balanced panel of city-level vehicle registration and air quality data, the study investigates the relationship between vehicle fuel composition and concentrations of **NO_2, PM_{10}, and $PM_{2.5}$**. Based on the Hausman test, the **random-effects panel regression model** was used for **NO_2** and **PM_{10}**, while the **fixed-effects panel regression model** was used for **$PM_{2.5}$.** The regression results indicate that **diesel-hybrid** and **petrol–CNG** vehicles have a statistically significant positive impact on **NO_2** concentrations. **Petrol–CNG** vehicles have a statistically significant positive impact on **PM_{10}** concentrations, whereas **battery-operated electric vehicles** have a statistically significant negative impact on **PM_{10}**. **Diesel vehicles** have a statistically significant positive impact on **$PM_{2.5}$** concentrations, while vehicles of other fuel types do not significantly affect $PM_{2.5}$. The study indicates that particulate matter pollution is critically high in the low-income states of Bihar and Uttar Pradesh, while high-income states exhibit favorable pollutant levels within the nationally determined standards. India is gradually moving towards cleaner fuel types, although petrol vehicles continue to dominate the road transport sector.

The study suggests that improved infrastructure for CNG refilling, use of clean fuel for power generation and use of cleaner vehicle fuels like bio-diesel and bio-fuel blends can improve urban air quality.

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[1] Corresponding author, email: yogapaninik2003@gmail.com

1. Introduction

Urban expansion is an essential feature of economic prosperity. Urbanisation has increased in the present millennium with the expansion of economies worldwide. As more people reside in cities and commercial and industrial activities expand, the demand for mobility has increased, resulting in rapid growth in the number of vehicles. Vehicular emissions are a major contributor to urban air pollution, prompting a transition towards cleaner transport fuels such as compressed natural gas (CNG), biofuels, and battery electric vehicles. In this study, we examine how vehicles using different fuel types influence urban air pollutant levels.

Air pollution is primarily caused by anthropogenic activities such as vehicular transport and industrial operations. Key pollutants include particulate matter ($PM_{2.5}$ and PM_{10}), nitrogen oxides (NO_x), carbon monoxide (CO), sulphur dioxide (SO_2), and hydrocarbons (HC), all of which substantially degrade urban air quality. Air pollution poses a significant global environmental and public health challenge. Around **7.3 billion** people worldwide are exposed to annual $PM_{2.5}$ concentrations exceeding safe limits, with nearly **80%** residing in developing and underdeveloped countries. China and India together account for approximately **38%** of global exposure to $PM_{2.5}$ concentrations above the WHO guideline **(Rentschler & Leonova, 2023).**

Air pollution is a serious challenge in India. According to the **2024 IQAir Report**, **74 of the world's 100 most polluted cities are located in India (IQAir, 2024).** More than half of India's population is exposed to pollution levels exceeding the National Ambient Air Quality Standard (NAAQS) **(Mathew et al., 2024).** Ambient air pollution is responsible for an estimated **870,000 premature deaths annually**, while road transportation emissions account for approximately **43,000 deaths each year (Peshin et al., 2024).**

Air pollution adversely affects public health, economic stability, and the environment. The economic losses resulting from premature mortality and morbidity were estimated at **US$36.8 billion** in 2019, equivalent to **1.39% of India's GDP (Tang, 2023).** Current annual health damages attributable to road transportation range between **US$2.6 billion and US$10.6 billion**, while total health and climate damages are estimated at **US$14.1 billion (Peshin et al., 2024).** Technological advancements such as catalytic converters, advanced fuel systems, and electric vehicles have significantly improved vehicle emission performance **(Wallington et al., 2022; Vidhi & Shrivastava, 2018).** However, since nearly three-fourths of India's electricity is generated from coal, the environmental benefits of electric vehicles depend on the transition to cleaner electricity generation **(Peshin et al., 2024).**

The review of existing studies indicates that automobile emissions are a major source of air pollution in India and other developing countries. Although previous studies have focused on the various sources and health impacts of air pollution, relatively fewer studies have examined the relationship between vehicle fuel types and urban air pollution in the context of developing countries. This study addresses this gap by examining vehicles using different fuel types across **24 Indian cities** during **2016–2023**. It analyses how different vehicle fuel types influence **NO_2,**

PM_{10}, and $PM_{2.5}$ concentrations and further examines how urban air pollution varies across low-, middle-, and high-income states in India.

2. Objectives

1. To analyse the trends in vehicle fuel-type usage and air pollutants (SO_2, NO_2, PM_{10}, $PM_{2.5}$) across 24 cities from 2016 to 2023.
2. To analyse how different types of vehicles impact air pollutants (SO_2, NO_2, PM_{10}, $PM_{2.5}$).
3. To study how urban air pollution varies across low-income, middle-income and high-income states in India.

3. Methodology

This study uses a panel data regression model based on vehicle registration and pollution data from 24 cities across 6 states in India from 2016 to 2024. This study primarily relies on data from government data repositories. This section describes the sampling method and the regression model used for the analysis, the data types, and the data sources.

3.1 Sampling method

For this study, six states were selected based on per capita state GDP level. Two high-income states (Goa and Sikkim), two middle-income states (Andhra Pradesh and Arunachal Pradesh), and two low-income states (Uttar Pradesh and Bihar). Approximately 10% of the Regional Transport Offices (RTOs) were initially identified through random sampling for each selected state. The selected RTOs were then checked for the availability of air pollution data from the Central Pollution Control Board (CPCB). If air pollution data were not available for a selected RTO, another RTO was randomly selected as a replacement. The study includes cities where both Regional Transport Office (RTO) data and corresponding Central Pollution Control Board (CPCB) air pollution data were available. Using this procedure, 24 cities were selected for the final analysis. Vehicle registration and air pollution data for the selected cities were collected from 2016 to 2023.

3.2 The Model

In this study, a panel regression model was used to examine the influence of vehicle fuel type composition on urban air quality. Based on the Hausman test, the random-effects panel regression model was used for NO_2 and PM_{10}, while the fixed-effects panel regression model was used for $PM_{2.5}$ for 24 cities over the period 2016 to 2023. In each model equation, the dependent variable is the corresponding pollutant concentration regressed upon vehicle registrations by fuel type.

The robust standard error method was applied to address heteroscedasticity in the PM_{10} model and serial autocorrelation in the NO_2 model. The model equation is given below:

$$PNTit = \beta_{01} + \beta_{11}CNGONLY_{it} + \beta_{21}DIESEL_{it} + \beta_{31}ELECTRICBOV_{it} + \beta_{41}PETROL_{it} + \beta_{51}DISELHYBRIDit + \beta_{61}PETROLHYBRID_{it} + \beta_{71}PETROLCNG_{it} + \mu_{it}$$

Where:

In each model, PNTit as a dependent variable, represents the pollutant concentrations (NO2, PM10, PM2.5) in 'i ' city at 't ' year.

β_{01}, β_{11}, β_{21}, β_{31}, β_{41}, β_{51}, β_{61}, β_{71} are the respective regression coefficients for the model.

$CNG\text{-}ONLY_{it}$ is the total number of CNG-only vehicles registered in the city *i* at time *t*.

$DIESEL_{it}$ is the total number of diesel vehicles registered in the city *i* at time *t*.

$ELECTRIC\ BOV_{it}$ is the total number of electric battery-operated vehicles registered in the city *i* at time *t*.

$PETROL_{it}$ is the total number of petrol vehicles registered in the city *i* at time *t*.

$DIESELHYBRID_{it}$ is the total number of diesel-hybrid vehicles registered in the city *i* at time *t*.

$PETROLHYBRID_{it}$ is the total number of petrol-hybrid vehicles registered in the city *i* at time *t*.

$PETROLCNG_{it}$ is the total number of petrol-CNG vehicles registered in the city *i* at time *t*.

μ_{it} represents the error term, it captures unobserved factors

3.3 Hypothesis

H_0: Vehicle fuel-type categories (petrol, diesel, CNG, electric, hybrid, and dual-fuel vehicles) have no statistically significant effect on the concentrations of NO_2, PM_{10}, and $PM_{2.5}$ across the selected cities.

H_1: Vehicle fuel-type categories (petrol, diesel, CNG, electric, hybrid, and dual-fuel vehicles) have a statistically significant effect on the concentrations of NO_2, PM_{10}, and $PM_{2.5}$ across the selected cities.

3.4. Data Source

1. Open Government Data (OGD) Platform India.
2. Ministry of Road Transport and Highways, Government of India.
3. Central Pollution Control Board (CPCB), Ministry of Environment, Forest and Climate Change (MoEFCC), Government of India.

3.5 Software used

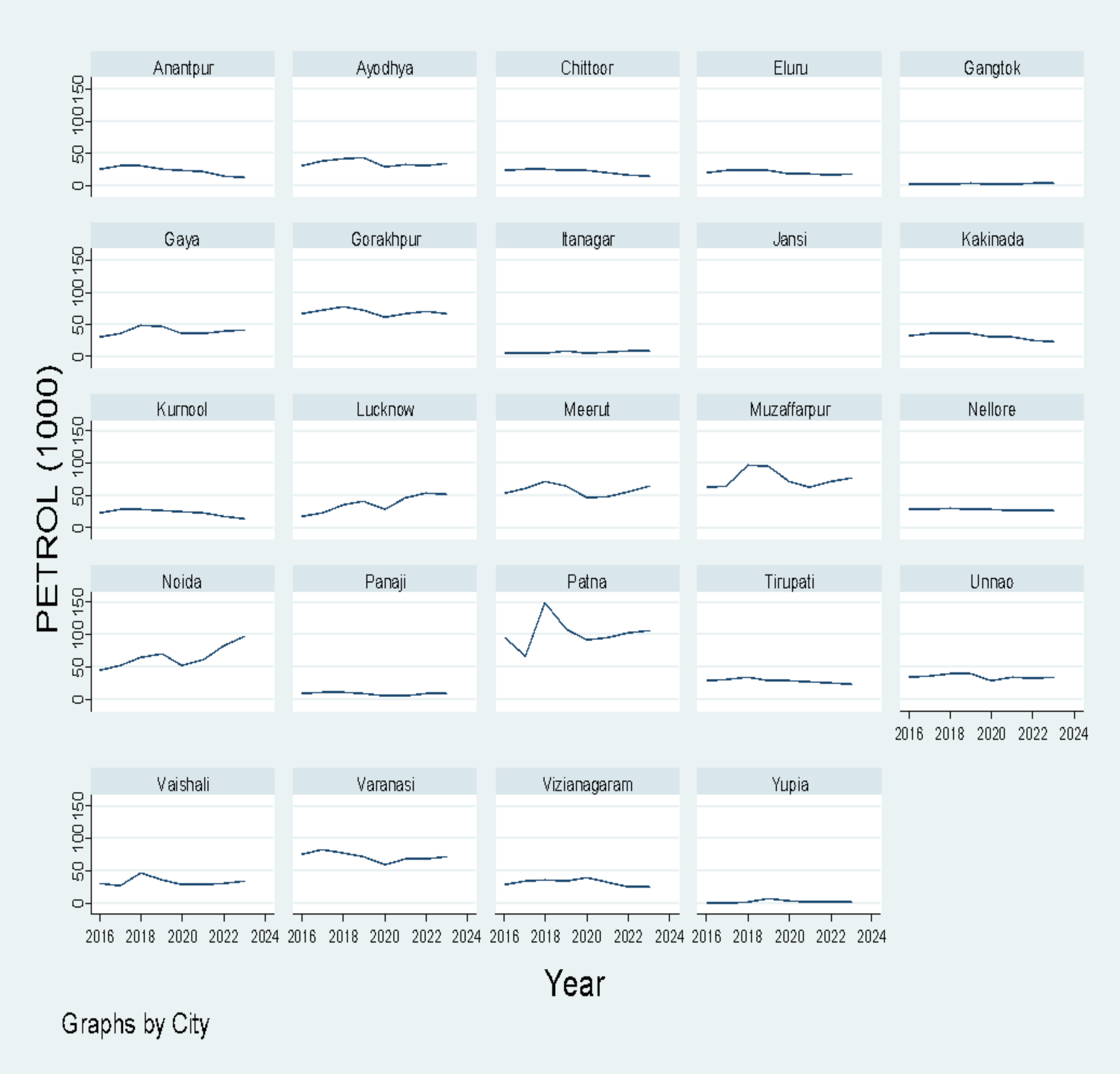
Microsoft Excel and Stata are used in this study. Data collection, cleaning, organising, and preparing the dataset for analysis were performed in Microsoft Excel 2021. Stata/SE-14 was employed to conduct descriptive statistics and panel-data regression.

4.An overview of vehicle registrations and pollution levels in the 24 cities of the 6 states of varying income levels

4.1. A study of city-wise vehicle registration by fuel type

Figure 1 depicts the number of vehicles of different fuel types registered in the 24 cities during 2016-23. From the vehicle registration trends, we observe that 8 cities had recorded growth in diesel vehicles registrations, Lucknow, Noida, and Itanagar recorded more than 5% growth, Jansi and Meerut recorded 2-3% growth, and Ayodhya, Unnao, and Yupia recorded less than 1% growth. Registration of diesel vehicles decreased in 16 cities. Yupia, Lucknow and Noida recorded remarkably high (10 – 27%) growth in the registrations of petrol vehicles while Itanagar and Gangtok demonstrated 8.4% and 6 % growth respectively. Eight cities, Gorakhpur, Vaishali, Patna, Ayodhya, Meerut, Muzaffarpur and Gaya are showed less than 5 % growth. Anantapur, Kurnool, and Chitoor experienced 5-8% fall in petrol vehicle registration, and in 8 other cities the decline was less than 5%.

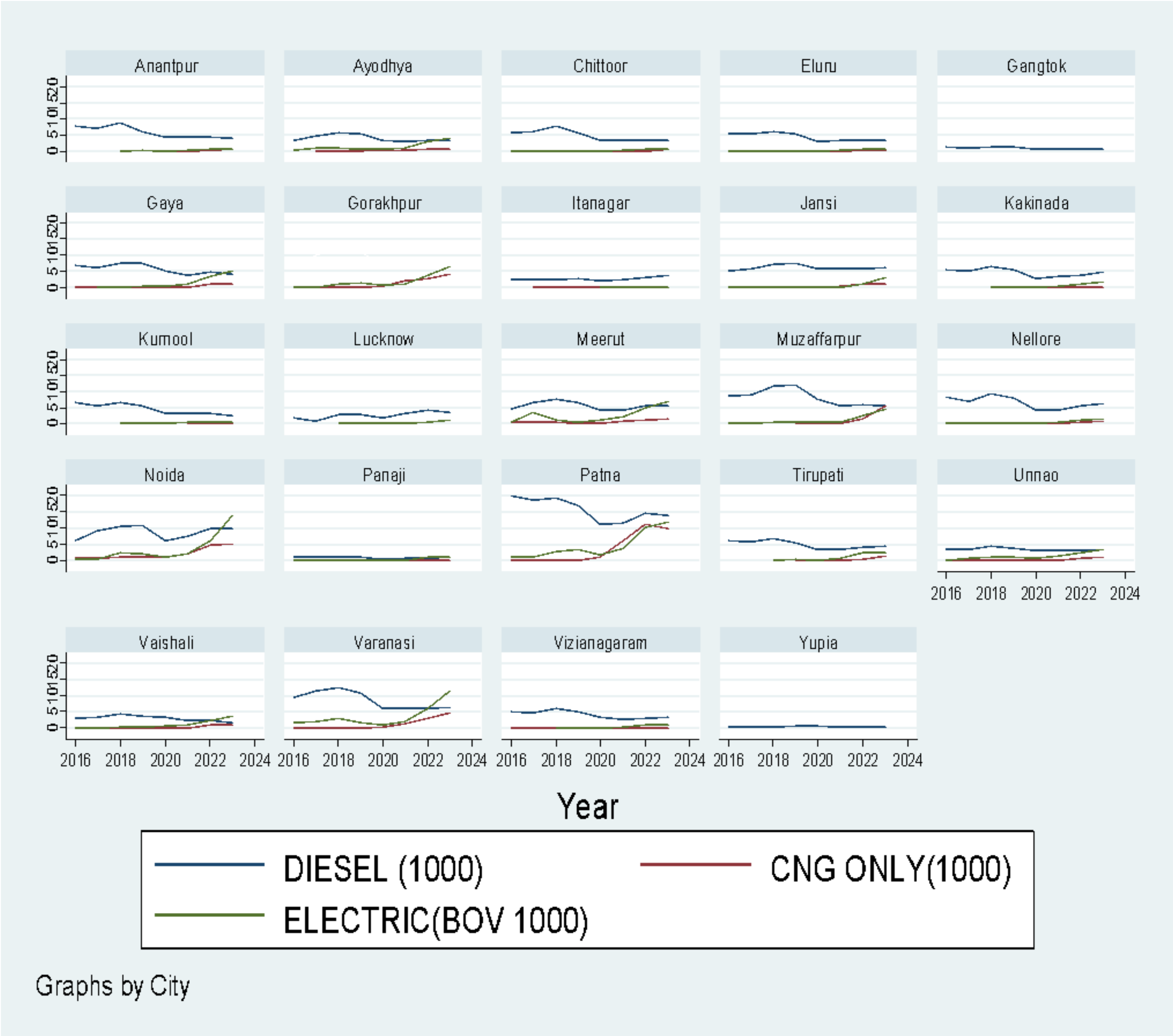
Figure 1: petrol vehicle registered in the 24 cities during 2016-23



Source: MoRTH and Author's computation

Nearly all cities show substantial growth in Electric vehicle registration from 2019 onwards, between 2016 to 2023, Tirupati, Jansi, Gorakhpur, and Gaya recorded more than 200% growth in Electric vehicle registration. Anantapur, Chittoor, Vizianagaram, Kurnool, Kakinada, Eluru, Nellore, Lucknow and Hazipur saw 100 – 200 % growth. The remaining cities demonstrate less than 100% growth. It shows increasing demand at present and potential demand in future for Electric vehicles. One of the major factors of EVs' growth is that they are eco-friendly in nature, but for India, the story is different. India generates ¾ electricity from coal. EVs can't be considered environmentally sustainable or friendly unless and until their electricity supply is derived from a clean and renewable energy source.

Figure 2: Vehicles of different fuel types registered in the 24 cities during 2016-23



Source: MoRTH and Author's computation

None of the cities experienced any decline in the registrations of CNG vehicles during the study period. Muzaffarpur city shows the highest growth rate of 243.94%., the first CNG vehicle was registered in 2019 and reached 5,694 in 2023. The remaining cities—Chittoor, Anantapur, Kakinada, Eluru, Nellore, Varanasi, Ayodhya, Jhansi, Gorakhpur, Unnao, and Gaya—show a growth rate of 100% to 200%. Panaji, Kurnool, Gangtok, Vizianagaram, Itanagar, and Lucknow have fewer than 50 CNG vehicles. It highlights that CNG is not universal and is highly dependent on the availability of CNG refilling infrastructure, and pipeline connectivity. Overall, CNG is regional and non-universal. Government encouragement can boost CNG.

Diesel-hybrid vehicles declined almost everywhere and reached nearly zero. Petrol-CNG vehicles show growth in most cities. Petrol-hybrid vehicles also show positive growth especially in Patna, Lucknow, Meerut, and Noida. Growth in petrol hybrid vehicles indicate a transition phase from petrol engines to cleaner mobility options.

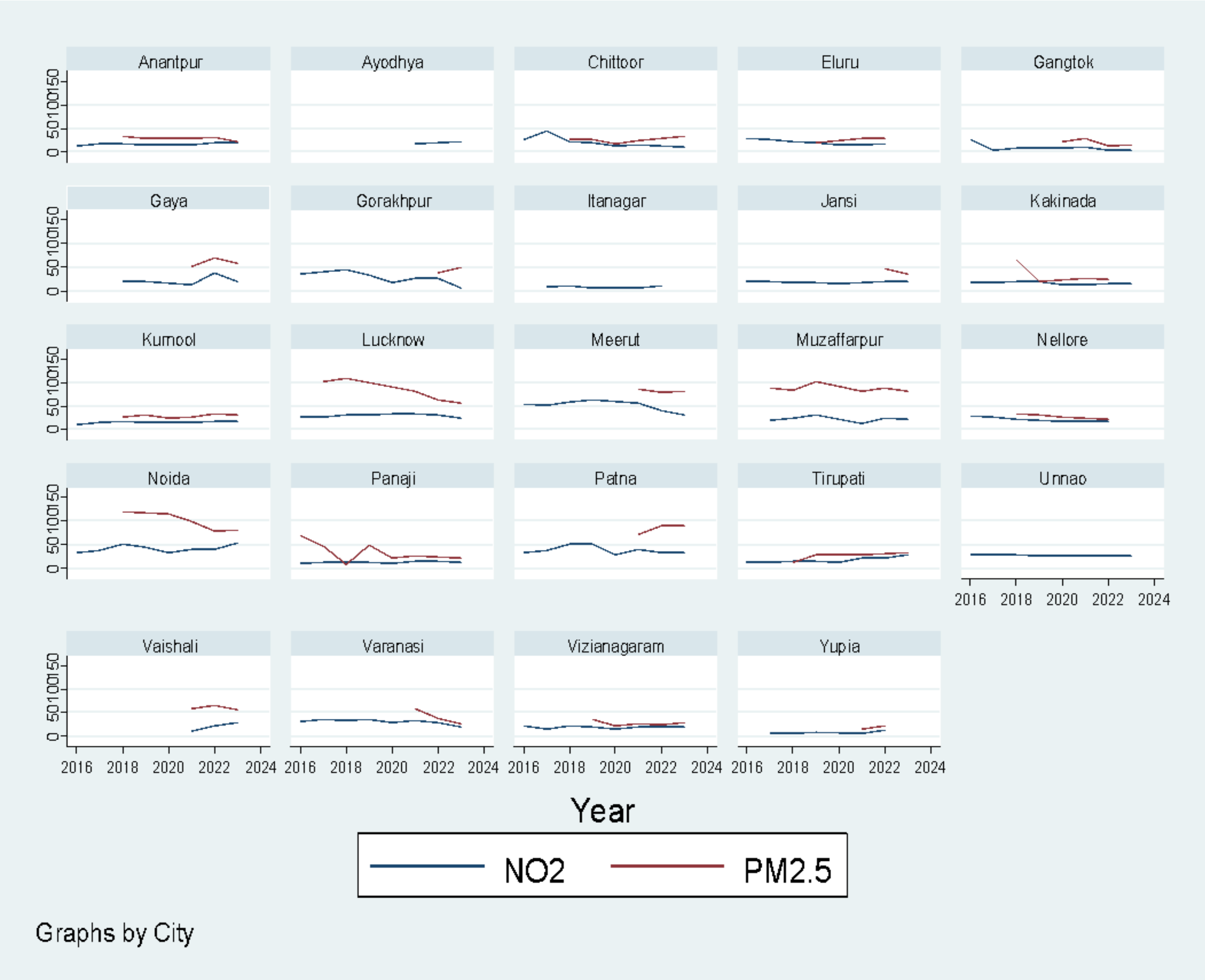
4.2. Study on city-wise air pollutant concentration

In Figure 2, the concentration levels of three pollutants are shown. The cities, Anantapur, Panaji, Lucknow, Meerut, Noida, Patna, Gorakhpur, Muzaffarpur, and Varanasi recorded increased concentration of NO2 in terms of CAGR (Compounded Annual Growth Rate) during the study period. Gangtok, Chittoor, Vizianagaram, Kakinada, Kurnool, Tirupati, Eluru, Ayodhya, Jhansi, Unnao, Vaishali, Gaya, Nellore, Itanagar, and Yupia cities showed decline in NO2 levels in the air.. CPCB–NAAQS standard- the annual limit of NO2 is 40 $\mu g/m^3$

The cities in which the NO2 level was below the maximum permissible limit are, Anantapur, Ayodhya, Chittoor, Eluru, Gangtok, Gaya, Gorakhpur, Itanagar, Jhansi, Kakinada, Kurnool, Lucknow, Muzaffarpur, Nellore, Panaji, Patna, Tirupati, Unnao, Vaishali, Varanasi, Vizianagaram, and Yupia. The average annual NO_2 concentration levels in Meerut and Noida exceeded the national annual limit.

The CAGR analysis for PM2.5 during 2016-2023 shows that Chittoor, Lucknow, Meerut, Noida, Patna, Gorakhpur, Muzaffarpur, Vaishali, and Varanasi experienced increased PM2.5 concentration while Gangtok, Panaji, Anantapur, Vizianagaram, Kakinada, Kurnool, Tirupati, Eluru, Ayodhya, Jhansi, Unnao, Gaya, Nellore, Itanagar, and Yupia enjoyed reduced levels of PM2.5 in the air. Major insights from the PM2.5 analysis suggest that many densely populated Indo-Gangetic Plain cities such as Noida, Meerut, Patna, and Lucknow heave high levels of PM2.5 in their air.

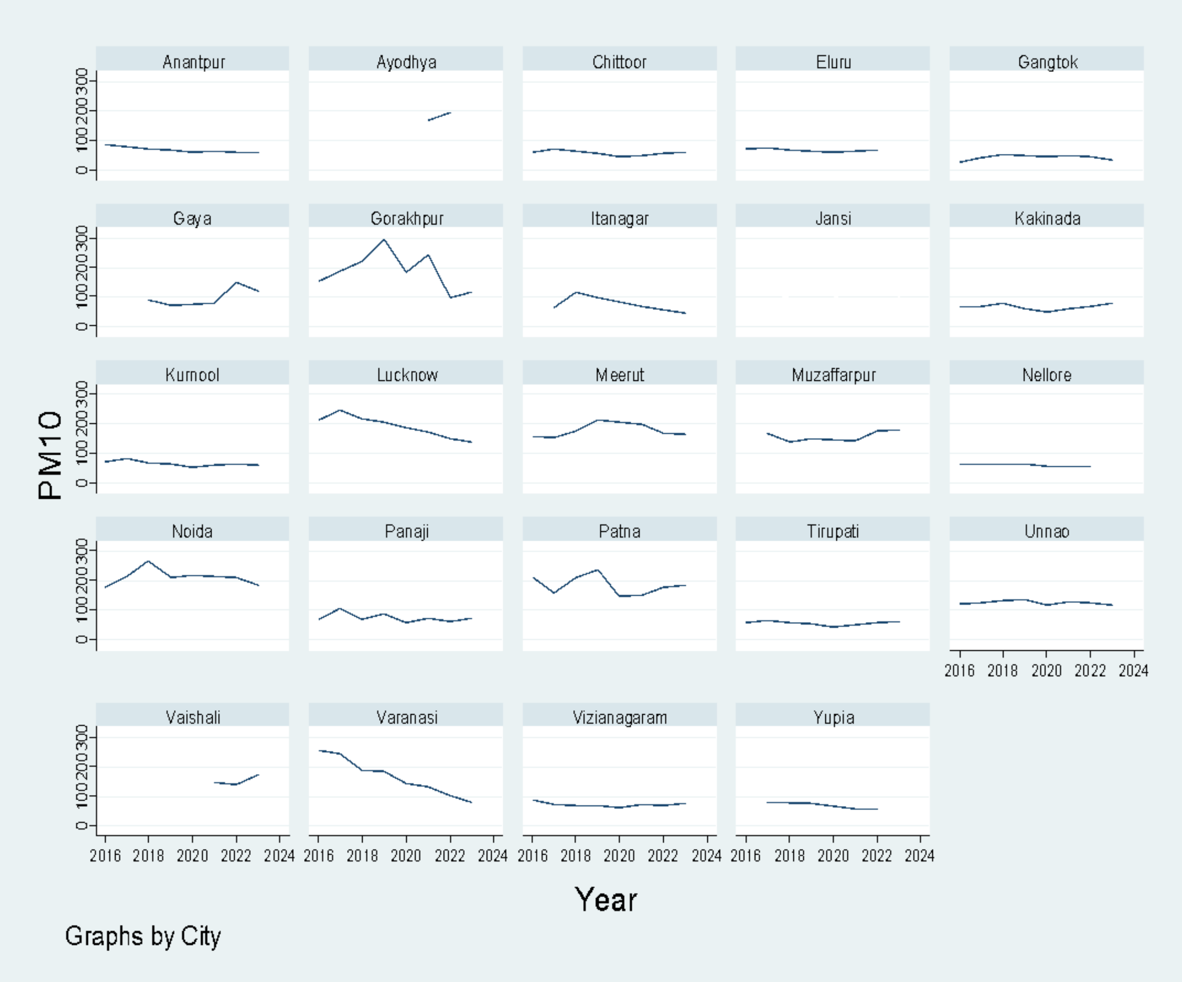
Figure 3: Concentration of NO2 and PM2.5 pollutants (µg/m³) in the 24 cities during 2016-23.



Source: CPCB and authors' computation

According to CPCB–NAAQS standards, the annual limit is 40 µg/m³. Average $PM_{2.5}$ concentration are within this limit in Anantapur, Ayodhya, Chittoor, Eluru, Gangtok, Itanagar, Kakinada, Kurnool, Nellore, Panaji, Tirupati, Unnao, Vizianagaram, and Yupia. It remained above the limit in Gaya, Gorakhpur, Jhansi, Lucknow, Meerut, Muzaffarpur, Noida, Patna, Vaishali, and Varanasi. Vehicular emissions, biomass burning, industrial activity, and secondary aerosol formation are the possible causes for the increase in PM2.5 in these cities. During the COVID induced lock-down period, almost every city experienced decline in $PM_{2.5}$ pollution which confirms the role of human activity in rising pollution levels.

Figure 4: Concentration of PM10 pollutants (µg/m³) in the 24 cities during 2016-23.



The CAGR analysis for PM 10 during 2016-2023 highlights that Gangtok, Panaji, Lucknow, Patna, Meerut, Noida, Varanasi, Gorakhpur, Muzaffarpur, Vaishali, and Gaya recorded increased concentration of the pollutant. Anantapur, Chittoor, Vizianagaram, Kakinada, Kurnool, Tirupati, Eluru, Ayodhya, Jhansi, Unnao, Nellore, Itanagar, and Yupia decline in PM10 concentration in the air. Most cities are within the CPCB–NAAQS standard of annual limit 60 µg/m³ the PM10 level in Chittoor, Gangtok, and Tirupati remained below the national average level. The pollutant level remained above the national average in Anantapur, Ayodhya, Eluru, Gaya, Gorakhpur, Itanagar, Jhansi, Kakinada, Kurnool, Lucknow, Meerut, Muzaffarpur, Nellore, Noida, Panaji, Patna, Unnao, Vaishali, Varanasi, Vizianagaram, and Yupia. Construction dust, road projects, vehicular resuspension, waste burning, windblown dust, industries, and traffic are the possible causes for increasing PM_{10} in the above-mentioned cities. During the COVID lock-down period, almost every city shows a decline in PM_{10} pollutant levels.

The relationship between vehicle growth and pollution level across the 24 cities shows a mixed pattern. Cities like Lucknow and Gorakhpur show an increase in EVs and also gradual improvement in particulate matter. In cities like Gaya, Meerut, and Muzaffarpur, pollution, especially particulate matter, crosses the national threshold limit even though EVs are increasing. It highlights the contribution of older vehicle fleets and other factors such as industry concentration, waste burning, etc. towards air pollution. In spite of the fall in the number of diesel vehicles, level of particulate matter increased in Kakinada and Panaji highlighting the role of other factors apart from vehicular emissions in increasing the pollutant level in the air. Anantapur and Vizianagaram show consistent improvement in particulate pollution because of continuous decrease in petrol and diesel vehicle and and adoption of policies towards improvement in urban environment. Noida, Patna and Meerut are the most pollutant stressed cities, especially for particulate matter 2.5. In these cities, EV registrations increased but fossil fuel vehicles also consistently increased. Overall, the data indicates that the relationship between the vehicle growth and the pollution level is complex and along with the vehicle growth, other city specific factors such as industrial activity, construction work, waste burning, etc. also contribute to the pollution level.

4.3 An analysis of the interrelationship between state GDP and pollutant levels in cities

The Six states, selected at random from different parts of the country, are classified on the basis of per capita state GDP into high (Goa and Sikkim), moderate (Andhra Pradesh and Arunachal Pradesh), and low per capita GDP (Uttar Pradesh and Bihar). The 24 cities, of the six states show different pattern in vehicle fuel use and pollutant levels. High per capita GDP states like Goa and Sikkim, exhibit favorable pollutant levels. Pollutants such as NO2, PM10, PM2.5 are within the nationally determined limit.

Moderate-income states show transitional patterns. In many cities like Anantapur, Chittoor, Kurnool, Kakinada, Tirupati, and Nellore in the state of Andhra Pradesh, the number of Diesel vehicle registrations is decreasing, and at the same time, EVs and CNG vehicles have shown rapid growth. As a result, particulate matter is decreasing. In Arunachal Pradesh, cities such as Itanagar and Yupia recorded slight increase in petrol and diesel vehicles, but NO2 concentration is low and PM10 is within national standards.

The cities in the low-income states, Uttar Pradesh and Bihar, indicate a strong association between the number of vehicle registrations and pollutant concentration in the air. In these cities, petrol, diesel, CNG -petrol, CNG only and hybrid vehicles increased over the last 8 years, as a result, pollutant levels in the air also increased in the cities. Pollutants have already crossed the national threshold level. In terms of the concentration of particulate matter, the air quality in these cities fall under poor or very poor category. Cities like Noida, Meerut, Lucknow, Jhansi, Gorakhpur, Patna, Gaya, Muzaffarpur are some of the affected cities. Cities in UP generally exceed the threshold of PM10 and cities in Bihar like Patna and Muzaffarpur have very high PM2.5.

5. Results and Discussion

The summary statistics of the data used for the analysis are presented in Table 1.

Table 1: Summary Statistics

Variable	Category	Mean	Std. Dev.	Min	Max	Observations
NO2	overall	22.9303	11.8674	4	63	N = 168
	between		10.3843	7.2	51.0714	n = 24
	within		5.92924	-0.946	46.4928	T-bar = 7
PM10	overall	110.47	60.6866	28	294.67	N = 167
	between		55.8176	42.375	211.469	n = 24
	within		24.5022	21.6774	219.347	T-bar = 6.95833
PM25	overall	46.2378	27.8322	8	119	N = 89
	between		25.3427	19	98.6	n = 22
	within		10.6397	19.2378	81.2378	T = 4.04545
CNGONLY	overall	797.614	1785.02	1	11244	N = 114
	between		832.617	1	3518.63	n = 24
	within		1509.18	-2710	8522.99	T-bar = 4.75
DIESEL	overall	5191.51	3534.6	305	19720	N = 192
	between		3261.82	366.5	15768.3	n = 24
	within		1497.95	768.26	9143.26	T = 8
ELECTRIC BOV	overall	1339.97	2244.35	1	13858	N = 154
	between		1229.59	6.5	4401.13	n = 22
	within		1872.13	-2216.2	11739.1	T-bar = 7
PETROL	overall	36647.7	25920.5	200	149335	N = 192
	between		25187.5	1557	102059	n = 24
	within		7791.86	1215.92	83923.9	T = 8

DIESEL-HYBRID	overall	28.4615	67.1715	1	404	N = 117
	between		32.0005	1	108.667	n = 24
	within		58.1992	-77.205	333.462	T-bar = 4.875
PETROL-CNG	overall	687.899	1463.11	1	10904	N = 178
	between		1287.11	2.33333	5661	n = 24
	within		672.538	-1654.1	5930.9	T-bar = 7.41667
PETROL-HYBRID	overall	302.83	577.413	1	5141	N = 141
	between		362.704	15.4286	1533	n = 24
	within		440.159	-1228.2	3910.83	T = 5.875

Source: Authors' Computation

The descriptive statistics show that, NO_2 concentrations remain comparatively moderate, with a mean value of 22.93 µg/m³. Particulate pollutants display much higher averages, PM_{10} at 110.47 µg/m³ and $PM_{2.5}$ at 46.24 µg/m³, indicating that particulate matter is the most serious air-quality concern. Vehicle distributions are dominated by petrol and diesel fleets, which exhibit very high mean values (36,648 for petrol and 5,192 for diesel), where CNG-only, hybrid, and electric vehicle categories show lower means and wide variability. This pattern suggests that although alternative, cleaner fuel technologies exist, the overall mobility structure is largely shaped by conventional petrol and diesel fuel.

Table 2 shows the random effects panel regression results to understand how vehicle fuel types affect air quality in the cities under study.

Table 2: regression result

VARIABLES	NO2	PM25	PM10
CNGONLY	0.0002	0.0003	0.0040
	(0.0015)	(0.0026)	(0.0057)
DIESEL	0.0002	0.0042**	0.0040
	(0.0011)	(0.0015)	(0.0047)
ELECTRICBOV	-0.0016	-0.0006	-0.0064***
	(0.0012)	(0.0024)	(0.0024)
PETROL	0.0001	-0.0005	0.0005
	(0.0002)	(0.0003)	(0.0007)
DIESELHYBRID	0.0466***		0.1093
	(0.0144)		(0.0680)
PETROLHYBRID	0.0016	0.0058	-0.0173
	(0.0029)	(0.0090)	(0.0170)
PETROLCNG	0.0031*	-0.0061	0.0166***
	(0.0016)	(0.0040)	(0.0057)
Constant	16.5960***	52.5826***	70.4216***
	(2.6234)	(9.2059)	(9.8068)
Observations	40	54	40
R-squared		0.4282	
Number of cityno	15	18	15

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Source: Author's Calculation

The regression results indicate that diesel hybrid and petrol CNG vehicles have a statistically significant impact on NO2 concentrations in the air. Diesel hybrids have a highly statistically significant positive impact on NO2. In other words, one new diesel hybrid vehicle registration will increase the NO2 concentration in the air by 0.05µg/m^3. Petrol CNG vehicles have a statistically significant impact on NO2 at 10% significance level. The impact of hybrid fuel vehicles depends on the proportion of cleaner fuel used, and so the statistical significance is low. The constant term is positive and statistically significant at 1% level. This shows other factors contributing to baseline NO2 pollution, such as traffic, congestion, industrial activity, burning fossil fuels, etc.

Petrol-CNG vehicles are the single most important vehicle type influencing PM10 positively. Increase in the number of Petrol-CNG vehicles by one unit tends to increase PM10 concentration by around 0.016 $\mu g/m^3$. Electric BOV vehicles has statistically significant negative impact on PM10 at 1%. Vehicles of other fuel types do not impact PM10 in a statistically significant manner. The constant term is positively associated with the PM10 and highly significant. This result highlights non-vehicular sources such as road dust, construction activity, mining, industrial emission, other factors all are contributing significantly to PM10 concentration in the urban areas.

PM2.5 concentration in the urban air in the cities under study is mainly impacted by diesel vehicles. Vehicles of other fuel types do not tend to impact PM2.5 in a significant manner. Introduction of one diesel vehicle in a city will tend to increase the PM2.5 concentration in the city air by 0.0042 $\mu g/m^3$. We can see that though the relation is statistically significant the magnitude of the impact of petrol vehicles on PM2.5 is very small for the cities under study. The constant term is positive and statistically significant. This highlights the contribution of non-vehicular sources to the PM2.5 concentration in the urban area. Industry emissions, household fuel use, and meteorological conditions are some major sources of non-vehicular emissions.

5. Conclusion

In this research we investigate how the composition of vehicles of various fuel types in a city impacts the pollutant levels in the city air. We studied 24 cities in India for a period of 8 years from 2016 to 2023 for pollutant types, NO2, PM10 and PM2.5. The 24 cities have been chosen randomly from 6 states. We have taken two low-income states, two middle-income states and two high-income states for the study so that there is representation of cities from states at different levels of growth and development. Our study indicates that particulate matter pollution is critically high in the low-income states of Bihar and Uttar Pradesh. These states also experienced increased registration of petrol vehicles. Regression analysis confirms that diesel vehicle registration has a statistically significant positive impact on PM2.5 and petrol CNG on PM10, and electric BOV has negative impact has a statistically significant negative impact on PM10. The result shows that diesel hybrid vehicles have a statistically significant positive impact on NO2. The study indicates that even the vehicles using hybrid system, diesel combustion contributes to NO2 concentration. Petrol CNG also contributes moderately to NO2 emissions.

Overall, India is moving towards clean fuel type gradually, but still petrol vehicles dominate the road transport sector, mixed fuel type vehicles are on the increase. Infrastructure for mixed and clean fuel vehicles should be increased to increase the use of these types of vehicles.

6. Limitations and Further Study

The study is based on secondary data and so it is limited to the availability of city level data. The study could have been more granular if city level data on industrial index and economic growth could have been incorporated. However, field level longitudinal studies can be conducted to give a clearer picture of how weather conditions, population, economic growth, industrial and commercial activities along with vehicular traffic concentration impacts city air. Such studies, though comprehensive, require time and adequate human and financial resources. But such a study is highly imperative for a sustainable urban design that incorporates economic growth along socio-environmental wellbeing.

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7. Appendix

7.1 NO2 Model

7.1.1 Hausman test:

```
Test:  Ho:  difference in coefficients not systematic

              chi2(7) = (b-B)'[(V_b-V_B)^(-1)](b-B)
                      =        5.51
            Prob>chi2 =      0.5977
```

7.1.2 Multicollinearity Test:

Variable	VIF	1/VIF
PETROL	7.38	0.135459
DIESEL	7.28	0.137326
ELECTRICBOV	5.92	0.169025
PETROLHYBRID	5.58	0.179266
CNGONLY	4.6	0.217552
PETROLCNG	3.82	0.26182
DIESELHYBRID	2.52	0.396989
Mean VIF	5.3	

7.1.3 Breusch–Pagan LM Test for Random Effects

```
Breusch and Pagan Lagrangian multiplier test for random effects

        NO2[cityno,t] = Xb + u[cityno] + e[cityno,t]

        Estimated results:
                         |       Var     sd = sqrt(Var)
                ---------+-----------------------------
                     NO2 |   187.0302        13.6759
                       e |   31.19873       5.585582
                       u |   43.92389        6.62751

        Test:   Var(u) = 0
                             chibar2(01) =     2.72
                          Prob > chibar2 =   0.0496
```

7.1.4: Wooldridge Test

Wooldridge test for autocorrelation in panel data

H0: no first-order autocorrelation

F(1, 2) = 24.599

Prob > F = 0.0383

7.2 PM2.5 Model

7.2.1 Hausman test:

```
Test:  Ho:  difference in coefficients not systematic

            chi2(6) = (b-B)'[(V_b-V_B)^(-1)](b-B)
                    =       36.84
          Prob>chi2 =      0.0000
```

7.2.2 Multicollinearity Test

Variable	VIF	1/VIF
PETROLHYBRID	6.65	0.150488
PETROLCNG	6.25	0.160029
ELECTRICBOV	5.91	0.169179
CNGONLY	5.79	0.172717
PETROL	5.5	0.181727
DIESEL	4.44	0.225177
Mean VIF	5.76	

7.2.3 Modified Wald Test for Groupwise Heteroskedasticity

```
Modified Wald test for groupwise heteroskedasticity
in fixed effect regression model

H0: sigma(i)^2 = sigma^2 for all i

chi2 (18)  =        208.78
Prob > chi2 =         0.0000
```

7.2.4 Wooldridge Test:

Wooldridge test for autocorrelation in panel data

H0: no first-order autocorrelation

F(1, 9) = 0.157

Prob > F = 0.7008

7.3 PM10 Model

7.3.1 PM10 Hausman test

```
Test:  Ho:  difference in coefficients not systematic

             chi2(7) = (b-B)'[(V_b-V_B)^(-1)](b-B)
                     =        7.47
           Prob>chi2 =      0.3817
```

7.3.2 Multicollinearity Test:

Variable	VIF	1/VIF
PETROL	7.38	0.135459
DIESEL	7.28	0.137326
ELECTRICBOV	5.92	0.169025
PETROLHYBRID	5.58	0.179266
CNGONLY	4.6	0.217552
PETROLCNG	3.82	0.26182
DIESELHYBRID	2.52	0.396989
Mean VIF	5.3	

7.3.3 Breusch–Pagan LM Test for Random Effects:

```
Breusch and Pagan Lagrangian multiplier test for random effects

        PM10[cityno,t] = Xb + u[cityno] + e[cityno,t]

        Estimated results:
                         |       Var     sd = sqrt(Var)
                ---------+-----------------------------
                    PM10 |   4096.245       64.00192
                       e |   440.2056       20.98108
                       u |    299.816        17.3152

        Test:   Var(u) = 0
                             chibar2(01) =     0.07
                          Prob > chibar2 =   0.3925
```

7.3.4 Wooldridge Test

Wooldridge test for autocorrelation in panel data

H0: no first-order autocorrelation

F(1, 2) = 0.630

Prob > F = 0.5106