Developing Speed-Based Emission Models for Passenger Cars in India Using a Portable Emission Measurement System

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Abstract

Passenger cars are the major contributor to urban air pollution in India. Generally, emission factors are developed in a laboratory setting using a standard driving cycle. However, laboratory-based emission tests do not represent real-world emissions. This research quantified the CO, HC, CO_2, and NO_x emissions for a diesel passenger car using the portable emission measurement system (PEMS) in Sangareddy town, India. The simple linear regression (SLR) technique was employed in this study to develop the speed-based emission models. The developed SLR models had higher accuracy, as evidenced by the coefficient of determination (R^2), root-mean-square error ($RMSE$), and mean absolute percentage error ($MAPE$) values. In this investigation, emissions rates (CO, HC, CO_2, NO_x in g/s) increased as speed increased, and the emission rates were particularly high at high speeds (90-100 kmph). The result revealed that emission rates were found to be minimal at an acceleration rate that tends to be 0 m/s^2 under a speed range of 30–60 kmph. The observed emission factors (CO, HC, CO_2, NO_x in g/km) in this study exceeded the Bharat Stage (BS)-IV emissions limits. The detailed analysis of the impact of speed and acceleration on tailpipe emissions will aid policymakers in comprehending the emissions patterns in heterogeneous traffic and frame policies in accordance.

Keywords: Tailpipe emissions; Passenger cars; Heterogeneous traffic, Speed; Acceleration.

1. Introduction

Passenger cars have become more prevalent in emerging nations like China and India in recent years. Passenger cars and two-wheelers constitute around 87% of the total vehicle population in India (MoRTH, 2016). Consequently, the emissions from passenger cars are a significant source of greenhouse gases and urban air pollution in India (Mahesh et al., 2018). Passenger cars and two-wheelers constitute around 87% of the total vehicle population in India (MoRTH, 2019). Furthermore, diesel is cheaper than gasoline (petrol), resulting in a rise in diesel-powered vehicles. Diesel vehicles are reported to emit more emissions of particulates, and black carbon than petrol vehicles (Mahesh et al., 2018). In 2019, nearly 17.8% of the total deaths in India were caused by air pollution (Nair et al., 2021). Several studies have measured the emissions of passenger cars (Pathak et al., 2016; Adak et al., 2016; Peng et al., 2015; Seers et al., 2015). However, the aforementioned studies were conducted in laboratory settings that utilized standard driving cycles for emission measures, that do not replicate real-world driving conditions. Previous literature reported that emissions were influenced by vehicle type, fuel, engine, and vehicle dynamic characteristics (braking, idling, speed, acceleration/deceleration, etc.) (Chandrashekar et al., 2022; Mahesh et al., 2018). Moreover, traffic on Indian roads is highly mixed in nature, with different vehicle types (three-wheelers, trucks, buses, etc.) occupying the same space on the roads, with a predominantly higher proportion of cars and two-wheeler. This poses challenging driving conditions on roads with regular lane changes, stop-and-go situations, and repeated acceleration/deceleration events (Asaithambi and Shravani, 2017; Kanagraj et al., 2015).

The above-mentioned factors are complex to capture in laboratory settings using a standard driving cycle. Quantifying the actual emission under actual driving conditions are essential to understand the gap between laboratory and real-world driving test (RDE). The disparity between laboratory tests and on-road real-world emissions poses a significant challenge in controlling harmful emissions from diesel passenger cars (Shahariar et al., 2022). Therefore, the primary goal of the study is to measure the emissions from diesel passenger cars in India using a portable emission measurement system (PEMS). In this study, speed-based emission models were developed employing a simple linear regression technique. The effects of acceleration and speed on various emission rates were examined. The observed emission factors from this investigation were also contrasted with the Bharat Stage (BS)-IV emission norms proposed by the Automotive Research Association of India (ARAI) and other studies.

2. Literature review

This review of the literature primarily focuses on the studies that assessed emissions from passenger cars in laboratory settings using conventional driving cycles, as well as the emissions measured under real-world driving situations utilizing PEMS, and is detailed below.

Traditionally, vehicle emissions were quantified in laboratory settings using a standard driving cycle that simulates driving conditions on the road. However, standard/conventional driving cycles fail to reflect actual driving circumstances (Joumard et al., 2000). Furthermore, many research assessed emissions using emission models like MOBILE6.2, Computer Programme to Calculate Emissions from Road Transport (COPERT), International Vehicle Emission (IVE) model, Computer Programme to Calculate Emissions from Road Transport (CMEM), and Motor Operating Vehicle Emission Simulator (MOVES) (Perugu et al., 2019; Pathak et al., 2016). However, these emission models consider the standard driving cycle for the estimation of emission. Since emission rates rely on an average speed during predetermined driving cycles, the possibility of considering alternative driving patterns is limited (Joumard et al., 2000). Although various driving cycles can result in the same average speeds, emissions are heavily dependent on particular deceleration and acceleration patterns. Therefore, actual emissions may be understated as a result of acceleration, deceleration, and aggressive driving behaviors (rapid acceleration/deceleration) not being sufficiently represented in the standard driving cycle (Joumard et al., 2000).

An efficient technique for regulating emissions in the transportation sector is the measurement of on-road vehicle emissions (Dallmann, 2018). PEMS is regarded as one of the most efficient methods for determining emissions while driving in actual traffic situations (Chandrashekar et al., 2022; Yang et al., 2020; Mahesh et al., 2018). This technique entails mounting equipment on an individual vehicle and driving it across the road whilst the sampling probe is connected to the tailpipe. Tsokolis et al., 2016 quantified CO_2 emissions from 8 diesel and 12 gasoline passenger cars using the Worldwide harmonized Light Duty Procedure (WLTP) and New European Driving Cycle (NEDC). The results showed that CO_2 emission measurements from WLTP were found to be 16% higher than NEDC. Mahesh et al., 2018 used PEMS to measure tailpipe emissions from diesel passenger cars in Chennai, India. The researchers concluded that the emission rates were affected by speed, acceleration/deceleration, and road type. Luján et al., 2018 measured the emissions from EURO 6 light-duty diesel vehicles in real-world driving circumstances using PEMS in Valencia, Spain. The findings revealed that repeated acceleration/deceleration at low speeds results in higher NO_x emissions. NO_x emissions were found to be higher in the urban section of the test route. Dimaratos et al., 2020 quantified emissions of bi-fuel cars (petrol/compressed natural gas) and diesel cars in Thessaloniki, Greece. The results showed that diesel cars emit more NO_x emissions. Cold start and high speed/load operations were the major contributor to CO emissions of the bi-fuel car in gasoline mode. Motorway driving was identified as a major contributor to total emissions. Bellin et al., 2022 measured emissions from gasoline and liquefied petroleum gas (LPG) passenger cars through laboratory and on-road tests in Italy. The results showed that shifting from gasoline to LPG reduced CO_2 emissions in both the laboratory and the on-road test.

Furthermore, Table 1 provides an overview of the literature assessment on measuring emissions from light-duty vehicles. The research includes both laboratory and field testing of petrol and diesel vehicles. The majority of the research listed in Table 1 was conducted in homogeneous traffic environments, which contain more than 90% of cars in the traffic stream. Choudhary and Gokhale, 2016 reported that emissions were found to be delicate to the incidence and force of the acceleration/deceleration resulting from various traffic circumstances. Furthermore, several countries (such as China, Japan, South Korea, and Europe) adopted real driving emissions (RDE) testing protocols using PEMS to minimize the discrepancy between laboratory and on-road tests (Shahariar et al., 2022). Therefore, it is crucial to comprehend the variation in emission trends of various driving patterns in heterogeneous traffic. This helps to improve emission standards and measurement procedures for vehicle emission testing to keep them low-emitting on roads.

Table 1. Summary of the literature study on the measurement of emissions for passenger cars

Region/Country	Fuel type	Test type	Traffic conditions	Findings	References
Leeds, UK	Diesel/ Petrol	On-road	Homogeneous	Estimated CO_2 emission levels using LiDAR-GIS road grade-based method	Wyatt et al., 2014
Guwahati, India	Diesel/ Petrol	On-road	Heterogeneous	Emissions were delicate to the incidence and force of acceleration/deceleration resulting from various traffic situations	Choudhary and Gokhale, 2016
Tier-II, India city	Petrol	Laboratory	-	Emissions were found 50-160% higher in real-world driving conditions compared to WLTP	Pathak et al., 2016
Seoul, Korea	Petrol	On-road	Homogeneous	NO_x emissions were highly affected by driving routes and air conditioner	Kwon et al., (2017)
Wilmington, MA, USA	Petrol	On-road	Homogeneous	NH_3 emissions were high during the cold start of the vehicle	Saurez-Bertoa et al., 2017
St. Petersburg, Russia	Diesel/ Petrol	On-road	Homogeneous	NO_x emissions of Euro 3 diesel vehicles were 28.9 times greater than those of Euro 3 petrol vehicles, and Euro 4 diesel vehicles were 17.6 times higher than those of Euro 4 petrol vehicles	Lozhkina and Lozhkin, 2017
Chennai, India	Diesel	On-road	Heterogeneous	Emission factors were affected by road type, speed, and acceleration/deceleration	Mahesh et al., 2018
Thessaloniki, Greece	Petrol	On-road	Homogeneous	Emissions were high during the motorway driving route	Dimaratos et al., 2020

Tianjin, China	Petrol	On-road	Homogeneous	Fuel consumption rate was influenced by vehicle-specific power. Further exhaust gas recirculation could improve fuel combustion efficiency and reduce emissions	Qu et al., 2020
Delhi, India	Diesel	On-road	Heterogeneous	Emissions were found low during the speed between 40-60 kmph and at an acceleration range of 0.5 to 0.5 m/s^2	Kuppili et al., 2021
Fuzhou, China	Diesel/ Petrol	On-road	Homogeneous	Emission factors were affected by a moderate upgrade, acceleration, and moderately high speeds	Zhang et al., 2021

3. Methodology

(1) *selection of test vehicle*: A diesel Swift Dzire (sedan) was chosen as the test vehicle for data collection, and the detailed specification of the test vehicle is shown in Table 2. The vehicle was frequently serviced every 10,000 km and timely maintained, as reported by the owner. The majority of passenger cars operating in Indian cities comply with BS-IV emission standards; hence the test vehicle of BS-IV norms was chosen for data collection.

(2) *selection of test route*: The study stretch, which spans a total of 14 km length from IIT Hyderabad to the Sangareddy bus stop, was chosen for the data collection. The test route consists of 2 signalized intersections, 3 uncontrolled intersections, and 10 mid-block openings. The detailed test route description is shown in step 2 from Fig. 1. The data collection was performed at a peak time between 10 am to 12 pm and from 4 pm to 6 pm. It was observed that passenger cars and 2-wheelers composed 72.8% of the total traffic, followed by heavy vehicles (20.7%) and 3-wheelers (6.43%) in the study stretch.

(3) *data collection*: The test vehicle was equipped with a high-frequency GPS system that records positional coordinates, longitudinal/lateral acceleration, and speed at a frequency of 10 Hz. With a frequency of 1Hz, the PEA-205 gas analyzer records the emission of CO and CO_2 in volume % as well as HC and NO_x in parts per million (ppm). PEA-205 gas analyzer function with a precision of CO ± 0.06%, CO_2 ± 0.5%, and HC and NO_x ± 12 ppm. A total of 30 PEMS test samples were collected using five various drivers. The time stamps of GPS data and emission data were synced and further validated by verifying the video using position coordinates.

(4) *data processing*: Extreme outliers from the data sets were found and removed using the interquartile range method (three times of (75th percentile (Q3) - 25th percentile (Q1)) (Dhahir and Hasan, 2016).

(5) *model development*: Developing speed-based emission models using simple linear regression techniques.

(6) *comparison of emission factors*: Comparing the observed emission factors from the current investigation with prior studies and BS-IV emission limits.

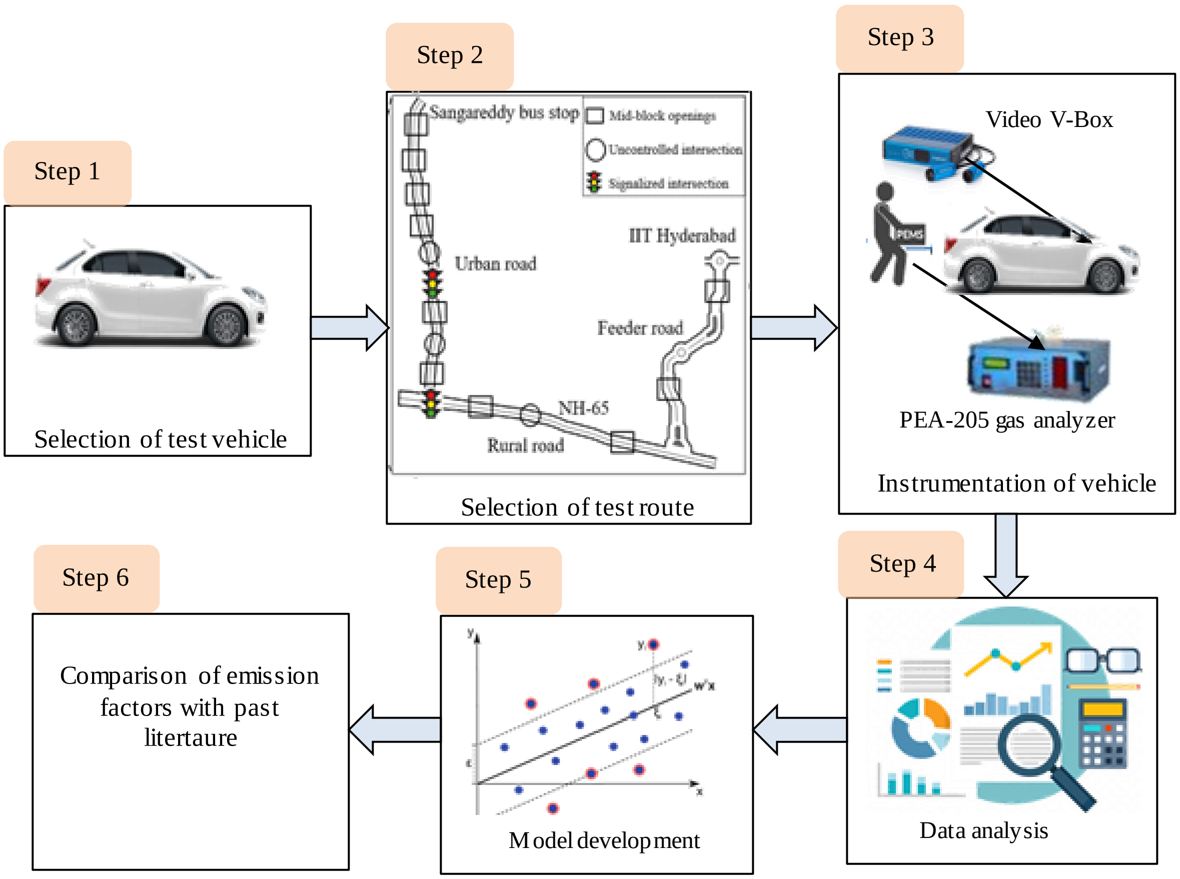


Fig. 1. Detailed experimental methodology

Table 2. Specification of the test vehicle

Vehicle Type	Swift Dzire
Odometer reading	30,500 km
Model	Maruti Suzuki
Fuel	Diesel
Model year	2018
Transmission	Manual
Maximum power (bhp)	74.02 @ 400 rpm
Curb weight (kg)	990

3. Calculation of emission rates and emission factors

The PEA-205 gas analyzer measures HC, NO_x, and CO in ppm as well as CO and CO_2 in % volume. Using Eq. (1-5) these observed emissions were translated to emission rates in g/s (European Commission, 2016).

$$EF_{[CO_2]} = (0.001518 \times m_{exhaust} \times \mathrm{E}_{[CO_2]})/3600 \quad (1)$$

$$EF_{[CO]} = (0.000966 \times m_{exhaust} \times E_{[CO]})/3600 \quad (2)$$

$$EF_{[HC]} = (0.000479 \times m_{exhaust} \times E_{[HC]})/3600 \quad (3)$$

$$EF_{[NO_x]} = (0.00158 \times m_{exhaust} \times E_{[NO_x]})/3600 \quad (4)$$

$$m_{exhaust} = \text{Volume flow rate} \times \text{density} \quad (5)$$

Where,

$EF_{[CO_2]}$ = CO_2 emission rate in g/s;

$EF_{[CO]}$ = CO emission rate (g/s);

$EF_{[HC]}$ = HC emission rate (g/s);

$EF_{[NO_x]}$ = NO_x emission rate (g/s);

$m_{exhaust}$ = Exhaust flow rate (kg/hr);

The emission factors are computed using Eq. 6 (Tong et al. 2000)

$$E_F = E_r \times \frac{3600}{v} \quad (6)$$

Where,

E_F = Average emission factor (g/km);

E_r = Instantaneous emission rates (g/s);

v = Instantaneous vehicle speed (kmph);

3. Results and discussion

3.1 Correlation analysis

To evaluate the association between the speed and the emissions rates, a correlation analysis was performed. Krehbiel (2004) provided a general rule of thumb to determine the significance of the observed value of the correlation coefficient.

Rule of Thumb: In general, a linear relationship exists if $|r_{xy}| \geq \frac{2}{\sqrt{n}}$.

Where n is the number of observations r_{xy} is the correlation coefficient value between two variables x and y, the threshold value ($2/\sqrt{n}$) was adopted to check the correlation between different emission rates (CO, HC, NO_X, and CO_2) and speed. It was found that the correlation coefficient value between emission rates and speed was higher than threshold values at a 95% confidence level (refer to Table 3). The association between the variables was investigated using a bivariate (Pearson) correlation matrix, and the results are displayed in Table 4.

Table 3. The thresholds for the significance of the correlation between two variables

Variables	n	$^{2}/_{\sqrt{n}}$
Speed-CO	20	0.44
Speed-HC	20	0.44
Speed-CO_2	20	0.44
Speed-NO_X	20	0.44

Table 4. Bivariate (Pearson) correlation matrix

Emission rates (g/s)	Speed (kmph)
CO	0.836* (r) 0.00
HC	0.867* (r) 0.00
CO_2	0.852* (r) 0.00
NO_x	0.824* (r) 0.00

** Correlation is significant at 0.005 level (2-tailed), r- correlation coefficient value.*

3.2 Effect of speed on emission rates

The collected data were classified into speed intervals of 5 kmph, and each speed interval consists of the entire speed data of 30 trips. The average emission rates were calculated for each speed interval. Further, the data were fitted using the linear regression model with emission rates as response variables and speed as the predictor variables. Eq. (7) depicts the form of the linear regression model.

$$y = a \times x + b \qquad (7)$$

Where y = Emission rates (g/s), x = Speed in kmph, $a =$ Coefficient of speed, and b is the Constant. The following conditions were also examined while developing the regression models:

a. The coefficient of determination R^2 must be significant at the 95% confidence interval.
b. The coefficient of the independent variables utilized in the formulation of the model should be significantly different from zero at the 95% confidence interval.
c. The error term needs to follow a normal distribution.

Table 5 provides a statistical summary of the developed model. The R^2 of the derived model ranges from 0.67 to 0.74, indicating that the model explains approximately 70% of the variability of the dependent variable (emission rates). All the speed variable and their coefficients were found statistically significant at a 5% level of significance. The error terms of all the emission rates were normally distributed (refer to Fig. 2(a-d)). The models presented in Table 5 comply with the assumption that follows the linear regression model. To examine the relationship between speed and emission rates, the speed ranges were classified into low (10, 20 kmph], medium (30, 50 kmph], and high (60, 100 kmph] speeds (Xue et al. 2013). Fig. 3(a) demonstrates that the CO emission rates observed at medium speeds were found to be 6.6% greater than those observed at low speeds, and the CO emission rates observed at high speeds were 28.5% higher than those observed at medium speeds. HC emission rates identified at medium speeds were 9.52% higher than at low speeds and the emission rates of HC observed at high speeds were 25% higher than at medium speeds (refer to Fig. 3(b)). At medium speeds, the CO_2 emission rates were found to be 13.8% higher than at low speeds, and at high speeds, the CO_2 emission rates were found to be 16% higher than at medium speeds (see Fig. 3(c)). In a similar pattern, NO_X emission rates were found to be 18% higher at high speeds than at medium speeds and 22%

higher at medium speeds than at low speeds (see Fig. 3(d)). In all the cases, emission rates were found to be increased with the increase in speeds. The results are consistent with a study by Huang et al. (2016), where the authors found that more emission rates were released at high speeds. As a result of intensified combustion, greater engine speeds were also found to produce more noticeable emission rates, which were also found to be enhanced by an increase in engine load (Mohamad and How, 2014).

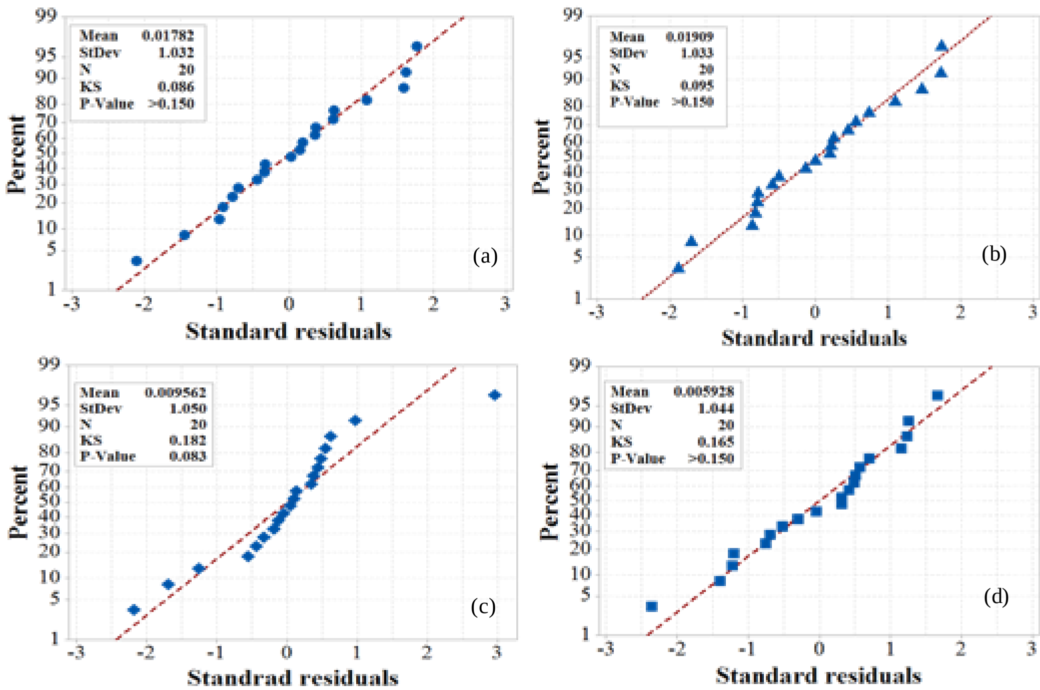
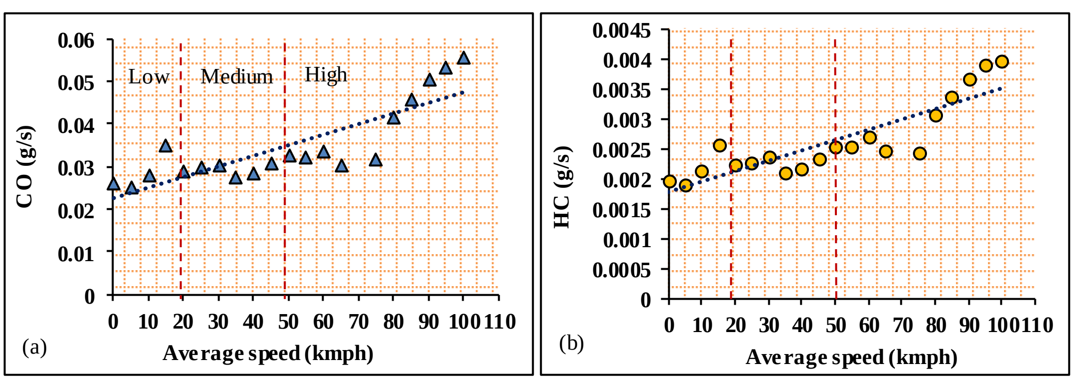


Fig.2. Normal probability plot for (a) CO, (b) HC, (c) CO_2 and (d) NO_x



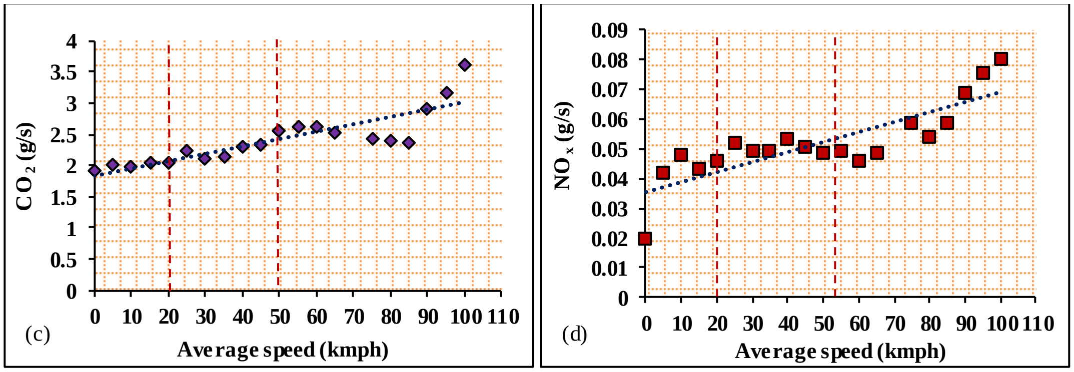


Fig 3. Average emission rates of (a) CO (g/s), (b) HC (g/s), (c) CO_2 g/s, and (d) NO_x (g/s) for different speed intervals

Table 5. Statistical summary of the developed models

Emissions (g/s)	Variables	Co-efficient	SE	t-value	p-value	$RMSE$	$MAPE$ (%)	R^2
CO	Constant	0.023	2.0e-3	10.44	0.00	0.0149	30.00	0.70
	Speed	2.45e-4	3.8e-5	6.48	0.00			
HC	Constant	0.001	1.3e-4	13.14	0.00	3.0e-4	0.965	0.74
	Speed	1.7e-5	2.0e-6	7.28	0.00			
CO_2	Constant	1.840	0.090	19.00	0.00	0.638	18.49	0.72
	Speed	0.011	1.6e-3	6.90	0.00			
NO_x	Constant	0.035	3.0e-3	11.37	0.00	7.0e-03	2.961	0.67
	Speed	3.3e-4	5.4e-5	6.16	0.00			

SE- Standard error, tested at a 5% level of significance.

3.3 Impact of speed and acceleration on emission rates.

The relationship between speed (kmph), acceleration (m/s^2), and emission rates (g/s) are shown in this section using a contour surface plot. The speed and acceleration are shown along the X and Y axes, respectively, and the associated emission rates are represented by contour bands (refer to Fig. 4(a-d)). The CO emission rates were found to be high (0.018-0.038 g/s) at rapid deceleration (a < 1.5 m/s^2) and rapid acceleration (a >1 m/s^2), as shown in Fig 4(a). CO emission rates were high at high speeds (70-80) kmph even at low acceleration rates (refer to Fig. 4(a)). Moreover, the CO and HC emission rates almost exhibit the same trend (refer to Fig 4(a) and (b)). CO_2 emission rates were low (0.14 g/s), with acceleration ranging between -0.3 and 0.3 m/s^2 at speeds between 20 and 60 kmph, as shown in Fig. 3(d). Rapid acceleration and rapid deceleration at speed between 40–60 kmph were found to result in high CO_2 emission rates (2.2–3.3 g/s) (Fig. 4(c)). The CO_2 emission rates were high (3.5-5.6 g/s) even at lower acceleration rates at high speeds between 80 and 95 kmph (refer to Fig. 4(c)).

Fig. 4(d) shows that the test vehicle exhibits the smallest NO_x emission rates (0.004 g/s) during near-constant driving (acceleration tended to 0 m/s^2 at speed between 20-60 kmph). NO_x emission rates increased at rapid acceleration and rapid deceleration at a speed region of 40-60 kmph (Fig 4(d)). However, NO_x emission rates were high (0.06-0.09 g/s) even at low acceleration rates at high speeds (80–95 kmph), as shown in Fig 4(d). Overall analysis revealed that high CO, HC, NO_x, and CO_2 emission rates were observed at high speeds (80-95) kmph even at low acceleration levels and under rapid acceleration and deceleration (Fig 4(a-d)). When operating at high speeds the engine speed and power increased and the volume of fuel pumped into the cylinder per unit of time increased, which led to higher emission rates. On the other hand, more fuel would be injected into the cylinder to generate more power at the rapid acceleration (a > $1 m/s^2$) and rapid deceleration (a < 1.5 m/s^2), which leads to high emission rates. All the emission rates were found to be low at an acceleration rate that tends to be 0 m/s^2 under a speed region of 30-60 kmph (refer to Fig. 4(a-d)).

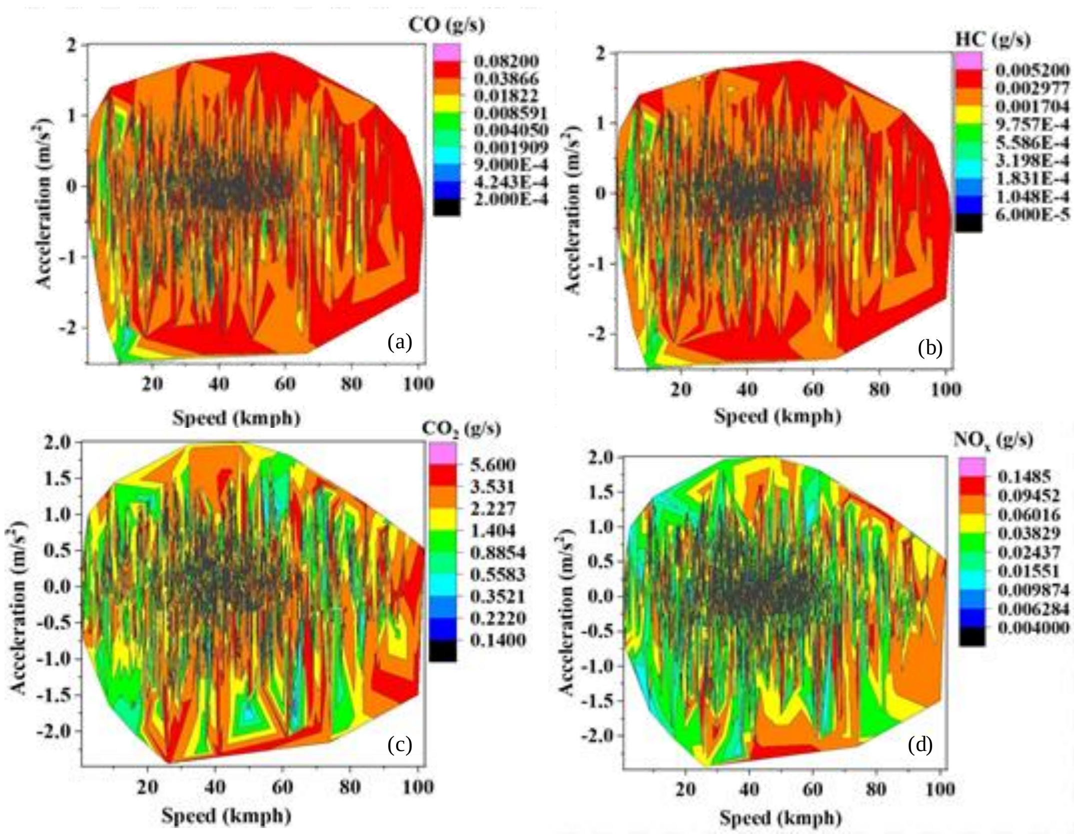


Fig 4. Contour plot of Instantaneous emission rates (g/s) of (a) CO, (b) HC, (c) CO_2, and (d) NO_x at different speeds and acceleration for the passenger cars

3.5 Emission factor dependence on vehicle speed

Fig. 5(a-d) shows the average emission factors for various speed ranges. A third-order polynomial function was fitted to the data, with speed acting as the predictor variable and emission factors as the response variable. The third-order polynomial is of the form shown in Eq. 8 and it was selected based on the lowest $RMSE$ and MSE values (refer to Fig.6(a-d)).

$$y = \beta_0 + \beta_1 \times x + \beta_2 \times x^2 + \beta_3 \times x^3 \quad (8)$$

Where y is the emission factor of CO, HC, CO_2, and NO_x in g/km, β_0 is the constant, $\beta_1, \beta_2, \beta_3$ are the regression coefficients, and x is the average speed intervals in kmph. The coefficients for each fitted curve are depicted in Fig. 5(a-d). The CO, HC, NO_x, and CO_2 emission factors obtained at low speeds were approximately 70% higher than at emission factors observed at medium speeds. The emission factors recorded at medium speeds were approximately 40% higher than at emission factors recorded at high speeds. The majority of the overall emission factors for a trip were emitted at the lowest driving speeds (0-20 kmph) (refer to Fig. 5(a-d)). The test vehicle experiences repeated acceleration and deceleration events and do not travel very far at relatively low average speeds (0–20 kmph). As a result, at extremely low speeds, the emission factors were quite significant, which typically occur in congested and interrupted traffic conditions, particularly during urban driving. Even speeds over 80 kmph can have a small negative impact on emission factors (refer to Fig.5 (a-d)). At high speeds, the test vehicle requires a greater amount of engine power, resulting in increased emission factors. The test vehicle traveling at a speed range of 60-80 kmph showed the minimum emission factors (refer to Fig 5(a-d)).

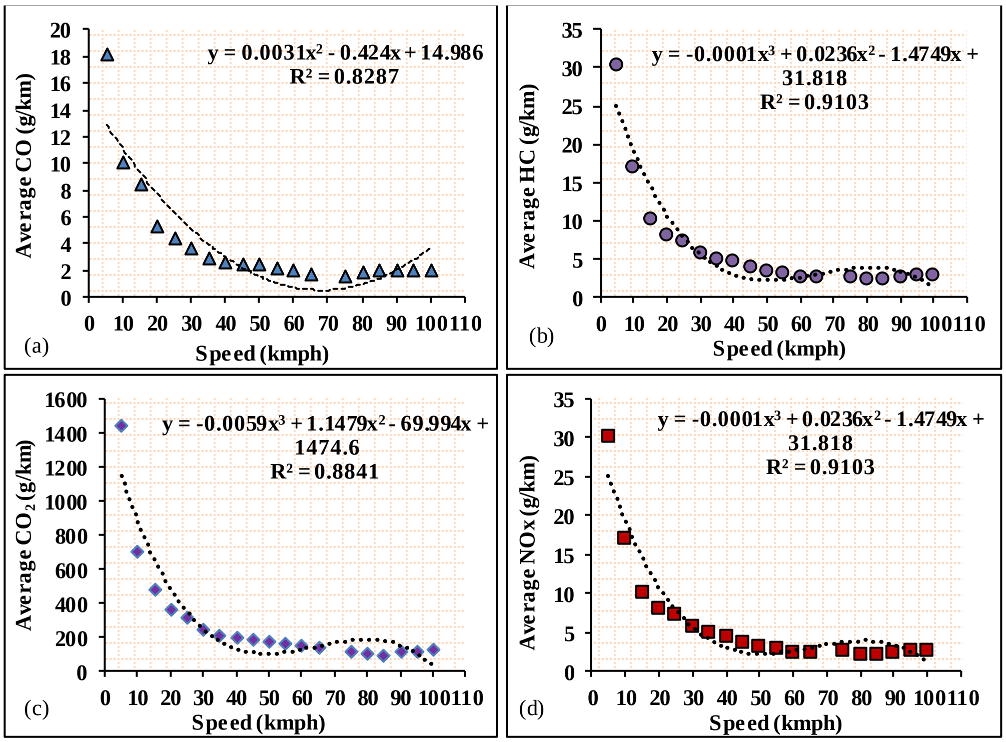
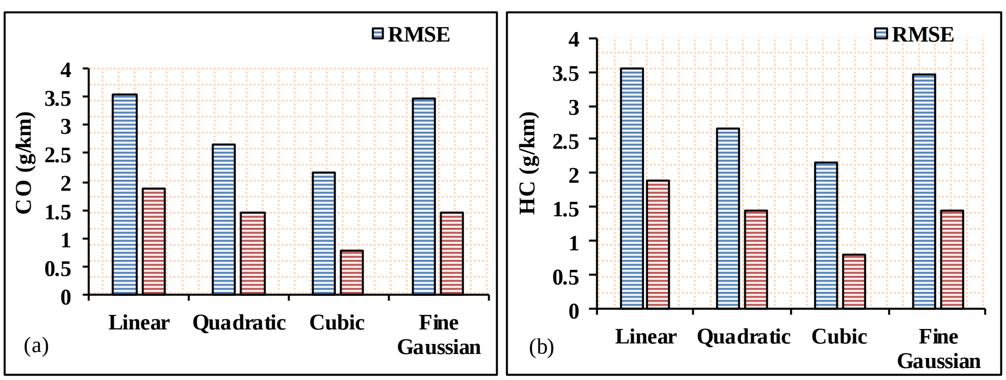


Fig 5. Emission factors of (a) CO (g/km), (b) HC (g/km), (c) CO_2 (g/km), and (d) NO_x (g/km) for different speed intervals



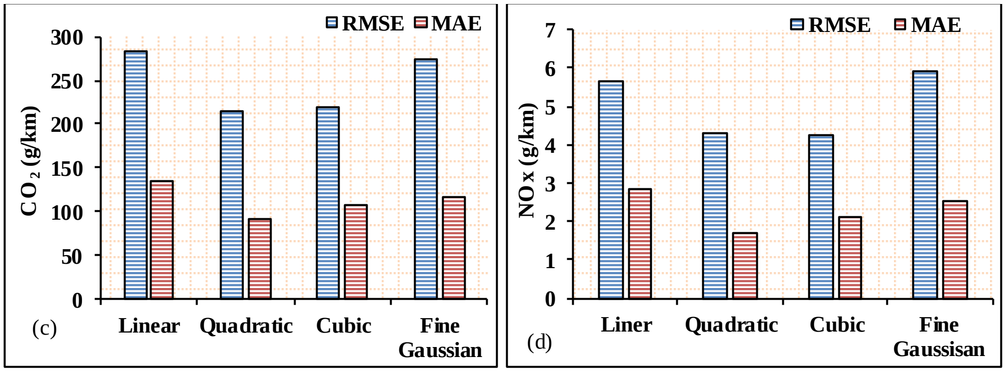


Fig 6. RMSE and MSE value for emission factors (a) CO (g/km), (b) HC (g/km), (c) CO_2 (g/km), and (d) NO_x (g/km)

4. Comparison with past research

It is essential to compare the findings from the current work with those from other research in order to comprehend the variation in emissions induced by various testing techniques, particularly for Indian vehicles. Fig 7 shows the emission factors of diesel swift dzire car in comparison with BS-IV emission standards recommended by ARAI and other studies. The average CO, HC, and NO_x emission factors for diesel vehicles were found to be 3.19, 0.22, and 4.96 g/km, respectively. The emission factors of CO from this study were found to be 6.3 times higher than the BS-IV limit (0.5 g/km). The CO emission factors were found to be almost 4 times higher than the CO emission factors reported by Mahesh et al., 2018; Jaiprakash and Habib, 2018; Jaiprakash et al., 2018; May et al., 2014; and Chiki t al., 2014 and approximately 2 times lower than CO emission factors reported by Qu et al., 2015 and Kuppili et al., 2021.

HC+NO_x emission factors were 14 times greater than the BS-IV standard (0.35 g/km). It was observed that the HC+NO_x emission factors were 7 times greater than those reported by May et al., 2014; Chiki et al., 2014; Qu et al., 2015; and Kuppili et al., 2021. NO_x emission factors were found to be 16.5 times higher than the BS-IV limit (0.30 g/km). Also, NO_x emission factors were approximately 5 times higher than the values stated by Mahesh et al., 2018; Jaiprakash and Habib, 2018; Jaiprakash et al., 2018; May et al., 2014; Chiki t al., 2014; Qu et al., 2015 and Kuppili et al., 2021.

Since CO_2 is a significant pollutant that is used to estimate the potential for global warming, it is crucial to assess CO_2 emission levels in various sectors. In India, policymakers do not consider CO_2 to be regulated pollution, while the European Commission (EC) considers the CO_2 emission levels in order to reduce the emission of greenhouse gases from various sectors. For new passenger cars, a regulatory standard of 130 g/km of CO_2 was set by EC. This standard is employed for comparison and to comprehend the impact of technologies on CO_2 emissions. The CO_2 emission factors obtained in this study were found to be 3.3 times higher than European norms (130 g/km) for passenger cars. The emission factor values provided in the earlier research considerably differed from our investigation, as shown in Fig. 7. The emission factors observed from the laboratory test were considerably lower than the real-world emission factors found in this study. The fluctuation in emissions may also be influenced by factors like fuel type, mileage, maintenance history, and vehicle age. As a result, using emission factors found by laboratory testing and Indian driving cycle-based emission models may result in an underestimation of actual emission factors. The majority of passenger cars on Indian roads efficiently met the present emission standards when tested in a lab environment. However, they fail to meet the emission regulation in on-road, real-world tests. This encourages the automobile sector to create cutting-edge technology that satisfies emission regulations in practical applications.

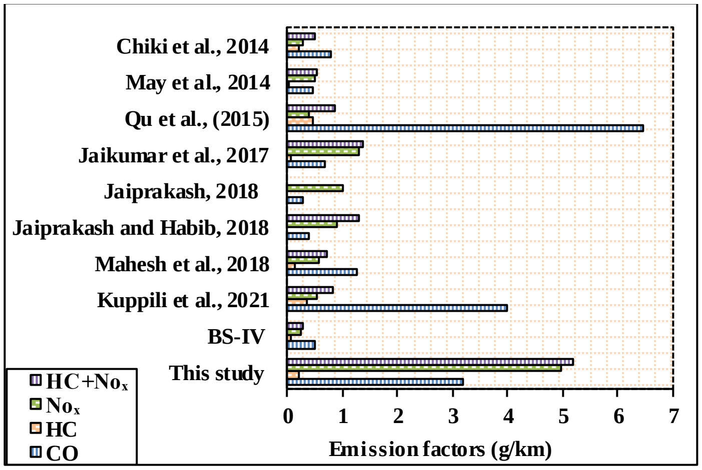


Fig.7 Comparison of emission factors

5. Real-world driving emissions and policy implication

Despite a significant increase in the number of vehicles in India, Indian emissions control standards fall well short of global standards (Mahesh et al., 2018). Emission regulations set by the ARAI were based on laboratory testing rather than paying much attention to monitoring emissions in the real world. India needs to implement real-world driving emission test methods in order to comprehend emissions under actual driving circumstances and to set effective emission reduction measures. Along with this, some traffic management systems are required to reduce emissions.

The following are a few strategies proposed that could be used to reduce emissions: (a) Congestion mitigation strategies: These strategies may help to increase the average traffic speeds from slower traffic speeds (For example , incident management, ramp metering, traffic management, travel option, etc.), (b) Speed management techniques: These techniques aim at reducing very high speeds to moderate speeds. For instance, the emission factors in this study were found to be high at speeds between 90 and 100 kmph, especially when driving on rural roadways. Intelligent speed adaptation (ISA) and active accelerator may assist the drivers with feedback via a visual or audible signal and can alert them to current speed restrictions and speeding. Drivers can limit their speed to a moderate speed level as a result, reducing emissions.

(c) Traffic flow smoothing techniques: These techniques aim to lessen the amount and intensity of individual accelerations and decelerations while also attempting to eradicate the stop-and-go impact. Traffic congestion may result in queues of the vehicle, which increases the intensity and density of the traffic flow, resulting in increased waiting time in the queue of vehicles. In this study, the emission factors were found to be very high at low speeds (10-20 kmph), occurred particularly in urban traffic. Implementing variable speed limits could warn drivers of impending congestion and uniformly slow down traffic to avoid stop-and-go conditions, which may result in a reduction in emission rates. Barth et al., 2008 stated that implementing the above-mentioned strategies could result in a 12% of CO_2 reduction. Furthermore, congestion pricing, carpooling, the proper infrastructure, and the introduction of electric rickshaws into city traffic should all be taken into account. The aforementioned regulations could be implemented to reduce reliance on fossil fuels and enhance air quality, depending on the local traffic situation.

6. Conclusions

The present study investigated the impact of speed on tailpipe emissions for a passenger car in real-world driving circumstances. The findings of this study are as follows:

- The simple linear regression model was employed in this study for the development of a speed-based emission model for passenger cars in the context of local traffic conditions in India.

- The result demonstrated that emission rates (CO, HC, CO_2, NO_x in g/s) increased as speed increased and reached even higher levels at high speeds (90-kmph).
- The impact of speed and acceleration on tailpipe emissions was investigated using a contour plot. The result revealed that all of the emission rates were low at an acceleration rate that tends to 0 m/s^2 under a speed range of 30–60 kmph. Meanwhile, emission rates were high at rapid acceleration ($a > 1$ m/s^2) and rapid deceleration ($a < 1.5$ m/s^2).
- The emission factors (CO, HC, CO_2, NO_x in g/km) were found to be significant at low driving speeds (10-20 kmph).
- The emission rates and emission factors were found to be low at speeds between 60-80 kmph.
- The analysis indicated that the CO emission factors were 6.3 times greater than the BS-IV standard (0.5 g/km), and NO_x emission factors were 16.5 times higher than the BS-IV standard (0.30 g/km). HC+NO_x emission factors were 14 times higher than the BS-IV limit (0.35 g/km).
  The emission rates found in the study for a specific city or region may help decision-makers implement traffic control measures and urban policy interventions to reduce pollution and improve air quality

7. Limitations and future scope for other studies

The present study has the following limitations (a) This study illustrates the emission patterns in the context of local traffic circumstances in India. However, only a limited number of test vehicles were considered and future research could incorporate heterogeneity in the vehicle types (engine size, fuel type, etc.) to conclude more definitive results, (b) Future studies may expand their scope by comparing the SLR with other machine-learning approaches (decision trees, artificial neural network, and support vector regression, etc.) by incorporating more input features to assess the accuracy of emission rate predictions, (c) Furthermore, the future research may also monitor the particulate matter emitted by vehicles which are also a significant contributor to urban air pollution.

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