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Impact of Urban Traffic Congestion on Emissions along a Section of James Gichuru Road in Nairobi County, Kenya

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Abstract

This study examined the impact of urban traffic congestion on air quality focusing on traffic volume and its emissions of carbon monoxide (CO), carbon dioxide (CO2), and particulate matter (PM2.5). Data collected revealed a strong correlation (r = 0.83) between traffic volume and emissions. The regression analysis indicated that each additional vehicle per hour resulted in a 0.07 unit increase in emissions, a statistically significant finding with a p-value of less than .001. During peak hours, traffic reached as high as 2000 vehicles per hour, contributing to alarming CO levels of 10 ppm and PM2.5 concentrations of 90 µg/m³. In contrast, off-peak hours averaged around 750 vehicles per hour, leading to significantly lower emissions. These findings underscored the considerable influence of traffic volume on air pollution, highlighting the urgent need for effective urban planning and traffic management to enhance air quality and public health in rapidly urbanizing areas. The study therefore recommended that traffic volumes, which rise during school hours, highlight the necessity for safe walking and biking paths to promote non-motorized transportation. It also suggested encouraging flexible work hours to reduce travel demands and enhancing community awareness as additional traffic calming measures. Furthermore, advocating for remote learning for students and educators could significantly decrease daily commutes to schools and the associated emissions. Collectively, these insights offer practical recommendations for addressing traffic congestion and improving air quality in urban areas.

Keywords: Emissions, queue length, traffic volume, travel time, urban traffic congestion

INTRODUCTION

Urban transportation in developing countries faces severe traffic congestion challenges, particularly in cities like Nairobi. Ramji (2024) highlights that urban growth parallels traffic progression since early population settlements, with Kenya experiencing a remarkable 7% growth rate in motor vehicles, outpacing population growth. This surge is driven by increased private vehicle ownership, leading to a significant concentration of vehicles in urban areas. As Ojo and Kolawole (2018) note, traffic congestion is a global issue likely to worsen over time. Nairobi's urban road network, which constitutes only 8% of the road infrastructure, supports 32% of the population, exacerbating congestion and reflecting a broader international crisis.

The consequences of this congestion are profound, impacting environmental sustainability, public health, and economic vitality. By 2010, emissions from Nairobi's transport sector reached 6 million tonnes of CO2, accounting for 10% of national emissions (Karthikeyan and Prathima, 2016). Projections indicate this could rise to 19% by 2030, highlighting a looming environmental crisis. Pollution from road vehicles is linked to 59% of health cases in Nairobi (Priyanka, 2020), revealing the critical intersection of environmental policy and public health.

Despite global initiatives combating emissions and climate change such as the Paris Agreement to the United Nations Framework Convention on Climate Change in 2015, developing countries struggle to effectively manage traffic congestion and emissions due to inadequate frameworks. There is an urgent need for comprehensive strategies that enhance understanding of vehicle emissions and the factors contributing to urban pollution. Stakeholders such as policymakers

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and urban planners must develop innovative approaches to urban mobility and strengthen local emissions regulations. Wallington et al. (2022) and Liang et al. (2023) emphasize the importance of integrating environmental health considerations into urban planning and transportation policies.

The objective of this study was to examine the impact of urban traffic congestion on air quality, focusing on traffic volume and its emissions of carbon monoxide (CO), carbon dioxide (CO2), and particulate matter (PM2.5). Addressing the challenges of traffic congestion and vehicular emissions in Nairobi requires concerted efforts from all stakeholders. Effective strategies must mitigate pollution, improve urban mobility, and contribute to sustainable urban development. Prioritizing research and data-driven decision-making is essential for fostering a resilient urban future.

THEORY

Bharadwaj (2017) argues that traffic congestion is challenging to define simply, as it encompasses both a physical phenomenon—where vehicles impede each other's movement in limited road space—and a relative phenomenon that compares driver expectations to actual road conditions. Many authors concentrate on the physical side of traffic. In a similar vein, road traffic congestion is described by Afrin and Yodo (2020) as a circumstance in which a high vehicle density interferes with regular traffic flow, leading to prolonged journey times.

Research from scientific studies worldwide indicates that traffic congestion directly contributes to an increase in greenhouse gas emissions. Around 50% of the world's fossil fuel consumption currently comes from the transportation sector, which also accounts for 25% of all carbon dioxide-related emissions worldwide. About 15% of global GHG emissions are attributable to the transportation sector, with road transportation alone responsible for 72% of these emissions (Albalate, 2019).

Increased travel time due to traffic congestion means that cars spend more time on the road, using more fossil fuels and producing more emissions (Mathew, 2021). Notably, a number of studies contend that this is probably going to rise due to the historically high rate of motor vehicle ownership and use, particularly in cities and metropolitan areas. The global car fleet is predicted to triple by 2050, according to the United Nations Environment Programme (UNEP, 2024), and the transportation sector's greenhouse gas emissions are increasing at a faster rate than those of other sectors. Furthermore, Bharadwaj (2017) suggests that the exponential growth in traffic leads to a corresponding rise in the emissions of pollutants such as particulate matter (PM), nitrogen oxides (NOx), carbon monoxide (CO), carbon dioxide (CO2), volatile organic compounds (VOCs) or hydrocarbons (HCs), and other pollutants that are linked to motor vehicles.

Traffic congestion is identified as a complex issue that significantly impacted urban mobility and overall quality of life in metropolitan areas. To effectively evaluate and monitor this phenomenon, researchers and urban planners developed a variety of tested measures, each grounded in several key performance criteria related to road transport (Afrin & Yodo, 2020).

These performance criteria encompassed a comprehensive analysis of several factors, including traffic volumes, vehicle speeds, travel times, and delays experienced by commuters. Additionally, queue lengths were assessed to understand how congestion affected the flow of traffic. Another important criterion was the degree of utilization of private transportation, which provided insights into how individual vehicle use contributed to congestion levels.

These innovative approaches enabled a more dynamic understanding of congestion patterns. Through these multifaceted evaluation methods, transportation engineers and urban planners aimed to address the challenges posed by traffic congestion effectively. For a visual representation of the various congestion measures categorized by type, one could refer to **Figure 1** on congestion measures in different categories.

Travel time and average speed were identified as pivotal indicators of traffic congestion, acting as direct measures of the efficiency and performance of the transportation network. These metrics offered valuable insights into how quickly and effectively vehicles could navigate urban roadways, particularly under varying traffic conditions.

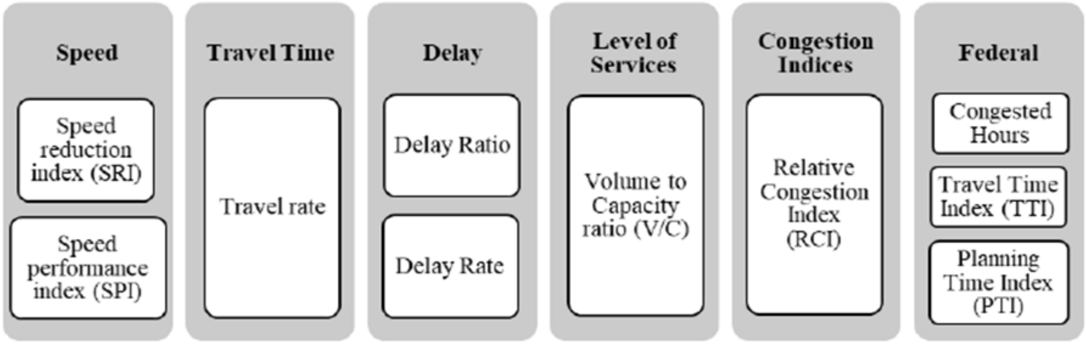

FIGURE 1
Congestion measures in different categories
Source: Afrin & Yodo, 2020

A comprehensive study conducted by Mingzhi et al. (2023) meticulously analyzed travel time data across multiple metropolitan areas, revealing significant declines in average speed during peak hours. This pronounced drop in speed served as a clear indicator of heightened congestion levels, reflecting the challenges faced by commuters and the transport systems that served them. The findings underscored the difficulties that arise when roadways become overwhelmed with vehicles, leading to longer travel times and increased frustration for drivers.

Similarly, traffic volume was also recognized as another crucial indicator of congestion that reflected the number of vehicles passing a specific point on a roadway over a designated period, typically measured in vehicles per hour. A high traffic volume often indicated increased usage of the roadway, which could subsequently lead to congestion. This congestion had a direct impact on travel times and overall roadway efficiency, making traffic volume a key factor in urban mobility studies.

Research conducted by Liu et al. (2020) provided compelling evidence that elevated traffic volume was closely associated with slower travel speeds and increased delays, particularly during peak rush hours in urban areas. This correlation highlighted the critical need for effective traffic management solutions, especially in cities that were experiencing rapid growth and a significant increase in the number of vehicles on the road.

As urban populations expanded and vehicle ownership surged, understanding the implications of traffic volume became increasingly important for planners and policymakers. By recognizing the relationship between traffic volume and travel efficiency, stakeholders could develop targeted strategies to alleviate congestion and improve overall transportation systems, ultimately enhancing the quality of life for urban residents.

According to Wu (2020), queue length was yet another key indicator of traffic congestion, visually representing the accumulation of vehicles waiting to move forward. This metric provided a concrete measure of the bottlenecks that occurred within the transportation network, reflecting the overall flow and efficiency of traffic at critical points, such as intersections. Their research revealed a significant correlation between longer queue lengths and increased levels of delay and frustration experienced by drivers, highlighting the negative impact of congestion on the commuter experience.

Utilizing both manual measurement methods and advanced technologies, including traffic cameras and sensors, Wu (2020) was able to accurately assess queue lengths at various intersections. Their comprehensive approach offered robust empirical evidence linking queue length to the severity of congestion, thereby reinforcing the value of this metric in understanding traffic dynamics.

Traffic congestion has far-reaching consequences, categorized into environmental, economic, health-related, and social impacts. These effects vary significantly across different cities, highlighting the complexity of addressing congestion (Ojo & Kolawole, 2018). On economic impacts, congestion raises transportation costs, leading to higher prices for goods and services and diminished competitiveness in global markets. It also reduces labor productivity, negatively affecting GDP. Zhang et al. (2024) stresses that efficient road systems are crucial for attracting investment and promoting economic growth.

On related social impacts, Ndatho (2018) suggests that congestion reduces urban residents' quality of life by lengthening commute times, which limits personal and social activities. Increased travel times contribute to stress, road rage, and aggressive driving. He further points out that congestion also hampers emergency services, potentially resulting in loss of life and property.

On environmental impacts, Bolaji and Adejuyigbe (2006) highlight that vehicle emissions from congestion significantly contribute to climate change and environmental degradation. They posit that fuel combustion releases harmful pollutants, leading to issues such as thermal air pollution and ozone depletion. In summary, traffic congestion presents a multifaceted challenge that affects urban life economically, socially, and environmentally.

Ramji (2024) rightfully notes that complete eradication of traffic congestion on roads is neither an affordable or easily achieved feat in economically dynamic settings. Sharma (2019) also argues that decoupling the expected growth in global transportation from the corresponding increase in emissions remains a big challenge across the world.

In Kenya, the standards for allowable emissions of hazardous gases from vehicles are primarily aligned with international regulations, notably the Euro emission standards. For petrol vehicles, the Euro 2 standard permits a maximum of 2.2 g/km of carbon monoxide (CO), 0.5 g/km of hydrocarbons (HC), and 0.5 g/km of nitrogen oxides (NOx). The stricter Euro 4 standard reduces these limits to 1.0 g/km for CO, 0.1 g/km for HC, and 0.08 g/km for NOx. For diesel vehicles, under Euro 2, the limits are set at 0.5 g/km for CO, 0.1 g/km for HC, 0.7 g/km for NOx, and 0.1 g/km for particulate matter (PM). Euro 4 further tightens these limits to 0.5 g/km for CO, 0.03 g/km for HC, 0.25 g/km for NOx, and 0.025 g/km for PM (Knight & Lopez, 2016). These standards are crucial for reducing air pollution and ensuring a cleaner environment.

RESEARCH METHODS

The study utilized a descriptive research design to analyze the characteristics of urban traffic congestion and vehicular emissions. This approach enabled the collection of both qualitative and quantitative data, enhancing the understanding of the research context. By employing a descriptive framework, the researchers provided a comprehensive overview of the current traffic situation, considering factors critical for urban planning and environmental management.

To determine the sample size, the researchers followed guidelines from Mugenda and Mugenda (2003), selecting a range of 10% to 30% of the total population. A specific 2-kilometer segment of James Gichuru Road was chosen to represent a larger 5-kilometer corridor, ensuring that the data collected would be relevant and applicable to the broader area, enhancing the study's reliability and validity.

A literature review was conducted to gather insights from secondary sources regarding traffic congestion and emissions, identifying gaps the current study aimed to fill. Systematic traffic volume assessments were performed, with trained enumerators manually recording traffic counts in 15-minute intervals to capture peak traffic times. Additionally, manual travel time monitoring provided valuable data on road usage efficiency, while qualitative documentation of traffic queue lengths helped identify congestion patterns.

Air quality monitoring was integral to the study, involving on-site measurements of PM2.5, CO, and CO_2 emissions using a Multi-gas analyser S360. This allowed for precise pollutant measurements and assessment of how ambient weather conditions affected emission levels. Standardized forms were used for emissions monitoring and traffic classification, ensuring data consistency and comparability. Data collection occurred in two phases: during school sessions and closures, facilitating a comparison of traffic and emissions under varying conditions.

Data analysis involved thorough clean-up and presentation through tables and graphs to visualize trends. Correlation and regression analyses were conducted to explore relationships among traffic metrics and emissions. Correlation analysis assessed the strength and direction of relationships between traffic volume, vehicle types, and emissions levels. A multiple variable regression model was then applied to isolate the effects of specific traffic metrics on emissions, providing a nuanced understanding of the interactions influencing air quality.

RESULTS

The findings from the study as shown in **Table 1**: traffic flow distribution and emissions, revealed significant insights into the relationship between traffic patterns and air quality. Analyzing the traffic flow distribution, we observe notable variability based on whether schools are in session. During off-peak hours, when schools are closed, traffic volume averages 750 vehicles per hour. However, this figure increases substantially to 1200 vehicles per hour during off-peak hours when schools are in session. The most striking difference is observed during peak hours, where traffic volume rises to 1100 vehicles per hour when schools are closed and escalates dramatically to 2000 vehicles per hour when schools are in session. This indicates that school-related traffic plays a crucial role in contributing to overall urban congestion, particularly during peak periods.

Moreover, there is a clear correlation between traffic volume and emissions concentrations. As traffic volume increases from off-peak to peak hours, emissions of carbon monoxide (CO), carbon dioxide (CO2), and particulate matter (PM2.5) also rise. During off-peak hours with schools closed, CO concentration is relatively low at 1 ppm, while CO2 and PM2.5 levels are recorded at 530 ppm and 50 μg/m³, respectively. In contrast, during peak hours when schools are closed, CO concentration increases to 5 ppm, with CO2 and PM2.5 recorded at 570 ppm and 70 μg/m³. The scenario becomes more alarming during peak hours with schools in session, where emissions reach very high levels for CO at 7 ppm, CO2 at 700 ppm, and PM2.5 at 95 μg/m³. This trend underscores the need for targeted traffic management strategies, particularly during peak times when schools are in session. The implications of these findings raise significant concerns regarding air quality and potential health risks for children and nearby residents. The marked increase in emissions especially during peak hours when schools are in session highlights the urgency for interventions aimed at reducing both traffic volume and emissions in urban areas.

These findings emphasize the importance of exploring traffic management strategies, such as carpooling initiatives, staggered school timings, or public transport optimization, to alleviate congestion and its environmental impact during peak hours.

The study found a strong correlation of 0.83 between traffic volume and emissions, indicating that increased traffic significantly raises emissions due to more idling and stop-and-go driving. This highlights the urgent need for effective traffic management to improve air quality and public health as shown in **Table 2**: variables correlation and significance levels.

TABLE 1
Traffic flow distribution and Emissions

Time Period	Traffic volume (Vehicles/ hr)	Averaged hourly CO Concentration (ppm)	Averaged hourly CO2 Concentration (ppm)	Averaged hourly PM2.5 Concentration (μg/m3)
Schools closed (Off-Peak hours)	750 veh/her	1	530	50
Schools closed (Peak hours)	1100 veh/hr	5	570	70p
Schools in session (Off-Peak hours)	1200 veh/hr	4	575	72
Schools in session (Peak hours)	2000 veh/hr	7	700	95

Source: Field survey, 2024

TABLE 2
Variables correlation and significance levels

	Pearson Correlation Sig. (2-tailed)	Traffic volume	Travel time	Queue length	Emissions
Traffic volume	Pearson Correlation Sig. (2-tailed)	1	0.65 (<.001)	0.52 (<.001)	0.83 (<.001)
Travel time	Pearson Correlation Sig. (2-tailed)	0.65 (<.001)	1	0.42 <.001	0.68 (<.001)
Queue Length	Pearson Correlation Sig. (2-tailed)	0.52 (<.001)	0.42 <.001	1	0.62 (<.001)
Emissions	Pearson Correlation Sig. (2-tailed)	0.83	0.68	0.62	1

Source: Field survey, 2024

Moreover, a moderate correlation of 0.68 between travel time and emissions suggests that longer travel times, often caused by congestion, lead to higher fuel consumption and emissions. Additionally, a robust correlation of 0.65 between traffic volume and travel time indicates that more vehicles result in longer delays. A correlation of 0.52 between traffic volume and queue length further shows that increased traffic leads to longer vehicle queues. Lastly, a correlation of 0.42 between travel time and queue length underscores that longer travel times are linked to extended waiting periods. Addressing these interconnected issues is essential for enhancing traffic flow and reducing emissions.

The regression model summary as shown in **Table 3**: regression model summary, indicates correlation coefficient (R) was calculated at 0.87, indicating a very strong positive correlation between the observed and predicted values of Emissions. This high correlation suggested that as one set of values increases, the other set tends to rise as well, demonstrating a robust relationship. The R-squared value was determined to be 0.76, meaning that approximately 76.12% of the variance in Emissions can be explained by the independent variables in the model, underscoring the model's effectiveness in capturing variations in emissions data. Additionally, the standard error of the estimate was found to be 5.92, indicating that the predicted values typically deviate from the actual observed values by an average of 5.92 units, which reflects the model's accuracy in forecasting emissions. To evaluate the significance of these findings, ANOVA was utilized, revealing an F value of 55.25 and a p-value of less than 0.001, confirming that the observed effect is significantly different from zero. The R-squared value of 0.76 further supports the model's capability to explain a substantial portion of the variance in emissions.

Table 4 represents the analysis of variance (ANOVA) that is essential for evaluating the model's fit to the data. The findings indicated that

TABLE 3
Regression model summary

R	R^2	Adjusted R^2	Standard error of the estimate
0.87	0.76	0.75	5.92

Source: Field survey, 2024

TABLE 4
Analysis of variance

Model	df	F	p
Regression	3	55.25	<.001

Source: Field survey, 2024

the F-Statistic, calculated at 55.25, tests the overall significance of the model by comparing it to one without predictors, facilitating the calculation of the p-value. The analysis yielded a p-value of less than 0.001, signifying highly statistically significant results and allowing for the confident rejection of the null hypothesis. This suggests that the independent variables significantly influence the dependent variable, Emissions. Overall, the ANOVA results demonstrate that the regression model is statistically significant, reflecting a strong fit compared to a model that lacks predictors.

Table 5 on regression model coefficients revealed the unstandardized coefficient B reflects the expected change in the dependent variable, Emissions, for each one-unit increase in the respective independent variable. The constant, estimated at approximately 8.22, represents the expected value of Emissions when all independent variables are zero, with a p-value of .034 indicating it is statistically significantly different from zero. This allows for the rejection of the null hypothesis that the constant's coefficient is zero in the population. The regression model was expressed as Emissions = 8.22 + (0.07) Traffic Volume + (0.66) Travel Time + (1.55) Queue Length.

For Traffic Volume, a one-unit increase results in a 0.07 unit increase in Emissions, with a p-value of less than .001, demonstrating a statistically significant difference from zero and supporting the rejection of the null hypothesis that the coefficient for Traffic Volume is zero in the population. In terms of Travel Time, a one-unit increase leads to a 0.66 unit increase in Emissions, with a p-value of .031, suggesting a statistically significant difference from zero and allowing for the rejection of the null hypothesis regarding Travel Time's coefficient. Lastly, for Queue Length, a one-unit increase results in a 1.55 unit increase in Emissions, with a p-value of .006, indicating a statistically significant difference from zero and enabling the rejection of the null hypothesis that the coefficient for Queue Length is zero in the population.

DISCUSSION

The study reveals that traffic volume significantly affects emissions along James Gichuru Road, with increased levels of CO, CO2, and PM2.5 during peak periods. Lei et al. (2023) found a direct correlation between traffic volume and CO emissions due to idling and congestion, while Kolzak (2018) noted that CO emissions were about 1.5 times higher during peak hours. CO2 emissions similarly increased by 30% during peak times, aligning with Lei et al. (2023) and supported by Sahraei & Ziaei (2024), who observed that more vehicles lead to higher CO2 concentrations.

The rise in PM2.5 during peak traffic is backed by Mingzhi et al. (2023), who identified traffic volume as a significant contributor to particulate matter, posing health risks. A regression model indicated a strong positive correlation between traffic volume and emissions, with a coefficient of 0.07 and a standardized Beta of 0.58, confirming traffic volume as a crucial predictor (p < .001). ANOVA results further validated that traffic volume is a key determinant of emissions, consistent with Sahraei & Ziaei (2024), enhancing the understanding of

TABLE 5

Regression model coefficients

	Unstandardized Coefficients	Standardized Coefficients					95% confidence interval for B
Model	B	Beta	Standard error	t	p	lower bound	upper bound
(Constant)	8.22		3.78	2.18	.034	0.63	15.81
Traffic Volume	0.07	0.58	0.01	6.12	<.001	0.05	0.09
Travel time	0.66	0.2	0.3	2.22	.031	0.06	1.26
Queue length	1.55	0.23	0.55	2.84	.006	0.46	2.65

Source: Field survey, 2024

vehicular impact on urban air quality.

On traffic composition on emissions, motorcycles contributed approximately 10% to carbon monoxide (CO) emissions, primarily due to incomplete combustion processes (Aftabuzzaman, 2011). Their prevalence in urban areas, coupled with their efficiency in congested traffic, exacerbates their impact on air quality. Small cars were significant contributors as well, accounting for around 25% of total CO emissions. Ojo and Kolawole (2018) attribute this high percentage to their popularity for daily commuting in urban settings, where their numbers amplify overall emissions, highlighting the need for improved fuel efficiency and emission controls.

Large cars contributed 15% to CO emissions. Bull (2004) explains that while they emit more CO per vehicle, their lower numbers compared to smaller cars make their overall impact complex. Poor maintenance and outdated technology in these vehicles further contribute to emissions, necessitating stricter regulations and incentives for cleaner alternatives (Kozlak, 2018; Sahraei, 2024). Vans and buses represented a substantial 35% of CO emissions, with older buses being major contributors due to inefficient emission control systems (Toledo, 2018). Many urban transit systems still rely on these older models, necessitating investments in cleaner technologies for improved air quality (Kozlak, 2018).

Finally, medium and large goods vehicles accounted for 15% of CO emissions (Zhang et al., 2004). Their emissions vary based on load and engine technology, indicating the need for a deeper understanding of their emissions profiles to develop effective strategies for reducing environmental impact (Kozlak, 2018).

The study revealed that vehicle emissions, notably carbon monoxide (CO), carbon dioxide (CO2), and particulate matter (PM2.5), significantly contribute to public health risks, including respiratory problems and other complications associated with pollution exposure. Alarmingly, it was found that 59% of health cases in Nairobi are linked to emissions from road vehicles (Priyanka, 2020). Specifically, the average carbon monoxide level in the study area was measured at 4.6 mg/m^3, which is below the acceptable limit of 5 mg/m^3 as per the Environmental Management and Coordination Act (EMCA, 2015). This indicates that the CO levels do not currently pose a health risk. In contrast, the study reported carbon dioxide levels at 6 mg/m^3, surpassing the acceptable limit of 5 mg/m^3. This violation highlights the necessity for targeted interventions to effectively manage and reduce CO2 emissions, which are critical for safeguarding public health and improving air quality.

CONCLUSION

The study highlights a strong link between traffic volume and emissions, with increased traffic, especially during peak hours, leading to higher levels of carbon monoxide, carbon dioxide, and particulate matter. Specifically, a unit increase in traffic volume results in a 0.07 unit rise in emissions. This emphasizes the need for effective traffic management to reduce congestion and improve air quality.

Additionally, the interplay between traffic volume, travel time, and queue length further exacerbates emissions during peak periods. Understanding these interactions is crucial for developing comprehensive traffic management strategies. The research aligns with existing literature on urban traffic congestion's impact on air pollution, reinforcing the need for proactive measures by transportation engineers and policymakers. Targeted interventions to reduce travel times and manage queue lengths can provide significant environmental benefits. A multipronged approach, including real-time monitoring and adaptive traffic control, is essential for effectively managing traffic and minimizing emissions.

The study identified several actions to minimize vehicle emissions and enhance air quality within vehicular zones and neighborhoods. Key strategies include developing safe walking and biking routes to encourage non-motorized transport, promoting carpooling and ridesharing initiatives to reduce the number of vehicles on the road. By tackling the issues within traffic dynamics, policymakers can create interventions that enhance air quality and promote sustainable urban transport systems, ultimately safeguarding public health in rapidly urbanizing regions.

RECOMMENDATIONS

The study identified multiple strategies to mitigate traffic congestion-induced emissions, particularly in urban areas with significant school-related traffic. Findings indicated that staggering school timings could effectively reduce peak traffic volume, which increased from 1,200 to 2,000 vehicles per hour during school hours. Promoting carpooling was highlighted as a crucial approach, given the strong correlation (0.83) between traffic volume and emissions. Enhancing public transportation options emerged as vital, as school-related traffic significantly contributes to overall emissions.

The study findings of increased traffic volumes during school sessions further highlighted the importance of developing safe walking and biking routes to encourage non-motorized transport. Encouraging flexible work hours to reduce the need to travel, and increasing community awareness were similarly recommended as additional traffic calming strategies. Lastly, promoting remote learning for students and their trainers could significantly decrease daily school-bound commutes and associated emissions. Together, these findings offer actionable recommendations aimed at addressing traffic congestion and subsequently improving air quality in urban settings.

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