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Fuel wastage and pollution due to road toll booth

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ABSTRACT

BACKGROUND AND OBJECTIVES: The study provides an assessment of fuel wastage, particulate matter particles pollution, and noise pollution at three toll booths near district Varanasi, India. The objective of the study is to analyze the effects of vehicle idling conditions on road tolls in terms of pollution and fuel wastage.

METHODS: The study used mathematical formulation on queuing observations for assessment of fuel wastage due to vehicle idling at toll booths. Handheld device HT-9600 Air Particle counter was used for getting the readings of PM2.5 and PM10. SL10 noise meter of Extech Instruments was used for measuring the noise levels at the selected three toll booths of Dafi Toll Booth, Lalanagar Toll Booth, and Mohania Toll Booth.

FINDINGS: The study assessed a greater extent of fuel wastage at all the three toll booths with maximum fuel wastage at Dafi Toll booth due to vehicle idling. In terms of air pollution, severe levels of particulate matter particles were observed over all the three toll booths. The noise levels over the three toll booths were also observed significantly high.

CONCLUSION: The study suggested that serious measures are required to control and regulate toll booths to avoid vehicle idling, which will lead to savings of fuel and air and noise pollution.

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INTRODUCTION

With the rapid growth in population, scarcity of natural resources and environmental degradation have emerged as serious concerns globally. Researchers are putting effort to identify all possible ways to limit the wastage of natural resources and control of environmental pollution. A significant source of natural resource consumption and pollution in the present world is transportation. In the United States itself, around 30 percent of Green House Gases emissions are accountable to the transportation sector only (EPA, 2017). A report from European Environment Agencies states that the transportation sector is liable for more than 13 percent to the total release of air pollutants, and over to that, more than 50 percent of NOx is coming from transport in the European Union (EPA, 2019). In developing countries like India, significant growth of air pollution has been observed due to the growing rate of vehicle transportation (Jason, 2015). Concerns with the transport segment are not limited to air pollution only. The transport segment also offers several other issues related to noise pollution, traffic congestion, augmented travel timings, and natural resources such as fossil fuel consumption. These issues have compelled researchers to find innovative solutions to optimize transportation systems in terms of minimum vehicular pollution, economic feasibility, and operability. Particularly, the road transportation accounts for a major share of fuel consumption as well as pollution emission (Jiménez-Uribe *et al.*, 2020). With more vehicles adding up every year in the road system, a rapid rise in fuel economy can be observed. Road transportation is also liable for environmental and health problems in the urban and rural areas linked with the roadways. Prolonged exposure to common vehicular pollutants like PM_{10} and $PM_{2.5}$ can lead to various respirational and cardiovascular issues. On an estimate, particulate matter particle pollution caused 620000 non-natural deaths in India in the year 2010 itself (Surendra, 2016). Another form of pollution that comes with vehicular emissions is noise pollution, and facts show that noise pollution due to traffic is also a severe concern posing adverse environmental and health effects (Espinoza-Arias *et al.*, 2019; Singh *et al.*, 2020). The excessive traffic on urban roads in cities and highways causes sound pollution, which is triggering hearing ailments in regular traffic commuters (Cai *et al.*, 2019). Any effort towards limiting the air and noise pollution and fuel wastage can be an aid in reducing the environmental health concerns and economic burden, especially in developing countries. A reasonable effort for reducing fuel wastage and minimizing vehicular pollution can be automation or removal of road toll booths (toll plazas). Road tolls are employed to generate funds from commuters using highways. These funds are used to incur the development and maintenance costs of the roadways. Tolls do not merely break the flow of traffic but also are a source of fuel and time wastage along with pollutant generation due to vehicle idling. Various incidents happened throughout the world in which highways were in traffic jam conditions for many hours and sometimes stretched for days and weeks, and in many such cases, the reason was inefficient systems at toll plazas, especially the manually operated ones (Deccan Chronicles, 2016; Gorzelany, 2015; You, 2015). In India, a report from Transportation Corporation of India and IIM Kolkata estimated that interruptions at toll plazas and slow pace of heavy freight vehicles had put a cost burden of USD 12 billion per annum on the Indian economy (TCI, 2016). The delays at the toll booths add up the immediate effect to rise in transportation cost and wastage of fuels and also present the severe concerns of air pollution (Lin *et al.*, 2020; Wang *et al.*, 2020) and noise pollution (Fider *et al.*, 2017), which can be avoided with efforts of optimizing the road tolls. One of the groups of people who directly get affected with pollutants and noises are the toll operators and servicemen in manually controlled toll booths. Since an enormous number of vehicles pass every day on tolls, emitting out much of pollutants and noises, toll workers become the victim of exposures causing severe effects on their health. Even limited exposure to diesel exhaust can be a reason for eyes and throat irritations, respiratory ailments, and pains in the chest and leg regions for the ones who are having some heart problems. Prolonged exposures to ultra-fine pollutant particles that are common at toll booths can lead to severe pulmonary health problems and even to DNA damage (Belloc-Santaliestra *et al.*, 2015). Besides the effects of air pollutants, noise pollution at toll booths is also a serious issue (Kim *et al.*, 2016). Many of the past studies have proved road toll booth employees and highway workers are exposed to noise levels, which are perilous to hearing

(Fider *et al*., 2017; Fiest *et al*., 2001; Nadya *et al*., 2010). In relation to the fossil-based fuels, there is an ascending price trend and growth in global demand due to the rapid industrialization and transportation advancements. Following the basic concept of demand and supply, as non-renewable resources become scarcer, the cost to obtain them will continue to rise. Supply for many of these fuels is at risk of ending, and gradually the price will hit a point that end-users will not be able to afford. India, being a developing economy, has also seen a rapid upsurge in the vehicular population in recent years. In the year 1951, the number of vehicles estimated to be around 0.31 Million, which rises to 115 million by the year 2014 (Road Transport Year Book: 2007-09, 2011). By the year 2040, the total vehicular population is forecasted to be around 206 million to 309 million (Tiwari *et al.,* 2013). The rising number of vehicles increased the issue of traffic chaos leading to avoidable vehicle idling, which is a major concern of fuel wastage and pollution. A research estimated that in the national capital of India, a car ran only at 4 kmph for 24% of their travel time and with such rate for a million cars running every day, will account for a total wastage of 0.25 million liters of fuel per day (Goel *et al*., 2015). Other than the traffic chaos, vehicle idling can often be seen at toll plazas on highways, which accounts for avoidable fuel wastage and pollution. In the presented work, estimation was done for the wastage of fuel due to vehicle idling in the queues at the toll plazas. Various efforts have been put by researchers throughout the globe for assessing the toll booth operations so that delays, as well as pollution and its impacts, can be avoided. Fu and Gu (2017) have given a relationship between traffic flow and the cost-benefit of a trip. They related it with the congestion and pollution externalities with and without the presence of toll booths on a fixed trip between two locations showing the effect of toll plazas on cost per trip and traffic flow. Blanc (1987); Chakroborty *et al.* (2016); Conolly (1984); Edie (1954); Haight (1958); Jaiswal *et al.* (2019a); Jaiswal *et al.* (2019b); Schwartz (1974), and several others have worked on assessing the queuing process at road networks as well as at toll booths and presented optimal queuing models for toll booths and highways. Congestion pricing (Zhang and van Wee, 2012), dynamic road pricing (Chang and Hsueh, 2006), AI-based system (Tan *et al*., 2017), drivers' adaptation (Heras-Molina *et al*., 2017) have also been analyzed for toll booth operations with time and environment optimized conditions. In the presented research study, three of the toll booths over Indian National Highways were observed for estimating the traffic flow, fuel consumption, particulate matter particle in the air, and noise levels. This study aimed to analyze the effects of vehicle idling conditions at road tolls to assess the fuel wastage and air and noise pollution at the toll booths. The paper presents an estimated analysis of the data generated for the total annual loss and pollution impact over the environment due to vehicle idling at toll booths on Indian National Highways. This study has been carried out for three toll booths on Indian National Highway 19 (NH-19) nearby district Varanasi in the states of Uttar Pradesh, India. The data was collected for the study in 2017.

MATERIALS AND METHODS

Region of study and data collection

Three of the road toll booths: Lalanagar Toll Plaza (Latitude: 25.267233, Longitude: 82.490525), Dafi Toll Plaza (Latitude: 25.248459, Longitude: 82.994053), and Mohania Toll Plaza (Latitude: 25.188447, Longitude: 83.561507), on Indian National Highways 19 near to district Varanasi were selected to collect the data for analysis over fuel wastage and pollutants. As the three toll booths are near to district Varanasi, the climatic conditions of the toll booths are also according to the city. These toll booths belong to a humid subtropical climate with dry winters, and temperatures ranged from 3°C to 18°C and rainy summers with a temperature higher than 22°C (Nistor *et al*., 2020). Fig. 1 shows the map of the selected toll booths for observation.

A survey was conducted over the three tolls to identify the peak hours and the off-peak hours of the traffic in a day. For air pollution data, a total of 5 samples each in the peak hours and non-peak hours were taken for 20 days from the period of 10 May 2017 to 14 July 2017. The mean of each day sample was assessed for the level of air pollutants in terms of Particulate Matter $PM_{2.5}$ and PM_{10}. A handheld device, HT-9600 Air Particle Counter, was used to get the readings of $PM_{2.5}$ and PM_{10}. For assessment of noise levels at the selected toll booths, handheld sound meter device SL10 from Extech Instruments was used. Five samples in peak hours and five samples in off-peak hours for an interval of 10 minutes were

Fig. 1: Geographic location of the study area along with the selected road toll booths for data and sample collection

collected for 20 days during a period of 10 May 2017 to 14 July 2017; overall, the three stated road toll plazas and its mean was assessed over the permissible limits. Descriptive statistics were used for the analysis of $PM_{2.5}$ and PM_{10} concentrations and noise levels at the three toll booths. Further, mathematical formulations were used for the assessment of fuel wastage at the selected toll booths. For assessment of fuel wastage and cost incurred due to waiting at toll plazas on Indian national highways, various observations were taken at each of the selected toll booths. The average waiting time in a queue for a vehicle and length of the queue were observed at all the three selected toll booths for different time clusters per day as of the survey of the peak and off-peak hours. The data for the total number of vehicles passing per day from a toll booth was retrieved from the website of Toll Information System-National Highways Authority of India (Toll Information system, 2017*)*. Various assumptions were made over the observed data, so the results assessed are subject to the assumptions made.

Mathematical formulations for fuel wastage due to toll booths

The present era is experiencing a fast degradation of non-renewable resources in terms of fossil fuel. As the primary energy source, the continuous use of fossil-based fuels not only led the world to a severe condition of fuel crisis but also offers another primary concern of environmental degradation. The continued exhaustion of fossil-based fuel also resulted in a subsequent upsurge of exhaust gasses and emerged as a major factor for global warming (Gonçalves and Simões, 2017). Researchers are putting effort all over the globe to save any potential wastage of fossil-based fuels. This study presents an assessment of fuel wastage due to vehicle idling at road toll that can aid in finding solutions for restricting the fuel wastage. In the present study for analysis of fuel wastage, various assumptions were made as; 1) All the vehicles were considered to be of similar types of passenger vehicles. 2) The fuel efficiency of the vehicles (f^e) was assumed as constant 16 km/L. 3) The average vehicular cruising speed in non-idling conditions (v^s) was assumed as 60 km/h) The vehicle engine assumed to be remained on during idling conditions throughout the waiting time. Several observations were made at all the three selected toll booths, and their mean values were considered for calculating the average waiting time for a vehicle in a queue at toll (q^{μ}), and length of the queue in meter (q^L), in each of the selected toll booths. With observations over all the three tolls, the average waiting time, q^{μ} and queue length of vehicles q^L, in ETC (Electronic Toll Collection), and manual lanes came approximately the same. The approximate total number of vehicles passing per day at the tolls (T^v) was retrieved from the website of Toll

Information System-National Highways Authority of India (Toll Information system, 2017). For estimations of fuel consumption with vehicle idling at tolls and savings of fuel when no tolls were present, average fuel consumed per hour by passenger vehicle in an idling condition (c^t) was calculated which was used to determine the fuel consumption of each of the vehicle while idling in the queues at toll (c^q), and fuel consumption of each vehicle if there was no toll (c^n). If no tolls are present, average fuel saved per vehicle (s^v), total fuel saved per day (s^d), and total fuel saving per year (s^y), were assessed. It was assumed that fuel efficiency (f^e) was16 km per liter, and average vehicular cruising speed (v^s) was 60 km per hour, so average fuel consumption for a vehicle per hour, considering vehicle was running at assumed speed throughout the hour became 3.75 liters per hour. According to Tong *et al.* (2000), in their defined conditions, for a passenger vehicle, the fuel consumption rate while cruising the vehicle is 39.10 gram per km, and at idling, the condition is 18.11 gram per km. It can be deduced from the results of Tong *et al.* (2000) that idling condition fuel consumption is 46.32 percent of the fuel consumption in the cruising conditions. If not considering the fuel consumption rates at accelerating and decelerating conditions of vehicles, the average fuel consumption for a passenger vehicle at idling condition (c^t) will be 46.32 % of the cruising speed condition making c^t equals to 1.737 liters per hour. With the provided assumptions, fuel consumed per vehicle while the vehicle is in the queue at the toll (c^q) was calculated in liter as the product of the average waiting time of the vehicle and average fuel consumption for a vehicle per hour in idling condition using Eq. 1.

$$c^q = q^\mu * c^t \tag{1}$$

Total fuel consumed per vehicle in liter if no tolls were present (c^n) was calculated as the ratio of the length of the road where the queue was there to fuel efficiency of the vehicle using Eq. 2.

$$c^n = q^L / f^e \tag{2}$$

Through, Eqs. 1 and 2, the total fuel saved per vehicle (s^v) in liter was calculated as the difference of the fuel consumed while a vehicle has to go in the queue if the toll was present to the fuel consumed by the vehicle if no toll was present, using Eq. 3.

$$s^v = c^q - c^n \tag{3}$$

Through Eq. 3, total fuel that can be saved in liter at each of the tolls was calculated as the product of total fuel saved per vehicle and the total number of vehicles passing through each of the tolls per day, using Eq. 4. The outcome was multiplied with 365 to get the total fuel that can be saved over the toll booths in a year, using Eqs. 5.

$$s^d = s^v * T^v \tag{4}$$

$$s^y = s^d * 365 \tag{5}$$

Using the equations (4) and (5), total fuel costs that can be saved per day and per year, if no toll was present, can be calculated by multiplying s^d and s^y with the fuel price per liter, respectively.

Measurement of noise levels and $PM_{2.5}$ and PM_{10} levels at toll booths

For measurement of noise levels at the selected toll booths, a sound level meter Extech SL10 was used, which is a pocket-sized handheld device for computing the sound levels. Extech SL10 sound meter has a measurement bandwidth of 31.5Hz to 8 KHz with a range of 40dB to 130dB operated over an A-weighting frequency. Frequency weightings for different noise meters are associated with the human ear response boundaries, and A-weighting frequency is the most common frequency used in most of the noise or sound meters (Pierre Jr and Maguire, 2004). Extech SL10 is accurate to ±3.5dB under reference conditions of 94dB and functions at operating temperature in between of 0 to 40° Celsius and operating humidity of 10 to 90 percent RH. For analysis of sound levels at all the three toll plazas – Lalanagar, Dafi, and Mohania, the calibrated SL10 was used to record the sound levels in the Max-Min mode, which measures the maximum and minimum sound levels over the area. From the survey results of peak hours and off-peak hours of the selected road toll plazas, five-sound samples of maximum levels were collected in each of the peak and off-peak time for 20 days during the period of 10 May 2017 to 14 July 2017. The samples were collected in intervals of 10 minutes, and the timing in seconds was recorded for different sound levels in decibels(dB) at the toll plazas. Mean of the 20 days' sample for a daily average of the 10 sample data collected in the peak and off-peak time were used for analyzing the level of noise pollution over the three toll plazas. For measurement of $PM_{2.5}$ and PM_{10} at the road tolls, HT-9600 particulate matter particle counter was used. Benefits associated with a particle counter are that it is easy to operate, moveable, and easy to carry, less costly and efficient in measuring concentrations of the particles for short time intervals (Tittarelli *et al.*, 2008). HT-9600 counts in 3 channels with a particle size of 0.3, 2.5, and 10 µm. HT-9600 particle counter comes with an optoelectronic type sensor with a laser diode as a light source. It measures the particle in microgram per meter cube (µg/m^3) and has a measurement range of 0 to 10000 µg/m^3. The instruments' flow rate of air samples is 1 liter/min and has a pre-defined sampling time of 50 seconds. So for HT-9600, all the readings were multiplied by a ratio of 6/5 and were rounded off for getting the 1-minute concentration of $PM_{2.5}$ and PM_{10}. With the instruments HT-9600, ten samples were taken for the three selected toll booths in a day distributed as five samples over the peak and off-peak times for 20 days from the period of 10 May 2017 to 14 July 2017. Mean values of per day 10 sample readings had given the 1-minute average concentrations of PM_{10} and $PM_{2.5}$ particles in µg/m^3 units. This mean 1-minute values of $PM_{2.5}$ and PM_{10} were used as day-average particulate matter particles for the analysis of the results.

RESULT AND DISCUSSION

Results of the study

In this section of the study, results are estimated and analyzed for the total fuel wastage due to the vehicle delays at toll booths of Lalanagar Toll Plaza, Dafi Toll Plaza, and Mohania Toll Plaza, on Indian National Highways 19 (NH-19) near to district Varanasi. Noise levels and concentration levels of $PM_{2.5}$ and PM_{10} are also assessed for the selected three toll booths in this section. Table 1 presents the results of the initial survey to identify peak hours of vehicle movement at three toll booths. The survey was conducted with the toll booth operators and workers of the three toll booths. As per Table 1, it can be observed that all the three toll booths are having a good number of peak hours with 6-8 hours of excessive traffics at these toll booths daily. Many times during peak hours, these toll booths observe long waiting queues of vehicles. Even in off-peak hours, it was found good and continuous traffic over these tolls leading to significant fuel wastage, air and noise pollution.

Fuel wastage at the toll booths

Taking several observations at each of the three toll booths in their respective peak hours and off-peak hours, average waiting time (q^{μ}) and length of the queue (q^{L}) were calculated and are presented in Table 2. The total number of vehicles passing per day at the toll booths (T^{v}) is as well presented in Table 2. As per the available data on the official website of *Toll Information System* of *Government of India*, Dafi toll plaza observed passing of 45468 vehicles, last recorded on 20th March 2017, Lalanagar toll plaza observed passing of 33287 vehicles, last recorded on 26th of May 2017, and Mohania toll plaza observed passing of 39705 vehicles last recorded on 21st April 2017 (Toll Information system, 2017). It can be observed from the results presented in Table 2 that Dafi toll plaza has the highest waiting time for a vehicle and apparently the most extended average length of the queue among all the three toll plazas. Mohania toll plaza has the second-highest waiting time, and average queue length followed lastly by Lalanagar toll plaza. A perceived reason behind high waiting time at Dafi toll plaza is that this particular toll is closest to the district Varanasi and traffic of the city very much impact the toll in comparison to the other two. Further, the results presented in Table 2 shows

Table 1: Vehicle peak hours at the three toll booths

Toll Booth	Peak Hours	Total Peak Hours
Lalanagar Toll Plazas	08:00-11:00, 16:00-20:00	7 Hours
Mohania Toll Plaza	09:00–11:00, 17:00-19:00 and 22:00–00:00;	6 Hours
Dafi Toll Plaza	08:00-11:00, 17:00-19:00 and 22:00-01:00	8 Hours

Table 2: Fuel consumption and amount of fuel wastage at the three toll booths

Particulars	Dafi Toll Plaza	Lalanagar Toll Plaza	Mohania Toll Plaza
Total number of vehicles passing per day at the toll booths (T^v) (Toll Information system, 2017)	45468 vehicles	33287 vehicles	39705 vehicles
Average waiting time for a vehicle in a queue at the toll booth (q^μ)	618 seconds	155 seconds	232 seconds
Average length of the queue (q^L)	295 meter	84 meter	127 meter
Fuel consumption per vehicle while vehicle be in queue at the toll booth (c^q)	0.299 liter	0.075 liter	0.11 liter
Total fuel consumption per vehicle if no toll booths were present (c^n)	0.079 liter	0.022 liter	0.034 liter
Total fuel that can be saved per vehicle in the absence of toll booths (s^v)	0.22 liter	0.052 liter	0.077 liter
Total fuel that can be saved per day (s^d)	10002.96 liter	1730.924 liter	3057.285 liter
Total fuel that can be saved per year (s^y)	3651080.4 liter	631787.26 liter	1115909.025 liter

that in a single day, these three toll plazas account for a total fuel wastage of 14791.17 liters of fuel in which the Dafi toll contributes maximum wastage of 10002.96 liters. Lalanagar toll contributes wastage of 1730.924 liters, and the Mohania toll contributes wastage of 3057.285 liters. The collective fuel that can be saved in the absence of these three toll booths in a year is approximately 5398776 liters of fuel. The statistics presented in Table 2 shows the gravity of the fuel wastage problem due to toll booths on highways.

PM particles pollution at the toll booths

Leading to more adverse effects of toll booths other than fuel wastage, Fig. 2 shows the amount of particulate matter particles ($PM_{2.5}$ and PM_{10}) observed at each of the three selected toll booths near Varanasi. From the line graph of Fig. 2, it is evident that $PM_{2.5}$ and PM_{10} levels are comparatively higher at Dafi toll plaza, followed by Lalanagar Toll Plaza and Mohania Toll Plaza. Fig. 2 also shows a very high concentration level of both the $PM_{2.5}$ and PM_{10} particles at all the three toll plaza. The variations of $PM_{2.5}$ were mostly observed between 150 µg/m^3 to 350 µg/m^{3,} with few observations also detected exceeding 350 µg/m^3. The observed variations of PM_{10} ranged in between 200 µg/m^3 to 400 µg/m^{3,} with several observed concentrations exceeding the levels of 400 µg/m^3. According to the report of Cardinal (2018), mapping the pollution concentrations with AQI values is presented in Table 3. The air quality index with respect to different pollutants is categorized into six categories of 'good,' 'moderate,' 'unhealthy for few,' 'unhealthy,' 'very unhealthy' and 'hazardous.' Below 35.5 µg/m^3 for $PM_{2.5}$ and below 155 µg/m^3 for PM_{10} is considered better standard for both the PM particles. On comparing the observed particulate matter particle levels with the standard values presented in Table 3, it is very much clear that the observed levels of $PM_{2.5}$ and PM_{10} at all the three tolls lied in 'very unhealthy' to 'hazardous' categories. The results show that not a single observation found at all the three tolls lied in the categories of 'good' or even 'moderate,' proving the extremely polluted conditions in terms of PM particles over these toll booths. The aggregate mean of all the observed concentration levels of $PM_{2.5}$ and PM_{10} also shows severe conditions compared to the standard levels in AQI mapping. The aggregate mean of all the observed levels at the Dafi toll booth for $PM_{2.5}$ is 279 µg/m^3 and for PM_{10} is 384.35 µg/m^3; at Lalanagar toll booth for $PM_{2.5}$ is 232.7 µg/m^3 and for PM_{10} is 329.7 µg/m^3 and at the Mohania toll booth for $PM_{2.5}$ is 194.8 µg/m^3 and for PM_{10} is 287.8 µg/m^3. The aggregate mean PM_{10} level of all the mean observed concentrations lied in the 'very unhealthy' category, whereas for $PM_{2.5}$, the Dafi toll booth lied in the 'hazardous' category, Lalanagar toll booth lied in the 'very unhealthy' category, and Mohania toll booth lied in 'unhealthy' category.

Noise levels at the toll booths

The standard value of ambient noise varies with respect to different regions and demographic zones.

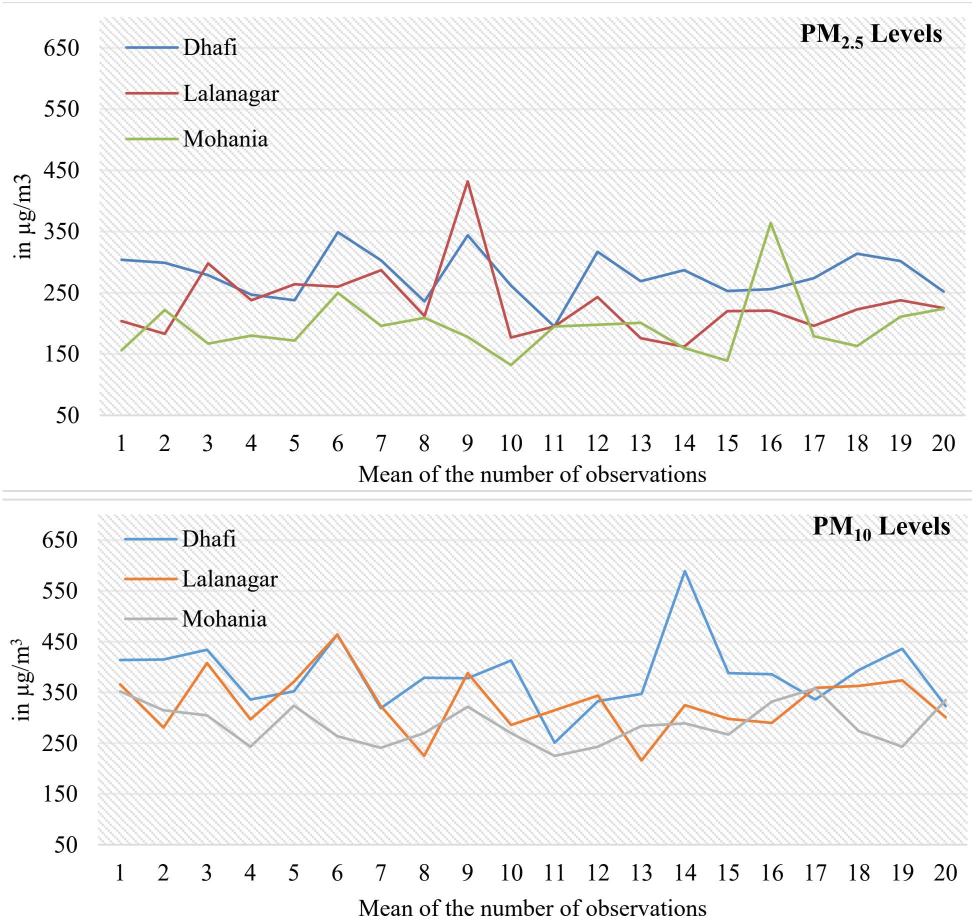

Fig. 2: $PM_{2.5}$ and PM_{10} levels in µg/m³ for the experimental study using HT-9600

Table 3: $PM_{2.5}$ and PM_{10} in µg/m³ mapping with AQI categories (Cardinal, 2018)

$PM_{2.5}$ (µg/m³)	PM_{10} (µg/m³)	Category
$C_{low} - C_{high}$	$C_{low} - C_{high}$	
24 h average	24 h average	
0.0 -12.0	0-54	Good
12.1-35.4	55-154	Moderate
35.5-55.4	155-254	Unhealthy for sensitive groups
55.5-150.4	255-354	Unhealthy
150.5-250.4	355-424	Very unhealthy
250 above	425 above	Hazardous

For average noise exposure, WHO, (2018) report acclaims that the noise generated by road traffic should be below 53 dB. The report mentioned that continuous exposure to high decibel sound levels of road traffic could lead to adverse health effects. According to National Institute on Deafness and Other Communication Disorders, in general terms below 85 dB noise can be considered as safe sound levels, and prolonged exposer to sound levels of 85 dB or above can cause severe hearing issues (Fink, 2017). In India, ambient noise is categorized under four areas that are industrial, commercial, resident,

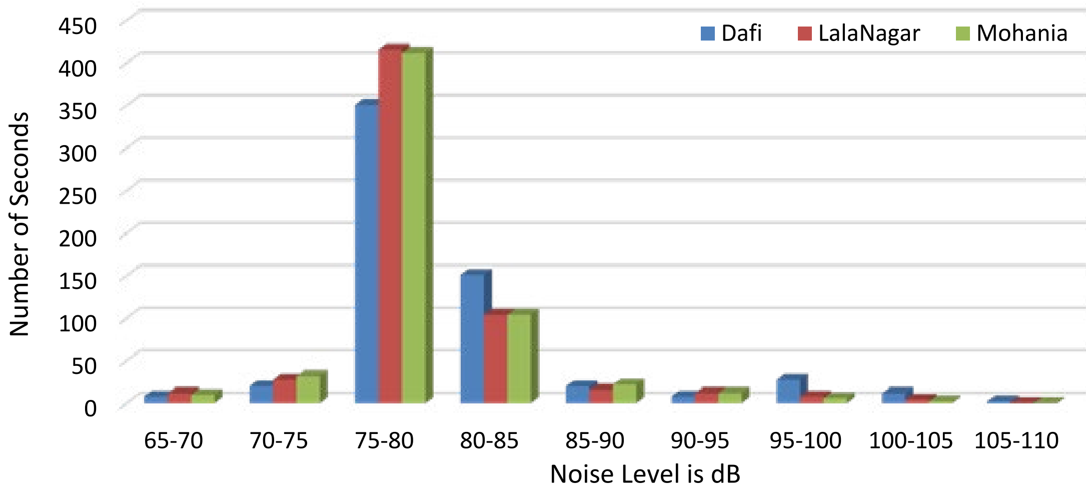

Fig. 3: Number of seconds of noise levels in dB in 10 min interval using Extech SL10

and silence zone. Toll booths can be considered under commercial area, and for it, the standard values of noise are 65 dB in the day and 55 dB in the night (Noise Pollution Rules, 2000). Noise levels at the three respective toll booths were observed significantly higher than the standard noise levels that can lead to severe problems to the toll workers. Fig. 3 shows the bar graph of sound levels in decibels (dB) of the three selected toll plazas. The noise levels in between 75 to 80 decibels have the highest percentage in the 10 minutes (600 seconds) mean readings for all the three toll plazas with 351 seconds at Dafi toll, 416 seconds at Lalanagar toll and 412 seconds at Mohania toll. The second-highest percentage of mean observed readings is between 80 dB and 85 dB. Mean reading values have shown a noteworthy percentage of noise levels above 85 decibels up to a maximum of 110 decibels with 70 seconds at Dafi, 40 seconds at Lalanagar, and 42 seconds at Mohania tolls. The results presented in Fig. 3 shows all mean reading above the 53 dB levels. With respect to the noise pollution standards by Noise Pollution Rules, (2000), the results from the study show that only 1.33 percent duration of noise levels at Dafi toll, 2 percent duration of noise levels at Lalanagar toll, and 1.66 percent duration of noise levels at Mohania toll were under the standard levels of noise. The noise levels obtained in the study proved to be unsafe and can cause several health issues to public health as well as can cause severe hearing aids to toll booth workers.

Discussion on the results of the experimental study

The results of the study confirmed various other past studies that have observed critical conditions of air pollution, specifically PM particles at toll booths (Lin et al., 2020; Wang et al., 2020). The hazardous levels of both $PM_{2,5}$ and PM_{10} at all the three toll booths observed in the study show the possibility of health issues like pulmonary health problems, as stated by Belloc-Santaliestra *et al.* (2015) to toll tellers and highway workers. The results presented in the above section of the study suggest the requirement of strict actions for controlling the pollution and wastage of fuels at toll booths. Fuel wastage at an intersection point or toll booths can be little for a vehicle, but collectively for hundreds of vehicles, it turns up to be a great source of potential fuel wastage (Sharma *et al.*, 2018). Results presented in Table 2 of the study confirms by showing the magnitude of fuel wastage in a day and a year over the selected three road tolls. The observed fuel wastage at all the three toll booths suggests necessary and specific measures. Works of Blanc (1987); Chakroborty *et al.* (2016); Conolly (1984); Edie (1954); Fu and Gu (2017); Haight (1958); Jaiswal *et al.* (2019a); Jaiswal *et al.* (2019b); Schwartz (1974) and others can be assessed for finding possible solutions for minimizing traffic congestions leading to lesser fuel wastage at toll plazas. With the absence of the road tolls or by making a strategy such a way that no vehicle has to stop over the road tolls, an enormous amount of these non-renewable fuels can be saved along with meaningfully contributing to the supply chain economy. The Government of India has taken a very serious step by the mandatory implementation of FASTag: an electronic toll collection at road toll medium from December 15, 2019 (Oza, 2020). Still, long queues of vehicles can be observed over road toll booths leading to vehicle idling and ultimately leading to wastage of fuel and vehicular pollution generation. As per as vehicular pollution is concern, while the Government of India already puts serious efforts to minimize vehicular pollution by promoting the use of E-vehicles and alternate transportation medium (Shalender and Yadav, 2018), discontinuing the use of the poor environmental standard of vehicles (Jaiswal *et al.*, 2019a), mandatory adoption of FASTag system on road tolls (Algonda *et al.*, 2018) and various other measures. Still, more efforts are required to curb vehicular pollution, and reducing vehicular pollution generation at a toll can be very significant in this order. Results from the study of Jaiswal *et al.* (2018) has shown that the air pollution, especially particulate matter particles ($PM_{2.5}$ and PM_{10}) are a severe concern at present as well as in the future for the district Varanasi, and the study presented in this work proved tolls nearby Varanasi is a significant contributor of $PM_{2.5}$ and PM_{10}. The study shows that any work reducing PM emissions at tolls of Dafi, Lalanagar and Mohania can considerably contribute to the reduction of overall PM levels at Varanasi. On a comparison among the selected three tolls, the Dafi toll booth has the worst conditions in terms of PM particle levels. Since it is the closest to the city Varanasi, the toll also very much adds PM particles in the city's urban environment. Considering the research study of Jaiswal *et al.* (2018), all efforts in reducing the air pollution at the Dafi toll will considerably contribute to improving the urban ambient environment of Varanasi. Besides, the toll booth workers are the first and potential victim of both the vehicular air pollution and noise pollution due to the continuous and vast number of vehicles passing and idling at the toll booth. The issue of sound pollution over toll booths has been addressed by various past research works (Kim *et al.*, 2016; Meier *et al.*, 2013) for different countries, and the presented study adds to the existing problem and proves that a serious solution to the issue is required. The noise levels detected at all the three toll booths are in accordance with the concerns raised by Fider *et al.* (2017) and Feist *et al.* (2001). The observed results show that the noise levels at all the three toll booths are much higher than the standard sound levels of 65 dB at day and 55 dB at night, as recommended by The Noise Pollution [Regulation and Control] Rules, (2000), Government of India. As India is concerned, past studies have proved the seriousness of high noise levels at traffic in India (Agarwal *et al.*, 2017; Kumar *et al.*, 2017; Tandel and Macwan, 2017). This work presented in this study adds to the literature about the concerns of higher noise levels, particularly at the road toll booths.

The implications of the study show that specific remedial measures are required at Dafi, Lalanagar, and Mohania toll booths for air pollution, noise pollution, and fuel wastage control. The study infers that with the control of PM particle emissions at the three toll booths, a significant improvement in the AQI of Varanasi can be observed. The study also infers that with the reduction of vehicle idling at road toll booths in India, a substantial amount of fuel can be saved from wastage along with controlling the air and noise pollution of urban areas. The following are the few remedial measures that can be considered for mitigating air and noise pollution along with controlling fuel wastage due to vehicle idling at road tolls.

- Restricting the manual operations of toll collections and mandatory implementations of FASTag electronic toll collections (Algonda et al., 2018) for all vehicles over every toll booth.
- Development of dedicated lanes for heavy traffic. Many of the countries are already using the dedicated lanes approach and the results are commendable in terms of pollution and fuel wastage reduction (Figueiras et al., 2019).
- Removal of toll booths and toll collection on the basis of distance traveled (Andrlík and Zborovská, 2019).
- Dynamic toll pricing for and congestion pricing in which road toll taxes are changed according to traffic congestion conditions to reduce vehicle idling at tolls leading to a decrease in pollution and fuel wastage (Chang and Hsueh, 2006; Zhang and van Wee, 2012).
- Restricting the use of lower environmental

standard vehicles (Jaiswal *et al*., 2019a) and encouragement towards the use of E-vehicles and alternate transportation medium (Shalender and Yadav, 2018).

- Including the strategies of polluter pay over road tolls to check and encourage commuters to control air and sound pollution (Andrlík and Zborovská, 2019).
- Use of engineering control method for confining toll plaza windows to obstruct noise transmission to reduce the effects of vehicle noise pollution (Fider *et al*., 2017) and use of active noise control headset (Feist et al., 2001).

CONCLUSION

Fuel wastage, PM particle pollution, and noise pollution were assessed over three toll booths on NH-19 around the district Varanasi in India in this study. The three selected toll booths of Dafi toll, Lalanagar toll, and Mohania toll over the national highway of India were assessed using device Extech SL10 for measuring noise levels, HT-9600 Air Particle Counter for evaluating $PM_{2.5}$ and PM_{10} levels and queuing model approach for calculating fuel wastage. The results presented in the study shows significant pollution levels for both PM particles and noise levels. The study also shows a good amount of vehicular fuel wastage at all three toll booths. For PM_{10} and $PM_{2.5}$, the analyzed data revealed very severe levels for the pollutants with all the average readings in the category of unhealthy to very unhealthy and even in hazardous conditions. These high levels of air pollution over toll booths not only cause health effects to the workers but also significantly contribute to deteriorating the ambient environment surroundings. Besides PM particle pollution, the presented study also shows the severity of noise pollution over the toll booths. The prolonged stay in such detrimental surroundings will have a direct effect on the health of toll booth workers. Other than pollution, the study emphasized on fuel wastage due to vehicle idling over the toll booths. The results presented in the study assessed enormous wastage of fuel over each of the three toll booths. The formulations for assessment of fuel wastage are limited to the assumptions made but still proved the necessity of real-time solutions for vehicle idling at tolls that will not only avoid fuel wastage but will also significantly contribute to reducing the time of transportation contributing in improving the logistical activities. The study presented in the paper is limited to a small number of data collected. The study is also limited to the assumptions made in the formulation model of fuel wastage due to vehicle idling at toll booths. Also, the study is carried out before the mandatory implementation of FASTag on road toll booths in India. In the future work of the study, a new data set can be collected with FASTag electronic toll collection medium over toll booths and can be compared with the results of this study.

AUTHOR CONTRIBUTIONS

A. Jaiswal performed the manuscript writing, collected the data and done the partial analysis work of the study. C. Samuel carried out the analysis presented in the study and also edited and corrected the manuscript.

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CONFLICT OF INTEREST

The authors declare no potential conflict of interest regarding the publication of this work. In addition, the ethical issues including plagiarism, informed consent, misconduct, data fabrication and, or falsification, double publication and, or submission, and redundancy have been completely witnessed by the authors.

ABBREVIATIONS

%	Percent
°	Degree
&	And
μg/m³	microgram per meter cube
μm	micrometer
AI	Artificial Intelligence
AQI	Air Quality Index
C_{low}	Concentration low
C_{high}	Concentration high
c^n	Fuel consumption of each vehicle if there was no toll

c^q	Fuel consumption of each of the vehicle while idling in the queues at toll
c^t	Average fuel consumed per hour by passenger vehicle in an idling condition
dB	Decibel
DNA	Deoxyribonucleic acid
ETC	Electronic toll collection
Eq	Equation
Eqs	Equations
E-vehicles	Electronic vehicles
f^e	Fuel efficiency of the vehicles
h	hour
Hz	Hertz
IIM	Indian Institute of Management
KHz	Kilo hertz
km	Kilometer
km/L	Kilometer per liter
kmph	Kilometer per hour
min	minute
NH	National Highway
NOx	Nitrogen Oxides
PM_{10}	Particulate matter particle up to size 10 micrometer
$PM_{2.5}$	Particulate matter particle up to size 2.5 micrometer
q^L	Length of the queue in meter
q^u	Average waiting time for a vehicle in a queue at toll
RH	Relative humidity
s^d	Total fuel saved per day
s^v	Average fuel saved per vehicle
s^y	Total fuel saving per year
T^v	Total number of vehicles passing per day at the tolls
v^s	Average vehicular cruising speed in non-idling conditions
USD	United States Dollar

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