Urban road traffic noise on human exposure assessment using geospatial technology

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ABSTRACT
The sounds produced by humans, industries, transport and animals in the atmosphere that pose a threat to the health of humans or animals can be characterized as noise pollution. Adverse effects due to noise exposure can involve speech communication interference and declining learning skills of children. Highway traffic noise contributes to 80% of all noise. It has grown to a massive scale because of growth in population along the roads leading to a rapid change in land use and has evolved into a common reality in various Indian cities. The main objective of this work is to develop a road traffic noise prediction model using ArcGIS 10.3 for the busy corridors of Chennai. The collected data includes traffic volume, speed, and noise level in lateral and vertical directions. Noise levels were measured in 9 locations using a noise level meter. It is observed that the noise levels vary from 50 dB to 96 dB. It is found that the noise problem is severe in 18% of the area, and 6.3% of people are exposed to the traffic noise problem. The results obtained in this study show that the city is affected by severe noise pollution due to road traffic.

Keywords: Exposure Assessment, GIS, Maps, Noise Pollution, Traffic Speed, Traffic Volume

1. Introduction
In the field of transport infrastructure, India is on the verge of a big forward push. Vehicular traffic in urban areas has, in recent years, increased manifold. This has resulted in traffic congestion. Noise due to traffic is associated with adverse effects on health [1]. Traffic congestion gives rise to many problems, including noise pollution. Noise is a recognized environmental pollutant that can negatively affect public health. Urban noise pollution is a growing concern of communities. A major environmental issue in the daily life of people is the noise produced by road traffic. Children’s brains may also be affected due to traffic noise. Environmental pollution is a major problem due to rapid industrialization, urbanization, and a rise in people’s living standards. Noise is inevitable in urban areas and hence noise levels have to be assessed [2]. The permissible noise levels as prescribed by Tamil Nadu Pollution Control Board (TNPCB) are given in Table S1. Noise is an environmental pollutant that has received much attention in the past [3]. According to the World Health Organization (WHO), the third most dangerous type of pollution after Air and Water pollution is Noise Pollution. The escalating effects of noise emissions have not been improved to the standard of other sources of pollution [4]. Generally speaking, Noise has given a significant concern to humanity that has not been addressed and discussed until recently [5].

A study on Realistic driving cycles for Thailand's road conditions was studied by Songwut Mongkonlerdmanee and Saiprasit Koetniyom [6]. They proposed a method of a realistic driving cycle and used time series clustering technique. Their study selected Kanchanaburi province, Thailand and collected data on 323 routes using on-board measurement. They concluded that the speed ranges
from 30-40 km/h. Noise can be characterized as an environmental pollutant that interferes with health and communication [7-9].

Study on urban noise emissions and their environmental implications has been researched by many countries [10]. Hangzhou, China, studied subjective annoyance caused by indoor low-level and low-frequency noise control methods [11]. They used the fuzzy mathematical principle to establish a relationship between indoor noise and noise annoyance. The other noise issue is that it causes interference with social interaction and reduces children's learning skills. The biggest source of noise is traffic [12] and as found by social surveys, a major source of annoyance and nuisance [13]. A study on the acoustical environment of urban areas related to city development [14] has established a relationship between urban development and noise pollution. His analysis is based on the primary and secondary data collected related to noise in the urban area. The author concluded that there is a strong relationship between urban development and noise level. Further proper planning should be carried out so that the noise level can be reduced.

Further, noise due to traffic constitutes a major economic impact on the real estate business. India has emerged from rapid industrialization and urbanization as a fast-developing country. The growing numbers of cars and electronic devices have contributed significantly to noise pollution [15]. A growing urban concern nowadays is Highway Traffic Noise (TN) and this is because of the growing population that gives rise to land next to roads being used. [16] have studied the health impact due to noise in a chromium alloy factory based on one-year noise data. They found that the factory noise ranged from 67.6 to 89.2 dBA. Further, they found from the statistical analysis a strong relationship between age and hearing loss.

Kalaiselvi and Ramachandraiah [17] undertook environmental Noise Mapping Study for Heterogeneous Traffic Conditions. According to them, the traffic noise characteristics in cities belonging to developing countries like India vary slightly due to the heterogeneous traffic composition associated with variance in geometrical road features, surface characteristics, honking conditions, and varying building density on either side of the road. A noise mapping study has been attempted to study the propagation and spread of traffic noise in the same areas. This study uses noise mapping through a computer simulation model (sound plan software) by considering several noise sources and propagation of noise to the receiver point. Some of the prediction models, such as the UK’s CORTN, the US’s TNM and their modified versions, have limited applicability for heterogeneity. Therefore, a separate multiple regression model is discussed to find the suitability of the heterogeneous traffic conditions for noise mapping purposes.

Environmental Modelling for Traffic Noise in Urban Areas was developed by Francis Cirianni and Giovanni Leonardi [18]. They have proposed a methodological approach for the quantitative analysis of traffic noise in urban settings in their study. They presented an analysis of the acoustic data measured in the city of Villa S. Giovanni (Italy). The results show how the neural network approach provides better performance than the classical solution based on statistical analysis.

With regards to the increase in the number of vehicles on the road, the density of the population within the city and industrial growth, as well as the lifestyle of the highest urban population, has led to an increase in noise levels on the road as well as the surroundings thus serving as the inspiration for this study. This increase in noise levels has been affecting people living along these roads. Their surroundings and the negative effects of noise pollution have been causing health issues, especially for children and senior citizens. These health issues vary from causing minor annoyances, irritation, and sleep disorders to more dangerous conditions such as the increased risk of contracting diabetes, hypertension, and cardiovascular diseases and loss of hearing in the most extreme cases. This study differs from other relevant studies by visualizing the extent of people and the area that is being affected due to noise pollution caused by road traffic. GIS will help estimate the effects of increased noise levels at different altitudes and distances from the road noise source.

Khan J et al. [19] examined air and noise pollution from urban road traffic and other significant factors such as the dispersion models used, the GIS-based methodology, the spatial scale of exposure assessment, the study location, sample size, traffic data type, and building geometry information. The potential for creating a uniform tool to quantify combined exposure to traffic-related air and noise pollution to facilitate health-related investigations is enormous. Due to its geographic nature, GIS is well-established and has a strong capability to address both exposures simultaneously. Zubair KH et al. [20] presented a new microscopic traffic simulator to deal with the unstructured road traffic streams of developing countries with a wide range of behaviors. The authors tested the viability of their proposed parser and simulator in real-world scenarios by parsing GIS street maps of four distinct places with an average accuracy of 86%, with 99% accuracy in terms of journey time following necessary calibration using real traffic data.

This study aimed to propose a GIS spatial analysis model-based methodology for detecting and mapping noise-sensitive zones. GIS databases represented the model's validated results, and the results serve as helpful maps for local government as a source of information in the decision-making process [21]. Bilaçoş Ş et al. [22] aimed to determine and map the levels of noise pollution in Safranbolu District Center, particularly in areas with high motor vehicle and pedestrian activity levels. The authors demonstrated that the overall quality of the acoustic environment in our research area was moderate, implying that long-term exposure to these levels can affect human health and quality of life.

Based on the review of previous research carried out in the road traffic noise pollution monitoring and GIS models, the objective is formulated. The main objective of this study is to develop a road traffic noise prediction model using GIS for the busy corridors of Chennai City. The sub-objectives are:

- To collect and analyze the existing noise level in the study area and the volume of traffic and spot speeds.
- To generate noise maps using ArcGIS to determine the extent of the area affected due to road traffic noise.

1.1. Human Health Risk Assessment of Noise Pollution

According to the WHO, noise must be recognized as a major threat to human health. Traffic-related noise is believed to be responsible for approximately 1 million healthy years of life lost each year due to illness. It may result in a disease burden second only to
that caused by air pollution [23]. One of the most serious auditory health consequences of workplace noise exposure is hearing loss [24]. Non-auditory sources of irritation include traffic noise, which disrupts sleep, communication, concentration, TV viewing, and learning [25, 26]. The following are the major health effects on humans due to road traffic noise:

- Hearing problems
- Health issues
- Sleeping disorders
- Cardiovascular issues
- Trouble communicating
- Reading comprehension
- Listening capacity
- Speech understanding
- Memory loss

2. Materials and Methods

The methodology of this research is the identification of the noise pollution problem and its adverse effects on people in the study area. The methodology adopted in this study is shown in Fig. S1. Various noise models are analyzed and reviewed to understand the noise pollution GIS model development using GIS. Secondary data such as population, Passenger Car Units (PCUs) factors are collected from census records. Comprehensive Traffic and Transport survey reports for Chennai city are also collected. Primary data such as type of vehicles, traffic volume, noise levels, spot speeds at the edge, and distances of 5 m, 10 m, and 15 m from the noise source were collected. Traffic volume data was collected using the manual count method at each location. Similarly, speed data was collected using the spot speed method on each intersection and both directions. Noise levels are recorded from 8.00 AM to 9.00 PM. The sound level meter used in this research is shown in Fig. S3, which has an accuracy of ± 2 dB(A). The Noise levels are measured using this sound level meter on Ground Floor and the First Floor to show a variation of Noise levels at different heights. Collected data is analyzed and exported to ArcGIS software for developing a GIS noise model. The procedure for the development of ArcGIS is discussed below. The GIS noise model is developed for horizontal direction from the center of the road and vertical direction from the measurements points. The models depict the zones or areas having hazardous noise levels with a colour scheme.

Spatial data of specific geographic area noise levels are given as input, including the survey point, road line, and other geographic features. The next stage defines the noise calculation methods to include the objects, attributes and limiting values. The noise changes logarithmically with distance. The initial noise generated at the source will be high and will be reduced quadratically as it moves away from the source. There are no standard interpolation techniques for this kind of situation in GIS. So, the noise model was developed using IDW (Inverse Distance Weighted) interpolation technique [27]. TIN is built by joining known points values into a series of triangles based on a Delaunay triangulation. The resulting triangulation satisfies the Delaunay triangles criterion, which ensures that no vertex lies within the interior of any of the circum-circles of the triangles in the network. The advantage of TIN is that it supports variable resolutions: an optimized data representation is possible through TIN even with the variable resolution, i.e., different triangle sizes [28]. In this research, the IDW interpolation method was implemented using the ArcGIS Spatial Extension model.

2.1. Study Area Characteristics

Chennai is selected as the study area, a combination of residential and commercial areas with a heavy volume of traffic and the study area map is shown in Fig. S2. The study area characteristics are also discussed to understand the traffic characteristics that contribute to noise in the city roads. The city of Chennai is situated along the southern coastline of India along the Bay of Bengal and is the capital of the state of Tamil Nadu. Chennai is a major educational, economic, and cultural center as well as the biggest and commercial center in South India. The city boasts a population of 4,681,087 and the population density is 24,682 per km². In 2011, the jurisdiction of the Chennai Corporation area was expanded from 174 to 426 km². In India, automobiles increased from 0.3 million in 1951 to around 160 million in 2012. The country’s total registered motor vehicles have increased by 23.9% at the Compound Annual Growth Rate (CAGR) between 2001 and 2016 [29]. Parry’s Corner, Villivakkam, Perambur, Kolathur, Adyar, Velacheri, Triplicane, T. Nagar, and Nungambakkam are selected for this study. Fig. S2 shows the 9 locations where the noise data were collected to develop the model.

2.2. Primary Data Collection

The observation point should be at a high density close to the object’s source, at a low-density parallel to the track, and farther away. The equivalent amount of noise refers to the sound pressure of the stationary noise source emitting the same acoustic energy as the real non-stationary source [30]. Since noise effects have many spatial components, GIS provides possibilities to optimize the quality of noise effect studies [31]. The outcome of the GIS noise maps helps to optimize the quality of noise in the study area.

The assessment of road traffic noise has two distinct objectives. First, for the individual testing of cars, it is important to assess if their noise is below the legal limit. Second, to study noise pollution from a traffic stream, collect data that can be used for the basic planning of road networks or the evaluation of the redistribution of traffic flow. The first category is not explicitly applicable to the essence of the work performed in this report. Hence surveys were conducted only to analyze the noise from a stream of traffic. A survey relating to the noise intensity and the distance of dispersion was conducted to understand the variation of noise concerning dispersal distance. The noise dispersion with distance is studied for various distances from the carriageway’s edge and different vertical distances. The dispersal is mainly due to the obvious phenomenon of inverse square law that establishes noise reduction with distance.

The sites chosen for this analysis are a mix of heavy traffic from both residential and industrial locations. A total of 9 locations are selected to collect the data, namely Parry’s Corner, Perambur, Villivakkam, Kolathur, Adyar, Velacheri, Triplicane, T. Nagar, and Nungambakkam.
2.3. Traffic Volume and Speed Data Collection
The traffic volume survey was conducted on the nine locations and the data is presented in Fig. 1. The total vehicular volume is directly used and PCU values are not used for model development. The vehicular volume increases gradually from 6:00 AM to 11:00 AM and then decreases until 2:00 PM. In the general evening, the peak recorded more vehicles between 7:00 PM and 8:00 PM. It is seen from Fig. 1 that the traffic volume is minimum (833 Vehicles per hour) in the morning peak hour and a maximum of 1681 vehicles per hour during the evening peak period. Fig. 2 presents the traffic stream speed measured in all 9 locations. The stream speed of 50.3 kmph on the far side and 41 kmph on the near side at 6.00 AM were recorded at Villivakkam. The stream speed decreases till 11:00 AM and then the stream speed increases gradually till 4:00 PM and then the stream speed again decreases. In general, the average speed is between 25 kmph and 30 kmph only. This shows that traffic noise levels are high in the study area.

2.4. Traffic Noise Data Collection
The location of traffic noise measurement is selected by considering Road geometry, Topographical features, the existence of buildings, etc. Measurements are usually carried out to assess the noise output of a highway at a crucial noise-sensitive receptor site or to assess traffic noise at a possible noise-sensitive venue. The noise levels at the edge of the road (i.e., zero distance from the road edge),
5 m, 10 m, and 15 m from the road edge on the ground floor and also on the first floor have been measured using a digital sound level meter between 6.00 AM and 9.00 PM. The sound level meter used in this research is Mastech MS 6700 with a range of 30 to 130 dB(A) and accuracy of ± 2 dB(A) with Resolution: 0.1 dB(A).

In urban areas, the trend is different when the speed is 35 to 40 kmph, the noise level will reduce, but when speed increases 70 to 80 kmph, the noise level will increase. With respect to the collected data, the same trend is observed in this research. Most researchers attempted to study the noise level from the source in the lateral direction only. In this research, the source's vertical and diagonal direction effect depicts that the noise is reducing.

Regarding traffic volume with noise, it is observed that noise correspondingly will also increase when volume increases. However, these increase up to saturation level of traffic volume after reducing the noise level [32]. Further, the volume alone is not a factor, and the type of vehicle also contributes to different noise levels. Particularly the heavy vehicles produce higher noise levels in the study area. In the study area, it is found that the mixed traffic flow condition is prevailing, but during the daytime, the heavy vehicles are less.

Fig. 3 and Fig. 4 present the observed traffic noise level for the ground floor and first floor at Parry’s Corner. It is found that the highest noise level is between 4:00 PM and 6:00 PM at peak evening hours. The noise level rises steadily from 6:00 AM to 10:00 AM and then from 10:00 AM to 11:00 AM to hit the morning high. Further, the noise level decreases from 11:00 AM to 2:00 PM, and from 2:00 PM to 4:00 PM, the noise level rises steadily. As the distance increases from the source of noise, the intensity of noise will reduce, and in the same manner, the same trend is followed in a vertical direction.

The noise levels data collected for all 9 locations on ground floor level and first-floor level are recorded and the same is used for developing a model. Table 1 shows the minimum and maximum noise levels observed in all 9 locations concerning peak hours in the morning and evening. The noise observed changes according to locational characteristics of intersection and types of intersection. The maximum noise level is observed at the T. Nagar intersection, which is due to the four-arm type intersection with the value of 90.5 dB. Mostly, noise levels were recorded maximum during morning 9–10 AM and evening 8–9 PM. Road intersections are very important in noise generators in the study area compared to along the length of the road.

Various statistical models have been implemented on traffic noise modeling for the selected study area [33]. The results obtained

| Sl. No | Location and type of intersection | Morning Peak Hour Noise Measured (am) | Evening Peak Hour Noise Measured |
|-------|----------------------------------|--------------------------------------|----------------------------------|
|       |                                  | Peak h  | Min | Peak h  | Max | Peak h  | Min | Peak h  | Max |
| 1     | Parry’s Corner (T-Junction)      | 7–8     | 63.9 | 8–9     | 86.8 | 5–6     | 74.45 | 8–9     | 89.8 |
| 2     | Perambur (T-Junction)            | 6–7     | 68.1 | 9–10    | 83.9 | 4–5     | 79.30 | 7–8     | 88.5 |
| 3     | Villivakkam (T-Junction)         | 7–8     | 68.5 | 8–9     | 86.8 | 5–6     | 74.45 | 8–9     | 89.8 |
| 4     | Kolathur (T-Junction)            | 6–7     | 69.5 | 8–9     | 86.6 | 4–5     | 77.7  | 8–9     | 88.8 |
| 5     | Adyar (T-Junction)               | 6–7     | 69.1 | 9–10    | 84.9 | 4–5     | 78.4  | 8–9     | 88.2 |
| 6     | Velachery (Y-Junction)           | 6–7     | 68.5 | 8–9     | 85.6 | 4–5     | 78.7  | 7–8     | 88.7 |
| 7     | Triplicane (T-Junction)          | 6–7     | 69.1 | 9–10    | 80.1 | 4–5     | 79.9  | 8–9     | 89.5 |
| 8     | T. Nagar (Cross Junction)        | 6–7     | 68.1 | 9–10    | 83.9 | 4–5     | 79.3  | 8–9     | 90.5 |
| 9     | Nungambakkam (Y-Junction)        | 6–7     | 68.5 | 9–10    | 83.9 | 4–5     | 79.8  | 7–8     | 88.2 |
from these studies showed the correlation between road traffic noise and its effects on people. However, these models fail to show the visual impact that traffic noise can have on the area surrounding the road as well as the effects that are felt in different heights and distances from the road.

2.5. Development of GIS to Earmark the Extend Area Affected During Peak Hour

The GIS noise model was developed using ArcGIS version 10.3 as described in the materials and methods section, based on noise measurements at each intersection for the study area and traffic characteristics (traffic flow and volume). In comparison to other models that were discussed earlier in the previous studies, the proposed model is better because it can visualize the implications of road traffic with the GIS noise model developed here, and the extent to which people and the surrounding area will be affected can also be tabulated using this model. The predicted noise values for all 9 locations are considered for preparing the noise prediction model for Chennai city. Fig. 5-6 and S4 show the noise maps developed for morning and evening peak hours at intersections. Table 2 presents the details of the areas affected due to traffic noise generated.

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Fig. 5. GIS noise level map for Villivakkam intersection; (a) Morning peak, (b) Evening peak.

Fig. 6. GIS noise level map for Perambur intersection; (a) Morning peak, (b) Evening peak.
From Fig. 5, 6 and S4, intersections are the main source of noise in the city compared to the roads. The noise affected area again depends on the intensity of traffic congestion developed at each intersection. The extent of noise affected by the source can be easily observed from these analyses and noise maps. The pavements are bitumen types in the study area, and the study locations are within the urban area. Hence the effect of noise on the type of pavement is not considered in this study.

3. Results and Discussions

From Table 2, it can be understood that the Perambur intersection causes the highest noise in the total affected area (3.8 km²). Another issue in this area is the Integral Coach Factory (ICF) which produces rail coaches. Hence, the noise level at this intersection is influenced by the local characteristics of the location. T. Nagar location is the next highest affected area due to traffic noise as this is a four-arm intersection. Further, many commercial activities are taking place in this area. Villivakkam is the least affected area due to noise pollution since this is, mainly, a residential area. Further from Table 2, it is possible to understand that in more than 50% of the study area, the noise level is less than 40 dB. Around 18% have a severe noise problem in the study area. Hence, an urgent measure is required to reduce the noise level in the study area due to road traffic.

The GIS-based noise map is a method for the accurate presentation of the situation in noise pollution. It is a tool that makes it possible to take the required decisions to reduce noise-related risks. The use of GIS tools makes it possible to collect information on a specific geographical region. GIS noise maps present the noise levels in all areas, other than data collected locations is possible. The average noise levels in the residential areas of Nigerian cities exceeds allowable limits [34]. Noise maps show that the noise is very high, and there are places where the levels are more than 75 dB. As a result of the studies, there is an increasing knowledge of the adverse effects of noise on human health. This leads to a serious approach to the problem of sound emissions caused by surface transport. Noise maps are generated using ArcGIS version 10.3 during morning (8–9 AM, 9–10 AM) peak hours and evening (5–6 PM, 6–7 PM) peak hours for the selected 9 locations. The impact investigation based on this GIS noise mapping shows that road vehicles create a high traffic noise impact in Chennai. It is evident from the study results that Chennai City is affected by significant noise pollution due to vehicle traffic. The GIS model’s validation for noise pollution study areas was performed using the direct comparison method. The noise level at the intermediate location and latitudes were observed and compared. The model results are found to vary 7% to 10% noise level compared to GIS noise model results.

According to the 2011 census, there are 11 lakh households in the city and a population density of 22,556 per km² in the study area. The city of Chennai covers 426 km² with a total population of 70.9 lakh inhabitants. Table 2 indicates the population exposed/affected by traffic noise at each site. Totally 4.5 lakh people are vulnerable to noise issues and 83 thousand people are severely affected (the noise level is above 60 dB). It is concluded that around 63% of people are affected by traffic noise. There is also an immediate need to reduce the noise in the areas that are the worst hit.

4. Conclusions

The main contributors of traffic noise are vehicle condition, road condition, the volume of traffic, speed, and intersection traffic handling capacity. Traffic noise measurements were carried out to estimate the extent of noise due to traffic in latitude and longitude. The results obtained in this study show that the city is suffering from severe noise pollution due to vehicular traffic. This is mainly attributed to congested traffic areas, unplanned road networks, reduced one-way traffic, construction of silence zone in the main area of the city, unplanned urban sprawl etc. Noise pollution adversely affects human health as the noise levels increase, so does

| Sl. No | Location and type of intersection | Area Affected due to noise pollution (km²) | Population Affected |
|-------|----------------------------------|------------------------------------------|---------------------|
| 1     | Parry’s Corner                   | 0.15 0.05 0.15 0.68 1.03                 | 27,349              |
| 2     | Perambur                         | 0.50 0.25 0.42 2.63 3.80                 | 100,901             |
| 3     | Villivakkam                      | 0.20 0.03 0.25 0.51                      | 13,542              |
| 4     | Kolathur                         | 0.21 0.08 0.46 0.03 0.78                 | 20,711              |
| 5     | Adyar                            | 0.20 0.11 0.12 2.18 2.61                 | 69,303              |
| 6     | Velachery                        | 0.13 0.13 0.37 1.06 1.69                 | 44,874              |
| 7     | Triplicane                       | 0.63 0.23 0.54 0.89 2.29                 | 60,806              |
| 8     | T. Nagar                         | 0.88 0.34 0.78 0.66 2.66                 | 70,630              |
| 9     | Nungambakkam                     | 0.24 0.34 0.22 0.87 1.67                 | 44,343              |
| Total Area Affected               | 3.14 1.56 3.09 9.25 17.04               | 452,463             |
| Total Area Affected (%)           | 18.42 9.15 18.15 54.28 100.00           | -                   |
| Population Affected               | 83,376 41,422 82,048 245,615 452,463     | -                   |
the impact of noise on the human body. With the noise levels observed to be greater than 90 dB, noise pollution is a great detriment to the people living in the city. Noise level is inversely proportional to height and distance (i.e.) the noise level on the first floor is lower than the ground floor of buildings. Noise levels also decrease as the distance from the road increases. These levels of noise are more than the established limits. An area of 100 metres radius around courts, educational institutions, hospitals, religious centres, or similar locations is declared silence zones by the pertinent authority (The Noise Pollution Regulation and Control Rules, 2000). The study shows that the city’s silent zones, including educational institutions, nursing homes, and hospitals, are under the immense influence of noise due to traffic.

The noise evaluation on the city of Chennai suggests a rise in the city's noise levels at a very rapid pace with an increase in population and a strong build-up of traffic. The proximity of intersections, the scarcity of arterial roads, and the lack of overpasses and bridges in certain city areas are responsible for the immense collection of vehicles resulting in a crowded and noisy environment. Therefore, it is felt that the noise environment in Chennai City could pose a significant threat to people's health. The noise map provides architects, developers, and others with the details to prepare and carry out their projects. Spatial maps are important to traffic engineers and urban planners for land pricing, land use, traffic control, and zoning. It is also proposed that an online and real-time noise-based information system be built and introduced along with multiple variables such as rainfall, ambient temperature, humidity, etc.

The noise level in the city's industrial areas approached 80 to 90 dB (A), while in the suburban areas, the mean noise level was 65 to 75 dB (A). In silence zones, the noise level was 65 to 75 dB (A). People live in all three different zones and the adverse effects of noise pollution affect society to a large extent. Hence, the following measures may be adopted to reduce the noise level.

- Providing more public transportation systems to replace private cars and encourage using them.
- They were implementing traffic management rules and regulations very effectively and efficiently. During non-peak hours speed violations need to be monitored and controlled. Authorities have recently installed video cameras to monitor traffic violations in a few study area locations, which should be expanded throughout the city to prevent accidents and noise pollution.
- Planting Trees might absorb noise to a great extent.
- Banning air horns at sensitive places like hospitals and schools and its uncompromising implementation might help reduction in the noise levels.
- Proper pavement maintenance and management system to have smooth riding. The bitumen pavement surface has potholes; hence, it is suggested to have the pavement condition checked every six months and service it.
- Noise Barriers may be provided at the intersections.

**Author Contributions**

P.P. (Professor) contributed to problem identification, data analysis, manuscript preparation. K.K. (Professor) involved in literature collection, data collection, manuscript preparation. P.N.E. (B. Tech Student) contributed to data collection, data analysis, model development, interpretation of results. K.S. (Professor) contributed to data analysis, manuscript preparation. B.A. (Professor) Involved in problem identification, data collection, model development.

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