Measurement, Modeling and Mitigation of Arterial Traffic Noise in a Medium-Size Urban Area

By

Bapatla P. Chandrasekhar*
P.A. Koushki**
Mohammed Ahmed Ali**
CSRK Prasad*

* Department of Civil Engineering
Regional Engineering College
Warangal, A.P., India
Fax: +91-8712-576 547
e-mail: **bpc@recw.ernet.in**

** Department of Civil Engineering
Kuwait University
P.O. Box 5969 SAFAT
13060 KUAWAIT
+965-481-7524
e-mail: **maali@civil.kuniv.edu.kw**

Paper No. 02-2048
Transportation Research Board
Annual Meeting , Washington DC
January 13-17, 2002

Total Number of Words (Including Tables) 7188

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B.P. Chandrasekhar, P.A. Koushki, M.A. Ali & CSRK Prasad

Abstract

Traffic noise has only recently been recognized as a problem in urban areas in India. The pollution Control Boards (PCB) are now considering the noise from traffic as a constituent of urban traffic pollution. A search of the literature indicates that pilot studies of traffic noise have, so far been conducted in few metropolitan areas, and no attempt has been made to address this problem in medium-size cities. Indications are that noise from the traffic is as intense and wide-spread in medium-size cities as in a metropolitan area. This research paper reports the findings of a study undertaken to investigate the characteristics of traffic noise in Warangal, a medium-size urban area in Andhrapradesh, India. Thirteen representative arterial roadway and four intersection locations were monitored for traffic flow variables and noise pollution levels simultaneously during both peak and off-peak periods. Noise was measured at 1,3 and 5-meter distances from the pavement edge. The mean L_{eq}'s ranged from a low of 72.3 (dBA), in off peak periods, to a high of 84.5 (dBA), during the peak periods. The interrelationship between traffic flow and the generated noise were also examined. A multiple linear regression has rather successfully modeled traffic noise as a function of distance and flow variables. The paper also outlines the mitigation and abatement options for urban traffic noise.

1. INTRODUCTION

Similar to the worldwide trend, the last few decades of the twentieth century have witnessed rapid urbanization in India. A large number of small towns have grown to become major cities in a very short period of time. This rapid urbanization process has brought in its wake, the usual problems of insufficient housing and transport infrastructure. The rising population and the increasing distances between places of residence and work have resulted in a growing demand for transportation. Lack of sufficient and attractive public transport systems, and increases in personal incomes have resulted in a rapid increase in the number of private autos and two wheelers, creating congestion, and air and noise pollutions. Although the problem of air pollution has rather been taken seriously by the policy planners in India, the growing problem of urban noise however has remained ignored until recently. The Noise Pollution (Regulation and Control Amendment) Rules 2000 (1) is an important step in the recognition of traffic noise as a major environmental problem in urban areas.

Road Traffic noise has been a subject of extensive research in many industrialized and non-industrialized countries over the least few decades (2,3,4, 5,6,7,8,9,10). Very few studies of traffic noise however, have been conducted in Indian cities. Rao (11) and Chakraborty (12) studied traffic noise in Vishakhapatnam and Calcutta respectively. Kumar & Jain (13) studied noise in different types of vehicles in Delhi. These studies all have indicated that noise from traffic in these urban areas were high and significantly above the standard outdoor limits.

This paper reports the findings of a research study aimed at: a)determination of traffic-generated noise level; b) examination of the relationship between traffic flow variables and generated noise, and c) development of a simple yet structured, model to estimate traffic noise for short-term decision policies. An implicit aim of the study was the determination of exposure level of individuals working/residing alongside the roadways, as well as the pedestrians and vendors who heavily utilize the sidewalks in the commercial districts of the city.

THE STUDY AREA

Warangal is an ancient town in the Telangana region of the southern State of Andhra pradesh in India. The city has witnessed rapid growth in the last decade (1991-2001). The population has increased from about 467 thousand to about 650 thousand (estimated) in 2001. The length of the roadway network of this city is 102 km. Warangal is house to many leading educational institutions of the State. It is the administrative capital of Warangal District and a center for business and trade for people living in many surrounding towns and villages in the region. Two major arterial roadways criss cross the city: The Hyderabad-Vijaywada road and the Karimnagar-Khamman road. Buildings are located within 5-7 m from the roadway edge and most of the urban commercial activities are located along these two major arterials. The roadway geometrics consist of 2 lanes in each direction, with the lane width of 3.5m. A median of 0.3m segregates the traffic. The land-use, and traffic flow characteristics of the study roadway locations are presented in Table 1.

DATA AND METHOD

Thirteen mid block sections and four major intersections covering the entire commercial district of the city were selected for monitoring noise and traffic flow. The study locations are shown in Figure 1b. Noise was measured at 1, 3 and 5-meter distances from the edge of the roadway. The measurement distances were chosen for the following reasons: a) the width of the sidewalk is generally five meters and occasionally seven meters; b) most sidewalks experience heavy volumes of pedestrians throughout the day and c) large number of vendors utilize the sidewalk for presentation of their goods.

The sound level measurements were carried out using 'Mediator 2238', an Integrating Sound Level Meter (SLM) from Bruel & Kjaer, Denmark. The sound level meter conforms to IEC 651 and IEC 804 type 1 standards. It also conforms to the forthcoming IEC 1672 class I standard. A polarized ½" condenser microphone type 4188 was used with this SLM. Traffic noise was measured in Fast(F) time weighting with 'A' frequency weighting. The sound level meter was calibrated with type 4231 at 94 dB and 114 dB. The AASHTO T-262 (14) procedure was followed in setting up the instrument.

The Equivalent sound level L_{eq} and the Traffic Noise Index TNI were calculated using the following equations

$$Leq = 10\log_{10}\left(\frac{1}{T}\int_0^t 10^{\frac{L}{10}}dt\right) \quad (1)$$

$$TNI = 4(L_{10} - L_{90}) + L_{90} - 30 \quad (2)$$

where,

T is the monitoring time period,

L is the instantaneous sound level,

L_{10} and L_{90} are noise levels exceeded 10% and 90% of the measurement time respectively, and

In addition, the L_{min}, L_{max} and the 50 percentile noise level (L_{50}), were also recorded for each monitoring period. Noise was measured for 30-minutes during both the peak and off-peak periods and repeated three times at each study location. Information on traffic volume and mix was also collected simultaneously with the measurement of noise. Traffic volume and mix were monitored manually, employing senior undergraduate students of the Regional Engineering College (REC), Warangal, using REC Traffic volume forms. Data was processed using SPSS ver10.0 in the Computer Center of Kuwait University.

FINDINGS

The all-location summary profile of the measured noise levels is shown in Table 2. For the mid-block locations, the mean equivalent noise level ranged from a low of 73.8 (dBA), to a high of 84.5 (dBA), for a total sample mean of 78.9 (dBA). The L_{10}, emphasizing the impulsive noise (sound of horns, loud motor bikes etc.) varied between 74.5 and 82.5 (dBA), with a mean of 79.4 (dBA). The mean of the maximum noise levels at mid-block locations was nearly 100 (dBA). The mean noise levels at the receiver distance are given in Table 3. Almost all the noise indicators were observed to be decreasing with increasing distance from the roadway edge.

At the study intersections, the traffic noise levels, and thereby, the noise percentiles were significantly above those of the mid-block sections, where the traffic flow is rather uniform and smooth. The start/stop and the sound of horns at the on-set of the green phases were the main contributors to the higher noise levels measured at the study intersections. The maximum noise levels reached painful levels (e.g. 116 dBA).

The measured noise levels and percentiles as well as the computed TNI by monitoring location are presented in Table 4. Major findings concerning the data in Table 4, include: a) the L_{eq}'s are all above the 75 dBA standard commercial noise limit at the mid-block locations, and very significantly higher at the intersections; b) the TNI vary from a low of 76 (dBA), to a high of 102 (dBA), clearly pointing to the noisiness of urban roadways in Warangal. A comparison of the TNI and the L_{eq} noise levels indicates that the TNI values are mostly larger than the L_{eq} levels. This reflects the fact that although the noise levels during the peak hours were generally constant (and high), the intruding single-event noises were sufficiently frequent to affect the value of L_{10}, and consequently, the TNI. The frequent misuse of the horns, improper acceleration/deceleration of vehicles (especially of 3-wheelers), are the reasons for the high TNIs at the study roadways.

The frequency distribution of the equivalent noise level, L_{eq}, and the percentile values for the mid-block measurements are presented in Table 5. The data clearly point to the continuos noisiness of urban roadways in Warangal. The L_{eq} distribution for example, indicate that in only 7.8% of the monitoring time, the noise at the study arterials was at the standard outdoor limit of 75 (dBA). In more than one half of the measurement time, the traffic noise was louder than 80 (dBA). The L_{10}, emphasizing the impulsive, and single-event noises was higher than 80 (dBA), for nearly 80 percent of measurement time.

A major negative characteristic of noise in Indian cities is not only, its unacceptable loudness, but also its uniformity and continuity throughout the day and evening hours. As presented in Figure 2, the difference in the percentage of peak and off-peak times that the traffic noise level exceeded the 75 (dBA) limit was only an insignificant 7 percent. At intersections, the measured L_{eq} and the L_{10} noise levels were both above 80 (dBA) consistently, and the difference between these two indicators of noise has nearly faded away (Figure 3).

The cumulative distribution of roadway noise levels by distance indicated that during 50 percent of the monitoring time, the L_{eq} was higher than 75 (dBA), at 1-meter from the roadway edge (Figure 4). Those at 3- and 5-meters exceed the 75(dBA) level in 40 and 32 percent of the time, respectively. In other words, even people working in their shops are exposed to noise levels above those of the standard limits, for nearly a third of the peak period duration. Unfortunately these individuals do not get any relief from noise pollution during the rest of the working day, neither, as indicated by the data in Figure 2.

The physical and geometrical limitations of the study arterials did not allow noise measurement at distances greater than 5 meters from the traffic noise sources at most locations. However , the decreasing level of noise with increasing distances from the source, may also be observed from the data in Figure 4. For example, considering the 50 percentile limit, the measured noise levels at 1,3 and 5m distances, were 73, 74, and 75 (dBA), respectively.

A PRACTICAL PREDICTIVE MODEL

Although the use and the spread of communication technology is gaining momentum in non-industrialized countries, the availability of practical, uncomplicated, and easy-to-implement methods for the prediction of traffic noise is of great desire by the local policy makers in India. The implementation of the current noise prediction models such as the FHWA's Traffic Noise Model (TNM), in a medium-size city in India still faces numerous technology, training, know-how and budgetary difficulties at the present time, and in foreseeable future. For example, the utilization of the TNM, requires as a pre-requisite, the development of Reference Energy Mean Noise Emission level for vehicles (small, medium, and large) in Indian cities. Development of REMLs require additional funds, skilled manpower, and the equipment – none of which may readily become available to the already overburdened local agencies in Indian cities. Herein, an attempt is made to model traffic noise as a function of traffic flow variables and distance from the noise source, providing a simplistic tool to the local policy makers.

A correlation analysis was first performed on the data. Results indicated that with the exception of the slow and rather uniform traffic speed throughout the monitoring peak and off-peak hours, the remaining flow variables (volume by type), and receiver distance, demonstrated strong and appropriate degree of association with both the L_{eq} and the L_{10} noise levels. As presented in Table 6, both, the L_{eq} and the L_{10}, were strongly and negatively correlated with the distance from the noise source (as expected), and correlated strongly and positively, with the volume of trucks and buses, and to a lesser extent, with the volume of 2 and 3 wheelers. With the exception of the correlation coefficient between the traffic noise and the volume of 2 and 3 wheelers (significant at 95% significance level), all other correlation coefficients were significant at the 99% level.

A number of linear, log transformation, and non-linear multiple regression models were calibrated using the developed data base. In all these models, the dependent variable (L_{eq}/L_{10}), was a function of receiver distance (D) and heavy vehicle volume (VHV), and the volume of 2-3 wheelers (VTW). Due to the problem of multi-collinearity, the *total volume* was not included as an independent variable in the models.

The following best two multiple regression models which explained 51.5 and 46.3 percent of variations in the L_{10} and the L_{eq} noise levels respectively - were selected and recommended as a preliminary tool for the prediction of traffic noise in Warangal:

$$L_{10} = \underset{(t=190.4,\ p<0.001)}{79.101} - \underset{(t=-7.41,\ p<0.001)}{1.458 * Log_{10}(D)} + \underset{(t=3.5,\ p<0.001)}{0.0517 * (VHV)} + \underset{(t=1.98,\ p<0.05)}{0.0517 * (VTW)}$$

(Model F=25.792 , $p<0.001$, R=0.715, R^2=51.1%)

$$L_{eq} = \underset{(t=151.5.4,\ p<0.001)}{77.796} - \underset{(t=-5.263,\ p<0.001)}{1.54 * Log_{10}(D)} + \underset{(t=3.97,\ p<0.001)}{0.08 * (VHV)}$$

(Model F=21.383 , $p<0.001$, R=0.603 , R^2=46.3%)

Where,

D = Receiver Distance in m
VHV =Hourly Volume of Heavy vehicles
VTV =Hourly Volume of 2- and 3- wheeled vehicles.

MODEL VALIDATION

In order to quantify the predictive ability of the calibrated multiple regression models, the flow variables (volume of heavy vehicles and 2-3 wheelers), and noise levels (at 5-m distance from the roadway edge) were simultaneously monitored at the arterial roadway locations during three peak periods. The collected values of the traffic flow and noise (L_{eq} and L_{10}) variables were then inputted into the respective model for validation. The model-predicted results and the actual measurement of the L_{eq} and the L_{10} are presented Figure 6. The Pearson correlation coefficients between the predicted and measured L_{10} noise levels was a strong $r_{xy}=0.715$ ($p<0.001$), that for the L_{eq}'s was $r_{xy}=0.603$ ($p<0.001$). Both values are significant at 99% level of significance. The accuracy of the developed model, as a preliminary investigative tool for estimating noise pollution level in a medium size city in India, was therefore judged reasonable. The models, however do not possess enough precision for estimating traffic-generated noise levels for noise-sensitive land-use development decisions.

MITIGATION POLICIES

Through their pioneering of technological development and use, the industrialized nations had provided two outstanding opportunities to the non– industrialized world: the *preventive* opportunity, and the *option* opportunity. The *preventive* opportunity was the chance to learn from the mistakes and inappropriate policies which have resulted in the deterioration of the urban environment in the industrialized world. More than three decades ago, unplanned/uncontrolled urban expansion, added to the extreme favoring of the private car as the dominate mode of urban travel, and neglect of non–motorized and group transport modes began to take their toll on air and noise quality, monetary and human losses in road traffic accidents, and daily traffic congestion and delays in urban areas.

Most unfortunately, the occurrence of similar, and worse, adverse urban environmental impacts in practically every urban area of the non-industrialized nations (e.g. Warangal) clearly indicate the valuable benefits of the *preventive* opportunity, have been lost. In spite of several decades of advance warnings, similar/worse mistakes have and are being repeated by the responsible policy–makers in the non- industrialized world.

Having lost the *preventive* opportunity, responsible urban policy–makers in India should at least take advantage of the *option* opportunity – the chance to choose from among a large set of already tested and evaluated alternative mitigation options, those that are best suited to the socio-economic, political and cultural environment of the region. A thorough search for the selection of the best working option, requires only a minimum of resource expenditures.

Several universally – applicable mitigation measures are available for the control of adverse impacts of traffic noise pollution on the urban environment. These mitigation measures complement one – another due to the fact that policies such as land–use control (zoning), supply and demand management of traffic, promotion of non–motorized and group transport that is directed to control, and/or reduce the negative impact of one type of urban pollution (e.g. noise) also minimizes the adverse effects of the other (i.e. air).

Mitigation measures may be grouped into the following categories:

a. Source emission control
b. Land–use control (zoning)
c. Demand and supply management of traffic

d. Promotion of transit and non-motorized modes
e. Public education and awareness programs

Each of these mitigation measure is discussed in the following paragraphs.

Source Emission Control

Source emission control requires the development of vehicles that are quieter. Significant progress has already been made by vehicle manufactures over the last two decades to reduce both vehicle noise and air pollution emissions, and continues to be made. The role of governments has been to establish and enforce environmental pollution standards. However, the establishment of pollution standards is useful if, and only if, these standards are implemented and enforced. The inspection of vehicles for emission levels annually would ensure compliance with criteria designed to maintain the standard limits of air and noise pollutions.

In general, the enormity of traffic related environmental problems defies these mere technical fixes for noise and air pollution emission reduction. Because, as addiction to autos continues in India and, worldwide, advances in fuel, economy and emissions reduction will be off-set by increased emissions due to increased driving, as experience in the industrialized nations has shown.

Land – use Control

This measure works best when urban land is yet to be developed. The primary aim of this measure is to establish (and enforce) regulation on the type of land development (zoning), so that pollution–sensitive land–uses are either prohibited in the proximity of roadways, or land developments are planned, designed, and constructed in such a way that traffic–generated pollution impacts are minimized. this control measure has potential applicability to future land–use developments in the expanding parts of the existing urban/metropolitan areas in India.

Demand and Supply Management of Traffic

Mitigation measures in the category are the most cost effective ways to minimize existing levels of environmental pollution in urban areas. They require a minimum of resources (very low cost), are mostly policy–oriented (minimum facility construction or none at all), and require a minimum of time for implementation.

One such example, is the alternate use of private autos based on odd/even license plate numbers (a demand management measure). The implementation of this measure requires only a short period of advance public warning (a month) and a minimum level of preparations of dealing with potential violators as well as establishing the means for effective enforcement of the policy. Other demand management tools include the promotion of non–motorized (walking and bicycling) modes of travel, and the promotion of public transit systems.

On the supply side are transport systems management tools, such as the spatial and temporal prohibition of trucks. Traffic signal timing evaluation and coordination could be implemented to minimize congestion, and delay (and consequently reduce air pollution) and analysis of one–way/two-way operations would lessen left–turning interruptions. The prohibition of on–street parking represents a supply side tactic which could ensure smoother traffic flow. Priority mechanisms could be established for service – operation improvement of non-motorized and public transit systems.

Promotion of Transit and Non–Motorized Modes

With traffic congestion and air and noise pollution plaguing every major city in the world – industrialized and non-industrialized alike, the alluring qualities of auto travel especially during the daily peak hours are now distant memories.

A new and more rational urban transport plan which emphasizes walking, biking, buses, trams and trains as the centerpieces of transport systems is now needed for medium urban areas of India before they become unmanageable. The non-motorized modes of travel in particular provide for a considerable share of urban travel in India cities. The city authorities must however cater to the basic and simple safety and level of services needs of pedestrians and cyclists.

Public Education and Awareness Programs

In India and other non–industrialized nations, the level of public education and awareness concerning the harmful impacts of massive use of autos on the urban environment is generally low, inadequate, disjointed, and low profile public education campaigns contribute to this deficiency. Comprehensive, continuous, and coordinated educational programs (supplemented by rigorous enforcement of rules and regulations) are needed instead. Such programs must promote:

a) Family–level planning to minimize daily household trip generation,
b) Ride-sharing and car-pools among family members, neighbors, and work-partners,
c) The use of transit and paratransit systems,
d) Appropriate driver behavior, and
e) A better understanding of the adverse productivity, health, and environmental impacts of traffic-generated air and noise pollutions.

CONCLUSIONS

Unprecedented growth in population and urbanization, massive increase in the fleets of private cars, favoring of the auto mode of urban travel, piece-meal and disjointed urban land–use/transport policies, and very low levels of public awareness concerning the harmful impacts of traffic–generated noise pollution, have all combined to deteriorate the living/working environment in most urban and metropolitan areas in India.

This paper reports the findings of a research study aimed at developing a profile of traffic–generated noise level in a medium-size urban area in India. The findings have highlighted the noisiness of the roadway network in the study area. The measured noise levels at the number of arterial roadway locations have indicated that noise from traffic was significantly and constantly above the standard outdoor limit of 75 (dBA) at commercial areas. The studied urban intersections were particularly noisy. In Warangal, only in less than 10% of the monitoring time, the noise pollution level was at or below the recommended outdoor standard level of 75 dBA.

While pointing at the loss of the *preventive* opportunity - i.e., avoiding the mistakes of major urban areas in the industrialized nation, the paper has also identified five groups of mitigation measure from among *option* opportunities, with proven record of effectiveness in cities of these nations. Timely and gradual implementation (based on the priority and availability of resources) of these measures is essential for the creation of sustainable urban transport system and a healthy urban environment

ACKNOWLEDGEMENTS

The authors acknowledge the support provided by Regional Engineering College, Warangal and Kuwait University, Kuwait. Thanks are also due to the senior under-graduate students of Regional Engineering College (REC), Warangal for carrying out the field survey. The insightful comments of the distinguished reviewers of the paper are also greatly acknowledged.

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LIST OF TABLES AND FIGURES

TABLE 1 Land-Use and Traffic Characteristics of Study Arterials

Site No.	Location Name	Land-use Type	Mean Values	
			Peak Hour Vol. (vph)*	Peak Hour Speed (km/hr)
	Mid Block Sections			
1.	Collector Street	Governmental	3043	30
2.	Ambedkar Statue	High density/commercial	2762	25
3.	S.P. Office (Karimnager Road)	Governmental/low density commercial	2581	41
4.	College of Education	Educational	3925	30
5.	Alankar Center	High density/commercial	3753	25
6.	Govt. Polytechnic	Educational	4690	26
7.	Municipal Corporation Warangal (MCW)	Governmental/medium density commercial	4325	20
8.	JPN Road	High density commercial	2041	25
9.	Khammam Road	Commercial/residential	1335	45
10.	Head Post Office	Medium density commercial	2681	27
11.	Metwada Police Station	Commercial/residential	1397	40
12.	State Bank of Hyderebad (REC)	Educational/residential	2039	32
13.	Regional Engineering College, Warangal Main Gate	Educational/residential	2057	34
	Intersections			
14.	MGM Hospital	High density commercial		
15.	Mulugu Intersection	High density commercial		
16.	Hanamkonda Chowrasta	High density commercial		
17.	Warangal Chowrasta	High density commercial		

* Total Volume in both directions, does not include non-motorized vehicles

TABLE 2 All-Locations Summary Noise Profile

	Mid-Block Noise (dBA)				Intersection Noise (dBA)			
Noise Level/ Percentile	Mean	Std.dev	Min.	Max.	Mean	Std.dev	Min.	Max.
L_{eq}	78.0	2.14	72.3	84.5	85.7	3.81	82.4	89.5
L_{10}	79.4	1.63	74.5	82.5	86.8	2.18	85.5	90.0
L_{50}	73.9	1.57	68.0	77.0	80.1	1.03	79.0	81.5
L_{90}	69.2	2.01	61.5	73.5	75.5	0.41	75.0	76.0
L_{min}	63.3	2.78	55.0	68.1	70.3	2.42	67.8	72.4
L_{max}	99.5	4.29	89.4	109.4	106.1	9.13	98.3	116.0

TABLE 3 Mid-Block Mean Noise Levels by Receiver Distance

Noise Level/ Percentile	Distance					
	1m		3m		5m	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
L_{eq}	79.4	2.014	77.6	1.514	76.9	2.138
L_{10}	80.7	0.981	79.2	0.977	78.4	1.829
L_{50}	75.0	1.095	73.8	1.123	72.9	1.628
L_{90}	70.1	1.657	69.0	1.879	68.6	2.236
L_{min}	64.1	2.861	63.1	2.14	62.5	3.092
L_{max}	100.9	4.382	99.2	3.721	98.4	4.509

TABLE 4 Mean Noise Levels, Percentiles and Indicators at the Study Locations

Study Location	Mean Noise Levels and Percentiles (dBA)						
	L_{min}	L_{90}	L_{50}	L_{eq}	L_{10}	L_{max}	TNI
Mid Blocks:							
1	62.2	68.8	74.2	**78.1**	79.3	99.4	80.8
2	60.4	66.8	72.3	**75.6**	77.9	94.8	81.2
3	64.4	69.6	74.0	**78.2**	80.1	100.8	81.6
4	63.5	70.6	74.8	**79.1**	80.0	100.3	78.2
5	64.6	70.1	74.3	**77.1**	78.8	97.7	74.9
6	66.6	71.5	75.7	**78.5**	80.9	96.3	79.1
7	64.9	70.5	74.6	**79.3**	79.8	100.9	77.7
8	64.7	70.5	74.8	**79.5**	80.2	101.2	79.3
9	62.4	68.8	73.3	**79.4**	79.4	102.7	81.2
10	66.3	71.1	74.9	**77.8**	79.8	99.5	75.9
11	62.4	68.0	72.4	**75.4**	77.5	100.0	76.0
12	58.9	65.9	72.4	**77.3**	78.9	100.4	87.9
13	61.1	67.8	73.2	**78.5**	79.7	99.6	85.4
Intersections:							
14	67.8	76.0	81.5	**89.5**	90.0	111.6	102.0
15	72.4	75.5	80	**82.4**	85.5	98.3	85.5
16	72.4	75.5	80.0	**82.4**	85.5	98.3	85.5
17	68.7	75.0	79.0	**88.4**	86.0	116.0	89.0

TABLE 5 Frequency Distribution of Measured Noise Level Indicators at Mid-Block Locations

Noise Level Indicator	Percent	Cumulative Percent
L_{eq}		
73-75.9	7.8	7.8
76-78.9	41.5	49.3
79-81.0	46.8	96.1
>81.0	3.9	100
L_{10}		
73-75.9	1.2	1.2
76-78.9	19.2	20.4
79-81.0	69.3	89.7
>81.0	10.3	100
L_{50}		
<68	1.3	1.3
68-70.9	2.6	3.8
71-73.9	51.3	55.1
74-77.0	39.7	94.9
>77.0	5.1	100
L_{90}		
<64	1.3	1.3
64-66.9	11.5	22.8
67-69.9	57.7	70.5
70-74.0	28.5	98.2
>74.0	1.3	100

TABLE 6 Correlation Coefficients Between Noise, Flow Variables and Distance

Noise Variable	Receiver Distance	Volume (vph)			
		Trucks	Buses	2-3 Wheelers	Total
Leq	-0.467	0.411	0.362	0.158	0.192
L_{10}	-0.583	0.425	0.315	0.266	0.272

FIGURE 1a Location of the Case Study Area

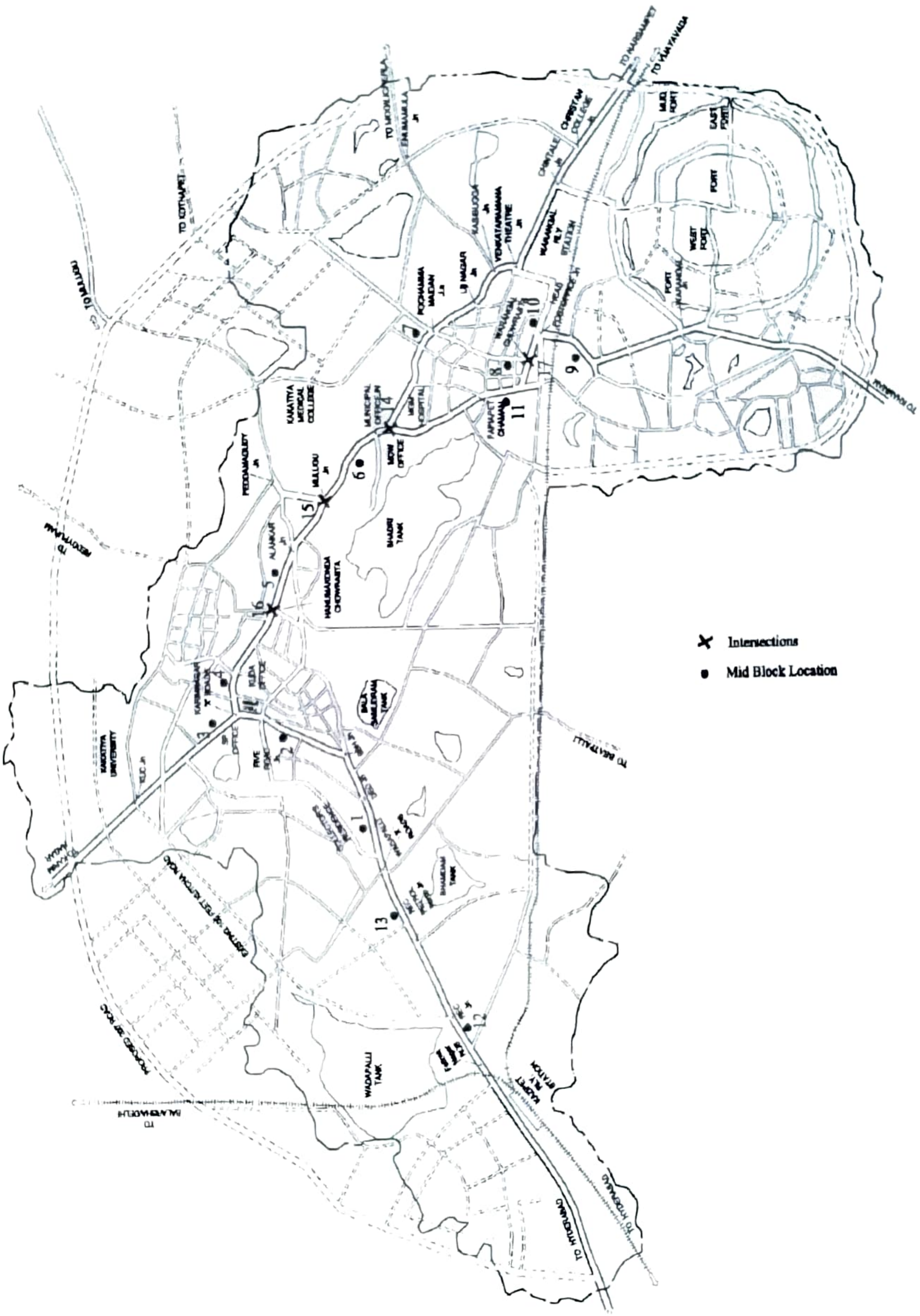


FIGURE 1b Study Locations

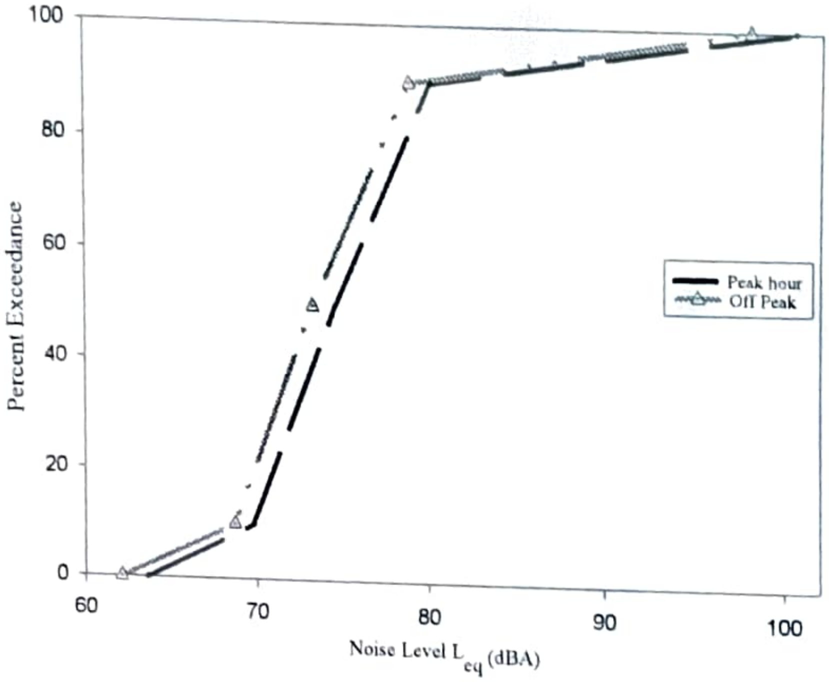


FIGURE 2 Cumulative Distribution of Noise Levels for the peak and off-peak periods

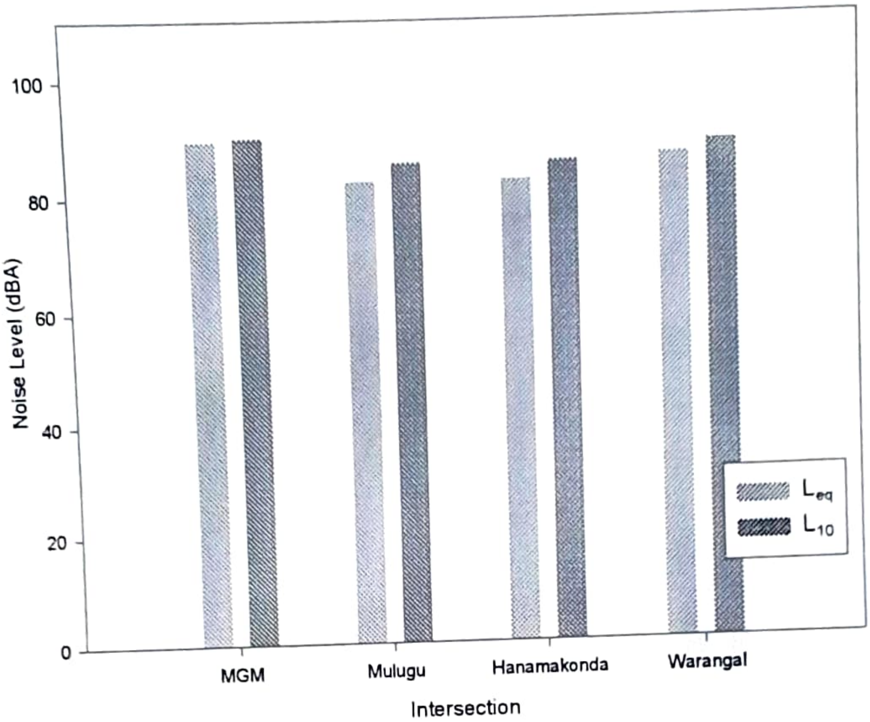


FIGURE 3 Mean Noise Levels at Intersections

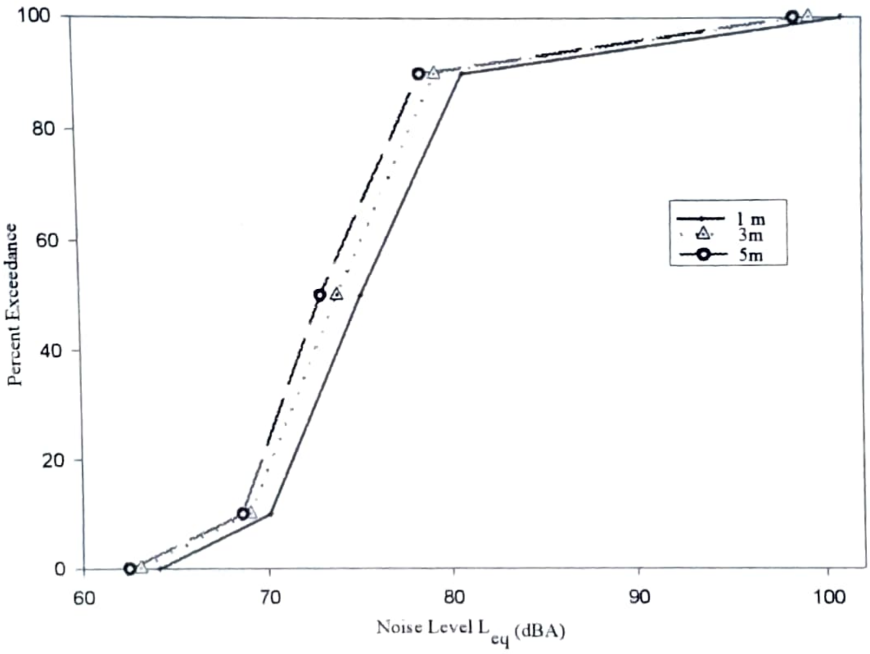
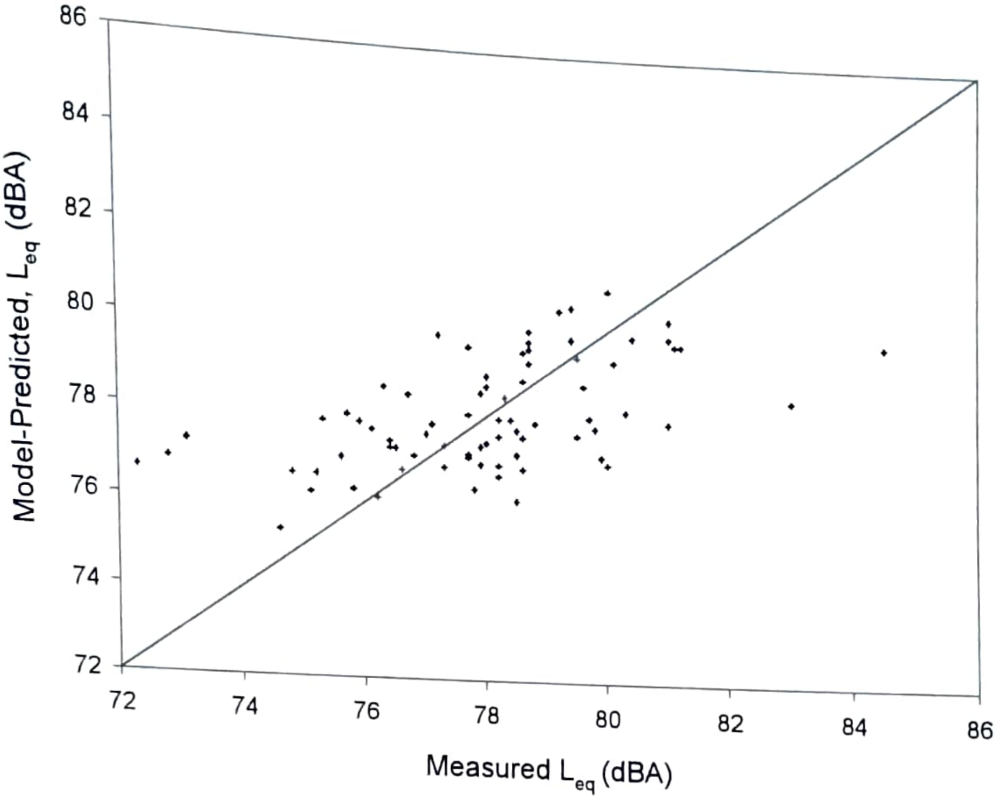
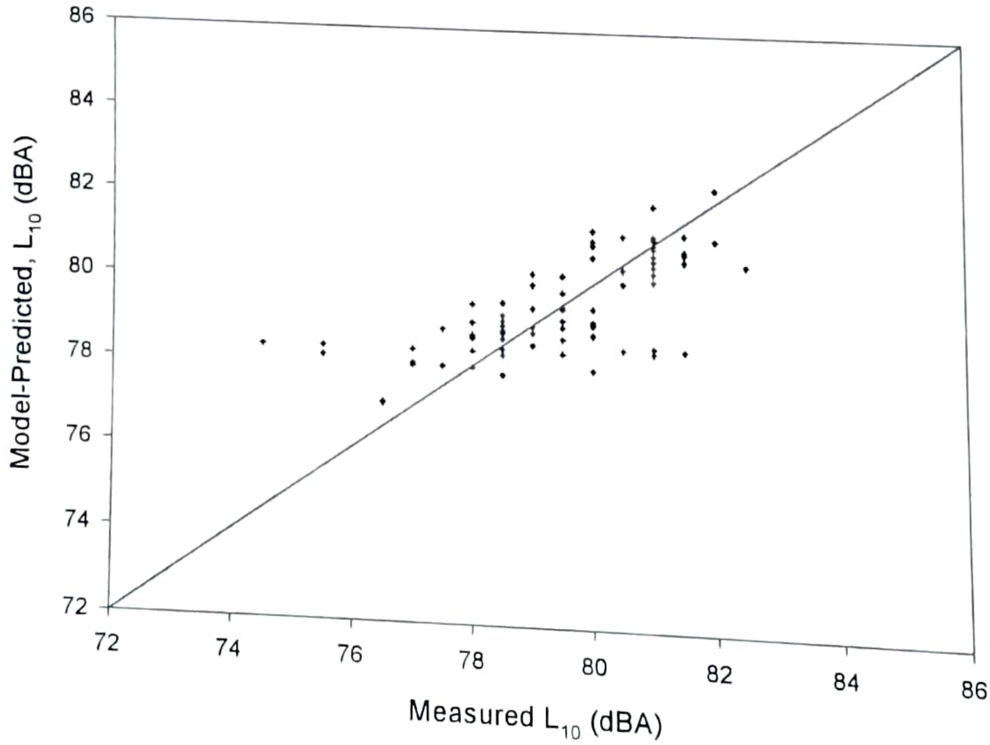


FIGURE 4 Cumulative Distribution of Noise Levels by Receiver Distance



(b)



(a)

FIGURE 5 Model-Predicted vs. Measured L_{10} (a) and L_{eq}(b)