1. INTRODUCTION

1.1 GENERAL

The number of mid-sized sprawls in India is growing at a rapid pace. Migration of rural population to such mid-sized cities is ever on the rise leading to population growth. This coupled with economic development and industrialization leads to increase in vehicle ownership which is responsible for the generation of air and noise pollution. Varanasi is one such mid-sized city which has experienced a significant influx of population from adjoining areas. As per census 2011, the city has a population of 11,98,491 [1] which is a gain of 17.32% during the last decade [2]. Ancient literature suggests that Kashi (Varanasi) used to be a vibrant habitation with a well-knit road network that commensurated with its rich economy, culture, religious content, education and tradition [3]. The place was blessed with liberal contributions from various Indian rulers, which has contributed to the physical content of the city.

1.2 TRAFFIC CONDITION

With the passage of time and change in vehicle size and traffic volume, the road network including the arterial roads, having hardly undergone any widening, have consequently become incapacitated, congested and choked to the extent that during peak hours, the traffic witness traffic jam for fairly long durations in the mornings and evenings. With about 20,000-25,000 vehicles being added to its road network every year, Varanasi traffic is gradually witnessing longer hours of traffic jam, consuming vital human hours stranded on roads, thereby increasing the psycho-physical stress levels of commuters. Encroachment of road land; near absence of footpaths; establishment of temporary vending huts; lack of modern planning & implementation by responsible Government and public bodies has led to a chaotic situation of Varanasi roads in terms of a significantly deficient road infrastructure apparatus. A similar situation is also arising in other mid-sized cities of the Indo-Gangetic plains of India, where the old city areas housing dense population with narrow right-of-way (ROW) are facing problems of commuting during peak hours of the day. It is important to underline here that the peak traffic period of such mid-size cities is consistently encroaching into the non-peak hours, and clamping traffic restrictions offer limited options for planning agencies. The situation is turning grim with extension in the duration of traffic jam, thereby creating conditions those are environmentally unsustainable in terms of vehicular pollutants. This has been the driving reason for undertaking the present study with the intention of enquiring upon traffic jam noise pollution at different floor levels near intersections of the mid-sized city of Varanasi. Literature suggests that such a study has not been attempted earlier.

It is estimated that about one-third population of Varanasi is due to floating population who come here for education, healthcare, tourism and religious activities as well as funeral processions, and are not covered under census reporting. The rising population has resulted in an increase of vehicle ownership overwhelmingly in favour of two-wheelers. The average traffic speed observed on arterial roads during day-time varies from a maximum of 45 kmph, down to a stand-still jammed condition. Lower travel speed is partly due to overcrowded vehicles on narrow carriageways, and partly due to the incessant digging of road structure by various agencies working with complete lack of coordination. An insufficient number of traffic police is yet another reason for the aggrieved situation of Varanasi roads coupled with lack of traffic sense in commuters and drivers. There is no established system for mass transport as yet, although mini city buses operate within limited areas and on specific routes. Three-wheelers are used by commuters as a common mode of transport which is obsessed with deficiencies like a lower speed of travel, higher cost of travel and generation of a high level of pollutants. Stray cattle are yet another nuisance on Varanasi roads whose presence casts upon lower traffic speed.

1.3 TRAFFIC JAM

Traffic jam is referred as an interrupted traffic condition arising on the deceleration lane of any leg of an intersection (signalized or unsignalised) either due to an inordinately longer duration of red-light signal owing to traffic buildup on other legs or due to uncontrolled movement of traffic from both directions hampering traffic movement partially or fully. This is a typical condition of incapacitation of traffic movement owing to high traffic volume. In this complex phenomenon, there is frequent braking and stopping of vehicles in the traffic followed by rearrangement of vehicles to occupy lateral and headway gaps. The stopped vehicles operate with a varying engine operating conditions (idling or stopped) and some or many of them may be involved in honking. The situation has a complex human-vehicle interaction in which the front and side margins available to any given vehicle play an important role. Length of the queueing vehicles is dependent on the volume of traffic buildup during traffic jam period. The jam clearing duration is proportional to the complexity and length of the buildup of a traffic jam. Heterogeneity of traffic composition, road surface condition, roadway geometrics and physical apparatus of the intersection are few responsible factors deciding complexity of traffic jam.

Human response to traffic jam under mixed traffic conditions is a matter of investigation. However, percentage occupancy of the road area by vehicles is an important parameter that helps determine the level of complexity of the traffic jam. This parameter signifying space constriction appearing to a commuter or driver is an important factor for his level of dissatisfaction and annoyance in the traffic jam scenario. Therefore, under conditions of a traffic jam, it may be stated that the users will exhaust their patience soon resulting in community response which needs to evaluated and addressed by transportation engineering professionals.

1.4 NOISE PARAMETERS

1.4.1 PERCENTILE NOISE LEVEL

Road traffic noise is strongly time-dependent and to account for this feature, measurements of noise parameters are important [4]. The observed noise level data is treated statistically to obtain the noise level exceeding a given percentage of observation time. Three such percentile noise levels are recognized, viz.

L_{10}: ten percentile time exceeding noise level, is the one which exceeds 10% of the total observation time. It indicates peak levels of intruding noise.

L_{50}: fifty percentile time exceeding noise level, is the one which exceeds 50% of the total observation time. It indicates average noise level.

L_{90}: ninety percentile time exceeding noise level, is the one which exceeds 90% of the total observation time. It indicates background noise level.

In order to replicate the response of human ear to annoyance caused by road traffic noise, the A-weighted sound level meter readings were obtained. Therefore, all sound levels (L) referred in this work are in terms of the A-weighted decibel or simply dBA.

1.4.2 EQUIVALENT NOISE LEVEL

Equivalent noise level (L_{eq}) refers to the equivalent steady-state noise level which in a defined period of time contains the same acoustic energy as a time-varying noise [4]. L_{eq} is an energy summation integration as shown in Eq. 1.1.

$$L_{eq} = 10\ log\left[\frac{1}{(t_2 - t_1)}\int_{t_1}^{t_2}\frac{p^2(t)}{p_r^2}\right]dt \tag{1.1}$$

where $p(t)$ is time-varying sound pressure, p_r is the reference sound pressure, and t_1 and t_2 are limits of the time period in question. Performing integration of the above equation and converting to Sound Pressure Level (SPL) in dBA, Eq. 1.2 is obtained.

$$L_{eq} = 10\log\left[\frac{\sum_{i=1}^{n} f_i . 10^{10/SPL_i}}{\sum_{i=1}^{n} f_i}\right] \tag{1.2}$$

where f_i is equal to the number of occurrences of SPL_i .

1.4.3 NOISE LEVEL INDICES

1.4.3.1 TRAFFIC NOISE INDEX (TNI)

It is a traffic noise rating index obtained from a combination of noise levels which gives a better correlation with dissatisfaction, and obtained on the consideration that L_{10} as an average peak noise level intrudes into L_{90} as average background noise level when A-weighted measurements are made outdoors [5]. Mathematically, it is stated as Eq. 1.3.

$$TNI = 4 \times (L_{10} - L_{90}) + L_{90} - 30\ \text{dBA} \tag{1.3}$$

The term $(L_{10} - L_{90})$ is called 'noise climate' by some authors and the final arbitrary constant is included to yield more convenient numbers. TNI assumes that extensive noise level fluctuations over time is the dominant factor in causing noise annoyance. It attempts to make an allowance for noise variability since fluctuating noise is commonly assumed to be more annoying.

1.4.3.2 NOISE POLLUTION LEVEL (NPL)

According to Robinson of the British National Physical Laboratory, L_{eq} in itself is an insufficient descriptor of the annoyance caused by the fluctuating noise. Road traffic noise is a significantly fluctuating noise. The index NPL was developed to estimate the dissatisfaction caused by road traffic noise comprising of two terms. The first term is L_{eq} and the second represents the increase in annoyance caused by fluctuations in that level [6]. For a Gaussian distribution, NPL may be expressed as Eq. 1.4.

$$NPL = L_{eq} + (L_{10} - L_{90}) \text{ dBA} \tag{1.4}$$

1.5 OBJECTIVES

The present research work is aimed at the assessment and modeling of traffic jam noise near the deceleration lane of various intersections of Varanasi city, and to study the variation of the traffic noise arriving at different floor levels of the building adjoining the carriageway. The following sub-objectives were framed to achieve the aforesaid objectives.

I. Determine the percentile noise levels (L_{10}, L_{50} and L_{90}), equivalent noise level (L_{eq}), TNI and NPL from the noise level data for quantification of traffic jam noise at ground level and to study their variation at different floor levels at a distance (d) from the noise source. To compare the obtained L_{eq} for traffic jam condition with permissible limits; study its reduction pattern with story height; and study its spatial decay rate for various floor levels.

II. Obtain noise climate $(L_{10} - L_{90})$ as conventional parameter and noise range $(L_{max} - L_{min})$ as a new parameter signifying noise variability for every data set. To evaluate their efficacy in modeling of traffic jam noise.

III. Obtain Passenger Car Unit (PCU) as conventional parameter and Weighted Flow (Q_w) as a new parameter representing traffic volume, which is an abstract representation of the strength of noise source that would acoustically influence the receiver. To evaluate their efficacy in modeling of traffic jam noise.

IV. Determine a parameter that would suitably represent the severity of traffic jam for heterogeneous and non-lane based movement of traffic for noise modeling from the strength of the literature.

V. Obtain floor-wise leg models, floor-wise intersection models, floor-wise city models, and consolidated city model for estimation of L_{eq} at confidence level of 95% as the representative traffic jam noise models for Varanasi city using parameters of noise variability, traffic volume, observer distance and severity of traffic jam.

1.6 SCOPE AND LIMITATIONS

a) The observer shall be acoustically influenced by a 50m trap length of queuing vehicles along the roadway involved in the traffic jam on the deceleration lane, and is located centrally and at a distance of 1.0 m in front of the building façade to account for the effects of reverberation.

b) Data was collected for intersections having two-way traffic movement. For parity of procedure for ambient noise enviroscape, legs having one-way traffic movement were avoided.

c) Noise level and classified traffic volume data were recorded for 10 minutes within the duration of a traffic jam.

d) Vehicles involved in the traffic jam had a mixed composition, and apparently, stood motionless. Infilling of lateral space by smaller vehicles and readjustment may continue to happen during the data collection.

e) Noise source is located at the centre of the carriageway and 0.50m above it. The ground floor level of the adjoining building is also 0.50m above the carriageway level.

f) Building façade is parallel to the roadway and has a true vertical profile.

g) Data was collected during day-time on normal working days during fair weather when wind speed was not exceeding 5 kmph. Sundays, festivals, extreme cold conditions and rainy days were excluded.

1.7 ORGANISATION OF THE THESIS

The thesis is divided into seven chapters. Chapter 1 gives an introduction to the selected work and dwells upon the reasons for undertaking the study. The second chapter presents the literature review. The literature review has been divided into nine sections keeping in view the need to explore published material on the topic in its essentiality and for working out the research gaps. Chapter 3 deals with detailing of the study area and locations of data collection sites. The methodology adopted for data collection is placed in Chapter 4, while field data and its analysis are presented in Chapter 5. Mathematical modeling using multivariate regression analysis is detailed in Chapter 6. The conclusions, recommendations, and scope for further work are annexed in Chapter 7. The references used for the study are finally placed.