Published by :
https://www.ijert.org/
An International Peer-Reviewed Journal

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 01 , January - 2026

Developing a Causal Model to Quantify the Impact of Vehicular Speed on Environmental Noise Descriptors in Urban Flyover Corridors.

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Abstract: - This empirical study investigates the contributory factors of traffic-generated environmental noise in urban corridors, specifically comparing at-grade and above-grade (flyover) road links. By analyzing noise descriptors and indicators across 24 locations in Nagpur, India, the research establishes a significant non-linear relationship between vehicular speed and noise generation.

The findings reveal that ambient noise levels at all studied locations exceeded permissible limits for their respective land uses. Notably, noise intensities were significantly higher on access-controlled above-grade links compared to at-grade locations, despite the latter carrying higher traffic volumes and densities. Data indicates a standard deviation of 3–4 dB(A) between these levels, with above-grade environments showing 50% less variability, suggesting a more constant and intense noise state.

The study concludes that vehicular speed—averaging 42 km/h on flyovers versus 23 km/h at-grade—is the primary driver of elevated noise levels rather than traffic volume. These results underscore the potential health hazards of high-speed urban interventions and provide a critical aid for stakeholders in planning, policy drafting, and the implementation of noise mitigation strategies.

Keywords: traffic, environmental noise, mitigation, noise descriptors, vehicular speed

1. INTRODUCTION

High traffic volumes and elevated vehicular speeds are primary drivers of unwanted environmental externalities and public health risks. Among these, noise-intense environments pose significant threats to populations in rapidly expanding urban areas and require urgent address. India is currently experiencing a period of accelerated urbanization, leading to a substantial increase in vehicular density and movement on its road networks. To mitigate the resulting congestion, urban planning often prioritizes high-capacity road interventions, such as building new links or retrofitting existing roads with flyovers.

While these infrastructure developments are intended to foster regional connectivity and boost economic growth, they often yield detrimental environmental effects, most notably noise pollution. Vehicular noise is a recognized pollutant that has been shown to cause significant annoyance and adverse psychological effects on human health. Unlike other pollutants, noise has a faster dissipation rate relative to time and distance [1,2]. Nevertheless, the expansion of road infrastructure designed to favour fast-moving, motorized modes of transport—such as wide links and flyovers—frequently relegates non-motorized transport (NMT) to higher-porosity roads with reduced mobility.

Flyovers are being popularly adopted in most urban areas of developing economies indiscriminately [3-5]. Despite the World Health Organization designating noise as the third most dangerous form of pollution after air and water, and the introduction of stricter manufacturing and traffic regulations in India, environmental noise levels continue to rise unabated [6,7].. This trend underscores the need to identify the specific causal factors behind noise generation. While noise audits and Environmental Impact Assessments (EIA) are standard practices in developed economies, such studies remain scarce in developing nations [8-11].

The awareness to curb the menace of noise has recently taken centre stage with laws and regulations restraining vehicles from blowing horns and speeding. There are also stringent checks and testing of vehicles at the manufacturing levels for noise emission in many countries including India [12-17]. Despite an abundance of ongoing researches and solution based on them to curb noise at source or studies about barriers and other mitigation measures, environmental noise seems to rise unabated. The reason for this phenomenon needs to be identified and hence an attempt to identify the causal factors of noise levels.

A review of literature indicates there are various studies carried out to investigate, measure and predict noise pollution levels in urban areas and it is a common practice to conduct noise audits and EIA (environmental impact assessment) assessment for

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ISSN: 2278-0181
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every road project undertaken in the developed economies but very few exist in the developing economies [17-19] Data collection and agglomeration is one of the important elements in the assessment and management of urban environmental noise [20]

Abundant literature is found where researchers and academicians studied and focused on the prediction of noise levels due to the presence of various parameters and factors [9, 21- 25] Studies are also location specific with rare examples of comparative studies and their analysis being done [26, 28]. Comparisons address the deviation on similar parameters, and this study aims to find the degree and deviation of noise levels of the two links studied.

The study outcomes are significant for they assist in creating awareness amongst stakeholders especially those having decision making powers to recommend changes, suggesting mitigation measures like barriers and noise reduction methods to overcome issues.

The main objective of the study is: 1) to determine the deviation in noise intense locations 2) to ascertain and identify contributory factors 3) to examine and analyse the co-relation between contributory factors.

This paper presents and develops a causal model to quantify the impact of vehicular speed on environmental noise descriptors in urban flyover corridors using the analysis of the measurements for locations along grade separators for environmental noise descriptors.

Nagpur, a city established on the Nag River has an evolutionary trajectory which is 300 years old and therefore has similar growth attributes to other cities in India. It is a radial city, is a blend of old and new areas, boasts of a GI of one major commodity “Oranges”. The city has a population of 24 lakhs with moderate to extreme climatic conditions. The expansion of the city has been driven by the SEZ and MIHAN as also by the tremendous impetus to developmental projects in the last 3 decades. Although the population growth is moderate, the vehicular growth rate in comparison is faster. Nagpur also boasts a staggering number of flyovers and ring roads built for connectivity and growth as a regional hub. With noise levels increasing, real-time measurement of traffic noise data, its analysis, and interpretation is significant and relevant in the wake of new development projects being sanctioned without duly considering the outcome of such decisions [29,30].

2. Method and instruments:
To investigate and compare noise level variations across urban flyover corridors in Nagpur, India, a systematic empirical approach was adopted. The study selected survey points along parallel road segments—at-grade and above-grade—to determine the degree of noise variance and identify primary contributory factors.

2.1 Study Area Selection for Noise Sampling:

Survey points were selected on road segments sharing similar land use, neighbourhood characteristics, built environment, and climatic conditions to ensure comparability and minimize extraneous influences. The site attributes included:

- **Land Use and Built Form**: Locations were primarily in commercial or residential zones with abutting developments averaging two to three stories in height.

- **Physical Infrastructure**: Road segments were generally six lanes wide with three unidirectional lanes. Above-grade links were constructed of concrete, while at-grade links consisted of macadam and coal tar.

- **Natural Elements**: Roadside trees with moderately thick foliage (average height of 8 m) were present across the study sites. Survey points were divided into two groups; above and at grade and noise levels were observed (Figure 1). Measurements were taken on the pedestrian pathway or the margins along the retrofitted flyover links recording (free field) sound levels.

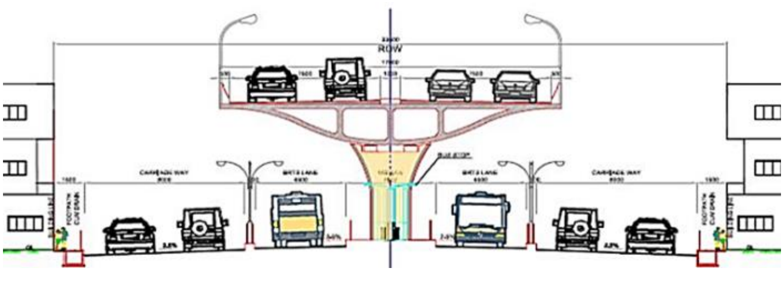

Figure 1: **Cross section of flyover corridors surveyed above and at-grade links**

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Simultaneous volume counts and modal split were recorded from 10.00 am – 12.00 am, 1.30 pm- 3.30 and 5.45 -7.15 pm using video cameras during traffic peak hours on weekdays were recorded. (Figure 2)

Figure 2: **Baba Tajjuddin Flyover, Sakkardara, Nagpur** (Source: Wikimapia)

A sound level meter (SLM), Anemometer and hygro –thermometer was used to record and measure noise levels, wind direction, temperature and humidity levels at locations. The SLM was mounted on a tripod in order to minimize any bodily vibration from the surveyors. The SLM head was at a height of 1.2 m. and a distance of 1.5 and 2 m. from the kerb side of the at grade road link locations and at a height of 1.2 ms and for above grade locations at a distance of 1.2 ms or as per spatial availability.

Measurements, when clear climatic conditions prevailed, were considered. Hence temperature, wind velocity, humidity levels were between prescribed levels to maintain consistency in measurements [13,28]. Sound level indicators and descriptors used are L10, L50, L90, LAeq, NC, TNI and L_{NP} since the choice and simplicity of noise descriptors or indicators play a crucial role in result analysis and interpretention and can become a basis to indicate biases. [28] Sound levels with a sampling of Lmax levels at a rate of 5per / min i.e. one in 12 seconds were recorded and the ten, fifty and ninety percent exceedance levels were calculated from the samples (L10, L50, and L90). The noise descriptors LAeq, NC, TNI, and L_{NP} were derived and results were compared and analysed.

2.2 Data Collection and Sampling Protocols

Noise sampling was conducted at 24 locations, categorized into two groups: at-grade and above-grade (flyover). Measurements were taken under clear climatic conditions to maintain data consistency.

- Peak Hour Observations: Measurements were recorded on weekdays during three distinct peak periods: 10:00 am – 12:00 pm, 1:30 pm – 3:30 pm, and 5:45 pm – 7:15 pm.
- Traffic Volume and Speed: Simultaneous to noise recording, video cameras were used to capture traffic volume and modal split. Vehicular speeds were found to average 23 km/h at-grade and 42 km/h on above-grade links.
- Equipment Setup: Sound Level Meters (SLM) were mounted on tripods at a height of 1.2 m to eliminate bodily vibration. The SLM was positioned 1.5–2.0 m from the curb for at-grade locations and 1.2 m for above-grade locations, depending on spatial availability. (Figure 3).

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2.3 Instrumentation

The following calibrated instruments were employed during the field surveys:

- **Sound Level Meter (SLM)**: ANSI S1.4 Type 2, A-weighted, with a range of 30–130 dB(A) and ±1.5 dB accuracy.
- **Anemometer**: Used to monitor air velocity (0–30 m/s) and ambient temperature.
- **Thermo-hygrometer**: Used to record humidity (20–90%) and temperature (-50 to +70 °C).
- **Digital Camera**: Used for video capture to determine traffic volume and modal distribution.

Figure 3: SL Meter Readings being noted.

2.4 Noise Descriptors and Indicators

The study utilized several standard descriptors and indicators to quantify noise intensity and variability:

- Exceedance Levels (L_{10}, L_{50}, L_{90}): Calculated from samples recorded at a rate of 5 per minute (one every 12 seconds).

  $L_{NP} = L_{Aeq} + (L_{90} - L_{10})$ (1)

- Equivalent Continuous Sound Level (LAeq): Represents the steady sound pressure level with the same total energy as the fluctuating noise over a given period.

- $LAeq = \ 10LOG\ [\ \frac{1}{N}\sum_{i=1}^{N}(\ Antilog\ (\frac{LAi}{10})n_i\ ]$ (2)

- Traffic Noise Index (TNI): Measures the variability in observed sound levels.

- $TNI = 4(L_{10} - L_{90}) + L_{90} - 30dB$ (3)

- Noise Pollution Level (LNP): Accounts for increased annoyance due to temporal fluctuations, calculated as LNP = LAeq + (L_{10} - L_{90}). (4)

- Noise Climate (NC): The range of sound level fluctuations over time, defined as

  NC = L_{10} - L_{90}. (5)

3. Results and discussion:

The recorded/registered Lmin levels at all locations, both at and above grade exceeded the standard allowable levels on both the links and at 90 percent locations regardless of other parameters, the noise levels are clearly in excess of the permissible standards for daytime in commercial land use zones as given by the central pollution control board, India dB(A)[6, 28-29] .(Refer Table 1)

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TABLE 1: Values Showimg Variation In L MAX And L MIN On Both Type Of Links AND RECOMMENDED LEVELS CPCB, 2010 AND WHO

LOCATION	ABOVE GRADE All values are in dB(A)			AT GRADE All values are in dB(A)			*CPCB 2010	**WHO 1999
	L MAX	L MIN	RANGE	L MAX	L MIN	RANGE	Recommended	Recommended
1	**101.8**	**66.1**	**35.7**	**98.35**	**74.4**	**23.95**	**65 dB(A) for commercial zones and land use**	**60 dB(A) outside bedrooms, hospitals, schools.**
2	**103**	**69.4**	**33.6**	**99.85**	**69.6**	**30.25**		
3	**102**	**66.8**	**35.2**	**100.25**	**61.45**	**38.8**		
4	**104.3**	**63.8**	**40.5**	**94.4**	**65.05**	**29.35**		
5	**103**	**70.1**	**32.9**	**97.3**	**72.25**	**25.05**		
6	**103**	**70.2**	**32.8**	**99.4**	**68**	**31.4**		
7	**104**	**65.7**	**38.3**	**95**	**63.05**	**31.95**		
8	**104**	**66.3**	**37.7**	**92.65**	**61.7**	**30.95**		

***Source : CPCB, 2010 Central Pollution and Control Board, India recommended environmental noise emission levels for cities in India. **Source: WHO, 1999 recommended environmental noise emission levels for cities.**

The ninety percent exceedance levels L90 were found to range between, 75.80 -68.84 dB(A) for at grade locations while they are between 80.00 – 75.38 dB(A) for above grade locations. Similarly, L50 levels were found very high than at grade locations they ranged between, 83.50 – 74.55 dB(A) for at grade locations and for above grade locations they are between 83.80 -- 79.60 dB(A). The L10 levels ranged between 82.51 -88.80 dB (A) for at grade locations and between 90.20 – 93.00 dB(A) for above grade locations. Therefore, variance in all three descriptors is smaller for all above grade locations when compared with at grade noise descriptors (Table 2).

TABLE 2: AVERAGE VALUES OF NOISE DESCRIPTORS AND THEIR DIFFERENCE (ON BOTH TYPE OF LINKS

Descriptor	**Above-Grade (High Speed)**	**At-Grade (Low Speed)**	**Difference**
L_{10} (Peak noise)	91.25 dB(A)	86.00 dB(A)	+5.25 dB(A)
L_{50} (Median noise)	82.03 dB(A)	79.11 dB(A)	+3.08 dB(A)
L_{90} (Background noise)	77.53 dB(A)	73.40 dB(A)	+4.13 dB(A)
Leq (Equivalent level)	85.19 dB(A)	81.85 dB(A)	+3.34 dB(A)

The derived indicators LNP, LAeq. Leq, TNI, NC is also very high. Further analysis shows that standard deviations for all noise descriptors and indicators for above grade links, when compared with at grade links, show that variability is 50 percent lesser. (Figure 3 A-C)

For above grade LNP std. dev is ± 2.94 dB (A) , TNI ±2.04 dB (A), LAeq ± 3.00 dBA, NC ± 0.02 dB(A) while at grade, LNP has a Std. Dev ± 3. 81 dB(A), TNI ± 6.88 dB(A),LAeq ± 3.45 dB(A), NC ± 2.24 dB(A) respectively. This indicates that the traffic volume, traffic stream characteristics and the physical attributes of the above grade links create conditions which fosters a more noise intense environment under same climatic conditions compared to those generated on at grade links. The narrow range of deviation implies that the noise levels

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are found nearer to their mean and therefore are more stabilized. It further indicates that the environment remains charged with intense environmental noise (refer to Figure 4).

The frequency distribution of noise levels when compared for both types of links shows similar trends for all locations. The Above grade distribution of frequencies for noise LMax values as recorded consistently remain between a range of 20 dB(A) while those at grade distribution have a wider spread with a range of 25 to 30 dB(A) and consequently a broader spread (Table 2).

The study recorded noise levels on above-grade links occasionally reaching the 100 dB(A) threshold, which is categorized by the World Health Organization (1999) and NIOSH (1998) as a critical level for acoustic trauma and irreversible hearing damage. [6, 31-33]

This highlights and elicits the significance of the spatial and traffic stream characteristics observed indicating that although traffic at grade is moving in a more confined space, is slow-moving, carries a higher traffic volume in total and consequently is denser than that of above grade tends to generate lesser noise emission and intensities [34-35]. The above grade conditions are free field with lesser volume and density of traffic and faster moving vehicles and still generate a more noise intense environment.

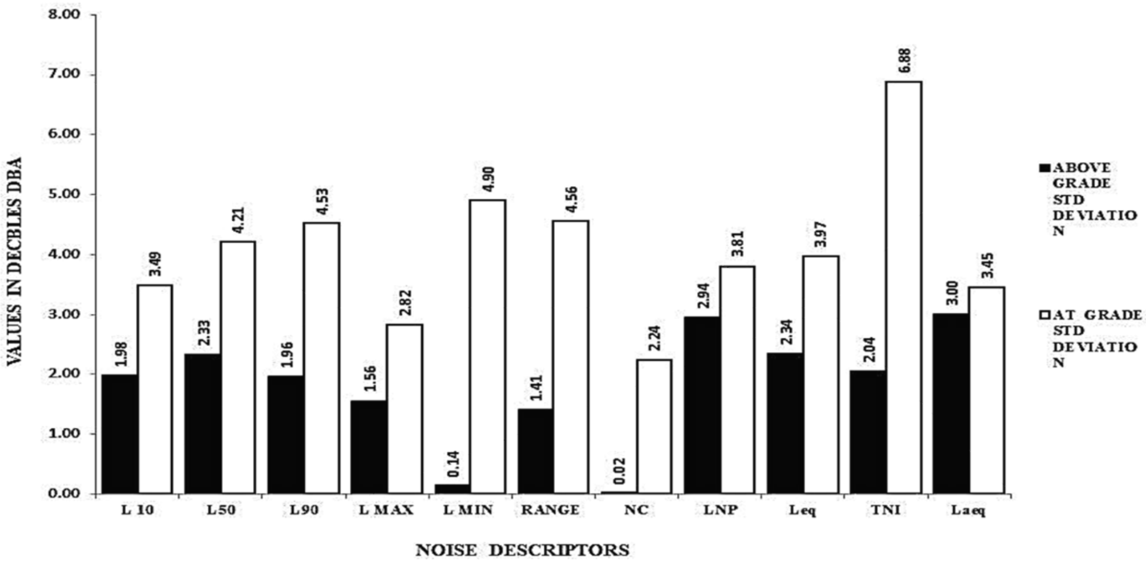

FIGURE 4 : COMPARISON OF STANDARD DEVIATIONS OF NOISE DESCRIPTORS
(VALUES ARE IN dB(A))

The overall results on noise pollution in different locations of the city indicates that the noise pressure levels deviated L10, L50, and L90 on the links at grade and above grade when compared showed a higher intensity of the noise on the above grade links and can be attributed to faster Movement of traffic for which they are built or provided. The study revealed the modal split and the traffic stream characteristics.

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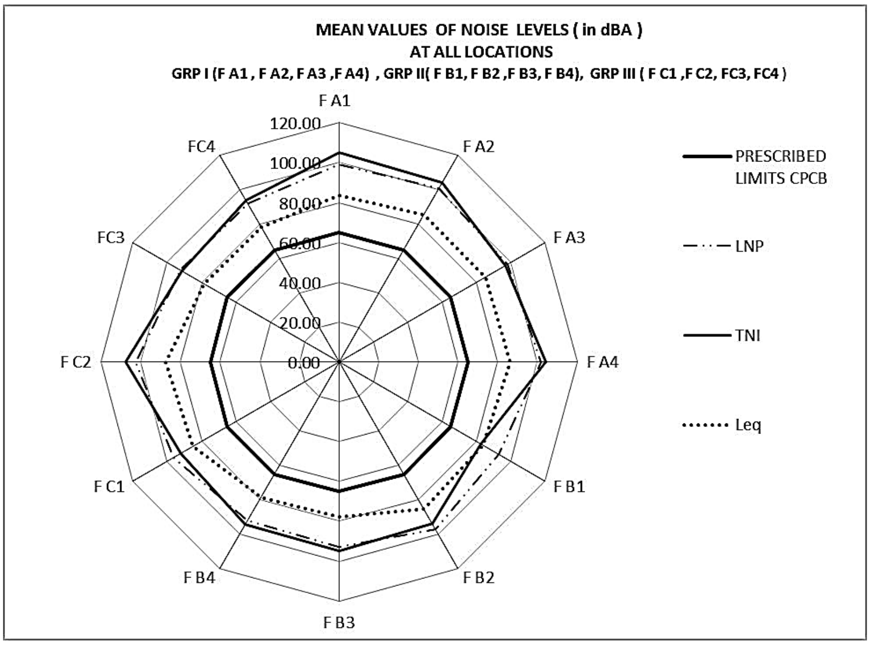

FIGURE 5: DISTRIBUTION OF LMAX LEVELS AT GRADE AND ABOVE GRADE FOR ALL STUDIED LOCATIONS

Out of the total volume carried by the parallel links the at grade, link carries a higher percentage of traffic volume compared by the above grade link. The modal split for at grade links showed a higher percentage of NMT's and HMV 's, the speed range was from 19 -30 Km/hr. The modal split for above grade link had a higher percentage of 2 and 4 wheelers and almost negligible NMT percentage, the speed range was 35 – 62 Km/hr (refer Figure 7).

The traffic volume count done along with the noise survey revealed that higher density traffic constituting mixed traffic plied on all at grade links and had comparatively slow speeds averaging 23 km per hour. Traffic volume on above grade links was lesser in density and flow and had higher speeds averaging to 42 km per hour. When compared this finding corroborates the observation that higher speeds could be one of the causes for noise intense environments and not the volume or density of traffic. The study proves that environmental noise is a risk to which neighbourhoods and commuters are exposed to unwittingly along links carrying fast-moving traffic. The noise descriptors had very fewer standard deviations where specifically speeds and not necessarily volume of traffic tended to be higher.

Noise externality due to traffic presence is well established but the causative aspects were not isolated as most studies are conducted for different links in the same city or in different cities or type of roads. The core of this paper is a statistical regression analysis to express a noise descriptor or as a function of speed and other factors. Therefore, as observed we can establish the following:

- Speed vs. Volume: Explicitly demonstrate why speed has a stronger correlation coefficient with noise levels than volume or density in the combined dataset justifying the focus. (Figure 5 and 6)

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ISSN: 2278-0181
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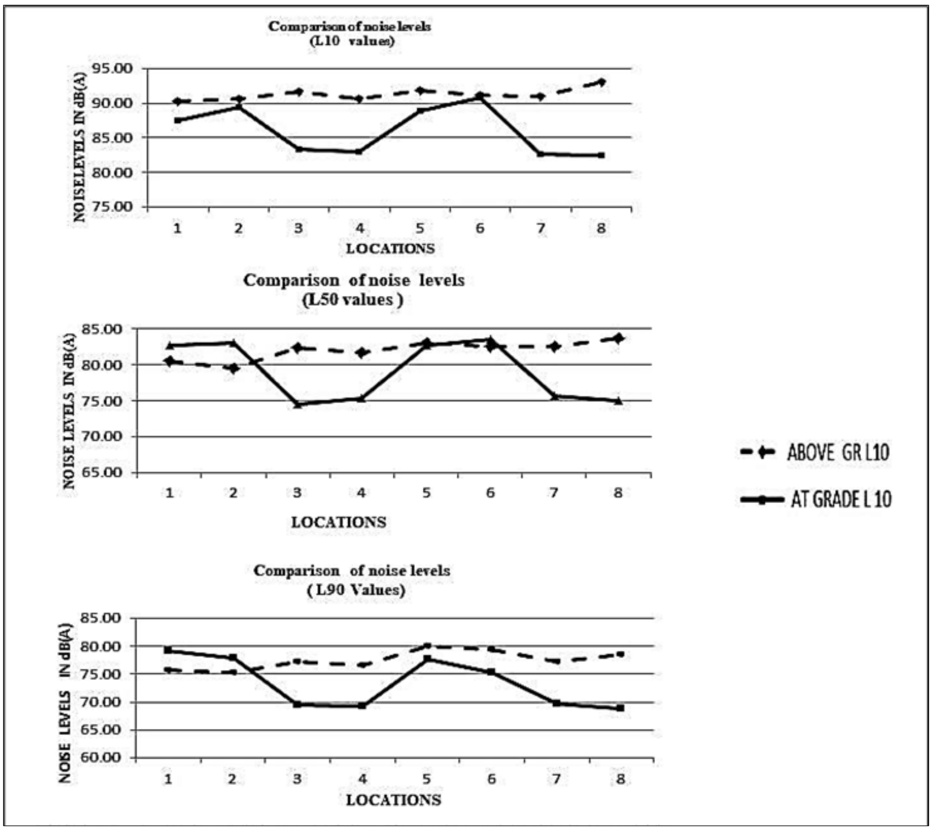

FIGURE 5: NOISE LEVELS AT GRADE AND ABOVE GRADE IN DBA

4. Model Validation: Validating the resulting speed-noise model by using a portion of the field-measured data. The speed-noise relationship for urban traffic is established by comparing at-grade (ground level) and above-grade (flyover) road segments.

Key Variables and Data Trends show vehicular speed as the primary causal factor for intense noise environments, more so than traffic volume or density.

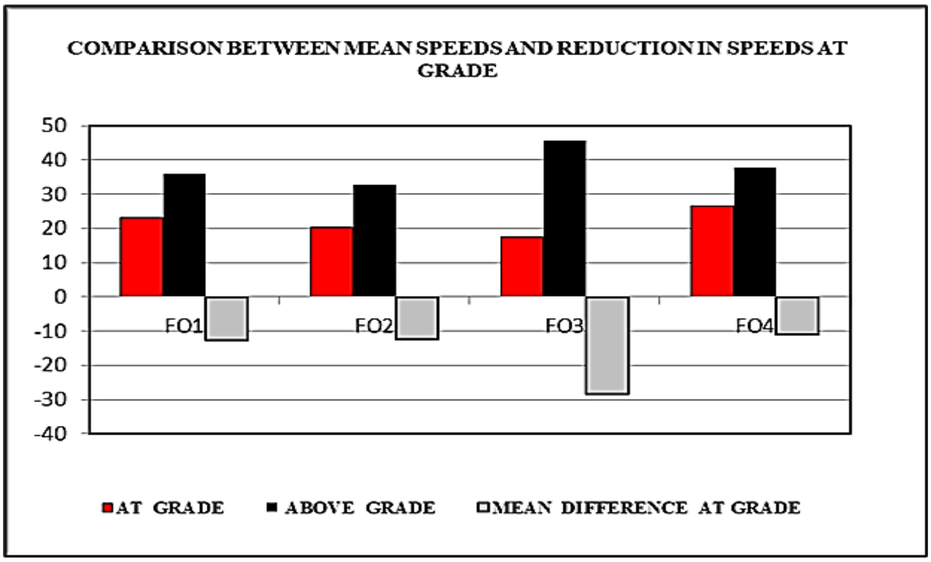

FIGURE 6 : SPEED REDUCTION AT GRADE AND ABOVE GRADE

- At-Grade Links (Slower Speed):
  - Average Speed: 23 km/hr (Range: 19–30 km/hr).

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  - Traffic Characteristics: Higher volume, higher density, and mixed traffic including non-motorized transport (NMT).
  - Noise Levels: Generally lower, with an average Leq of 81.85 dB(A).
- Above-Grade Links (Faster Speed):
  - Average Speed: 42 km/hr (Range: 35–62 km/hr).
  - Traffic Characteristics: Access-controlled, lower volume, and dominated by 2 and 4-wheelers.
  - Noise Levels: Significantly higher and more stable, with an average Leq of 85.19 dB(A).

i. Comparative Noise Descriptors: The model uses several descriptors to quantify the impact of speed on noise:

ii. Causal Relationship and Mathematical Indicators

The paper uses specific formulas to calculate noise indicators that are affected by speed-induced fluctuations; Noise Pollution Level (LNP): Accounts for annoyance due to temporal fluctuations, Traffic Noise Index (TNI): Measures variability in sound levels, Noise Climate (NC): The range of sound level fluctuations.

4.1 Findings of the Model:

The model demonstrates a **non-linear relationship** between speed and noise generation. Even with lower traffic volumes, the faster-moving traffic on flyovers creates a more "noise-intense" environment because the sound levels are found nearer to their mean (lower standard deviation), making the noise more persistent and stabilized. High-speed above-grade links showed roughly **50% less variability** in noise descriptors compared to at-grade links, indicating a constant state of high-intensity noise.

In the research paper, the speed-noise model is not presented as a single formula, but as a **causal analysis** that establishes a non-linear relationship between vehicular speed and noise descriptors across different road geometries.

The paper identifies speed as the **major contributor** to noise emission, particularly on access-controlled links (flyovers) where speeds are higher. The "model" is comprised of the following mathematical indicators and empirical findings:

4.2 Comparative Model Findings: The model differentiates between **At-Grade** (ground level) and **Above-Grade** (flyover) links to demonstrate how speed affects noise:

Table 3 : Comparative Model Findings

Feature	At-Grade (Slower Speed)	Above-Grade (Higher Speed)
Average Speed	-23 km/hr	-42 km/hr
Noise Level (Leq)	81.85 dB(A)	85.19 dB(A)
Standard Deviation	Higher variability	Lower (3–4 dB(A))

4.3. Key Model Conclusions:

This study establishes a definitive causal link between vehicular speed and the intensification of environmental noise in urban corridors. While traditional urban planning often assumes that traffic volume or density are the primary drivers of noise pollution, this empirical analysis demonstrates that vehicular speed is the more significant contributory factor. The existing data provides perfect conditions to analyze this phenomenon:

- Rolling Noise Dominance: At low speeds (typical of the congested at-grade link), propulsion noise (engine, exhaust) dominates. However, at higher speeds (typical of the above-grade link), rolling noise (tire-pavement friction) becomes the dominant and rapidly increasing noise source. The study's finding of higher noise on the high-speed link confirms this physical principle.
- Quantifying Impact: Research suggests that a 10 km/h speed difference can increase noise levels by more than 1 dB(A) for a passing vehicle. Hence speeds being more on flyover link above grade noise levels are more and can prove health hazard.
- Policy Relevance: Focusing on speed directly leads to actionable mitigation strategies, as reducing speed limits or managing traffic flow is a primary tool for noise reduction in urban areas.

Key findings from the causal model include:

- **Impact of Speed over Volume**: Above-grade links (flyovers) recorded significantly higher and more constant noise levels than at-grade links, despite carrying lower traffic volumes and densities.
- **Noise Intensity and Variability**: The model reveals that higher average speeds—42 km/h on flyovers compared to 23 km/h at-grade—resulted in a more "charged" and stable noise environment, with above-grade descriptors showing 50% less variability and a standard deviation of 3–4 dB(A) higher than at-grade locations.
- **Threshold Violations**: Noise levels at 90% of the study locations exceeded the permissible standards set by the CPCB and WHO. On several occasions, above-grade links reached the 100 dB(A) threshold, which is associated with irreversible acoustic trauma.
- **Causality:** High speed is the primary driver of intense noise environments, even when traffic volume and density are lower (as seen on flyovers).
- **Stability:** Higher speeds on flyovers lead to a "stabilized" noise environment where sound levels remain consistently high with less deviation, making it more hazardous than fluctuating ground-level noise.
- **Non-Linearity:** The study concludes that there is a non-linear relationship where increased speed significantly shifts the noise descriptors (L10, L50, L90) upward, even in access-controlled environments.

The study proves that providing infrastructure for high-speed mobility creates a significant health risk for both commuters and neighbouring residents. Consequently, these findings serve as a critical aid for stakeholders and planners, suggesting that mitigation strategies—such as noise barriers, stricter speed regulations, or alternative infrastructure designs—must be integrated into the ex-ante assessment of any new urban transport project. Ultimately, the notion of urban development through high-speed connectivity must be balanced against the detrimental psychological and physiological externalities of traffic-generated noise.

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Vol. 15 Issue 01 , January - 2026

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