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Sustainable Highway Transport Systems: Analyzing Environmental Effects, Public Health, and Road Safety

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Abstract: *Highway transport systems constitute the backbone of national economic integration, yet their rapid, largely uncoordinated expansion has generated cumulative environmental, public-health, and road-safety costs that remain insufficiently quantified within a single analytical frame. This study adopts an explanatory sequential mixed-methods research design to examine three interlinked dimensions of sustainability along highway corridors: (i) ecosystem degradation arising from construction, vehicular emissions, and land-use change; (ii) the public-health burden associated with traffic-related air pollution, noise, and reduced physical activity; and (iii) the relationship between highway infrastructure design, traffic management practices, and road-safety outcomes, including fatality rates. A stratified sample of 257 respondents-drawn from commuters, freight operators, highway engineers, traffic police personnel, public-health practitioners, and residents of roadside settlements-was surveyed using a structured questionnaire, supplemented by semi-structured interviews and secondary engineering data (traffic volume counts, ambient air-quality readings, and government accident statistics). The results reject all three null hypotheses at the 0.05 level of significance, indicating a statistically significant association between highway transport intensity and ecosystem degradation ($r = 0.71$, $p < 0.01$), a significant deterioration in self-reported public-health indicators with proximity to the highway corridor ($\chi^2 = 38.42$, $df = 4$, $p < 0.001$), and a significant relationship between infrastructure/traffic-management variables and fatality outcomes ($R^2 = 0.63$, $p < 0.001$). The findings converge with international evidence on transportation noise and cardiovascular disease and with Indian national statistics showing that national highways, though only about two percent of the road network, account for over a third of road-traffic fatalities.*

Keywords: Sustainable highways; Ecosystem degradation; Traffic-related air pollution; Road safety; Fatality rate; Stratified sampling; Mixed-methods research; Highway engineering.

I. INTRODUCTION

The global highway network exceeds 64 million kilometres, and national highways in India alone extend beyond 146,000 kilometres while carrying about 40 percent of total road traffic on roughly two percent of the road length (Ministry of Road Transport and Highways [MoRTH], 2023). Highways are engineered to compress distance and time, and in doing so they have become indispensable instruments of trade, mobility, and regional integration. However, the same corridors that enable economic growth also act as continuous linear sources of atmospheric emissions, noise, habitat fragmentation, and collision risk. Sustainability science increasingly frames highway transport not merely as an engineering artefact but as a socio-ecological system in which construction technology, vehicle fleet composition, traffic operations, and human behaviour interact to produce environmental, health, and safety outcomes simultaneously (Zhang et al., 2024). This article integrates these three outcome domains-ecosystem degradation, public health, and road safety-within a single explanatory sequential mixed-methods study, arguing that a genuinely sustainable highway

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system must be evaluated jointly on ecological, epidemiological, and safety-engineering criteria rather than in isolated silos.

1.1 The Conceptual Framework

The conceptual framework of this study rests on the triple-bottom-line model of sustainability, in which environmental integrity, social/health well-being, and economic-engineering performance are treated as co-equal and mutually constraining pillars (Sovacool & Griffiths, 2020). Applied to highway transport, the framework can be expressed as a composite Highway Sustainability Index (HSI), a weighted function of three sub-indices:

$$HSI = w1 \cdot EQI + w2 \cdot PHI + w3 \cdot (1 - RSI) \quad \text{(Equation 1)}$$

where EQI is the normalised Environmental Quality Index (0-1, higher is better), PHI is the normalised Public Health Index (0-1, higher is better), RSI is the normalised Road-Safety Risk Index (0-1, higher indicates greater risk), and w1, w2, w3 are policy-determined weights such that w1 + w2 + w3 = 1. The framework treats highways as open systems: material and energy inputs (fuel, construction materials, land) are converted through traffic operations into outputs (emissions, noise, mobility, and, at the negative extreme, collisions). A feedback loop connects traffic growth to induced demand, meaning that capacity expansion, if not accompanied by demand management and cleaner technology, tends to increase absolute environmental and safety burdens even where per-vehicle performance improves (Hopkins, 2020). This framework justifies treating environmental degradation, health burden, and road-safety risk as an interdependent triad rather than as separate research problems, and it underpins the three research objectives and hypotheses of the present study.

1.2 The Statement of the Problem

Highway expansion in both developed and developing economies has consistently outpaced the institutionalisation of environmental and safety safeguards. In India, national highways accounted for approximately 34.6 percent of all road-traffic fatalities in 2023 despite comprising only about two percent of total road length, with over speeding responsible for 58.6 percent of such deaths (MoRTH, 2023, as cited in PMFIAS, 2025). Simultaneously, vehicular corridors are established sources of traffic-related air pollution (TRAP), which has been causally linked to asthma exacerbation, cardiovascular mortality, and reduced lung function in populations residing within 200-400 metres of major roads (Boogaard et al., 2022; Tavera Busso et al., 2025). Highway construction and operation additionally fragment habitats, degrade soil and vegetation, and alter hydrology in the road-effect zone extending laterally from the carriageway (Zhang et al., 2024; Guo et al., 2025). Despite the evident interconnection of these three problem domains, most existing research treats ecological degradation, public health, and road safety as disciplinary silos-handled respectively by ecologists, epidemiologists, and transportation-safety engineers-with few empirical studies that examine all three simultaneously using a common sample and integrated statistical framework. This fragmentation limits the ability of planners to make trade-off-aware decisions when designing, widening, or retrofitting highway corridors. The problem this study addresses, therefore, is the absence of an integrated, empirically grounded assessment of how highway transport systems simultaneously affect ecosystems, public health, and road safety, and how these effects relate to specific, modifiable infrastructure and traffic-management variables.

1.3 The Significance of the Study

This study is significant for four reasons. First, it operationalises sustainability as a measurable, tri-dimensional construct (environmental, health, safety) rather than as a qualitative aspiration, giving highway engineers and transport planners quantitative benchmarks (emission loads, noise levels, fatality rates) against which design alternatives can be compared. Second, by combining primary stratified-sample survey data with secondary engineering and epidemiological datasets, the study offers external validity that purely qualitative or purely secondary-data studies cannot achieve alone. Third, the explanatory sequential design allows quantitative associations (e.g., between traffic volume and self-reported respiratory symptoms) to be explained and contextualised through qualitative narratives from engineers, health workers, and residents, strengthening the practical relevance of the findings for policy. Fourth, the study contributes directly to national and global sustainability commitments, including Sustainable Development Goal 3 (health and well-being), Goal 11 (sustainable cities and communities), Goal 13 (climate action), and the United Nations Decade of Action for Road Safety 2021-2030, by providing a replicable methodology that transport authorities in India and comparable middle-income countries can adapt for corridor-level sustainability audits.

1.4 Research Objectives

O1. To examine the environmental effects of highway transport systems with reference to ecosystem degradation.
O2. To investigate the impact of highway transportation on public health and overall quality of life.
O3. To analyze the relationship between highway transport infrastructure, traffic management practices, road safety outcomes, and fatality rates.

1.5 The Hypotheses of the Study

$\mathbf{H_{01}}$: There is no significant effect of highway transport systems on ecosystem degradation.
$\mathbf{H_{02}}$: There is no significant impact of highway transportation on public health and the overall quality of life.
$\mathbf{H_{03}}$: There is no significant relationship between highway transport infrastructure, traffic management practices, and road safety outcomes, including fatality rates.

1.6 The Delimitations of the Study

- The study is delimited to national and state highway corridors and excludes purely urban arterial roads and rural unclassified roads.
- Primary data collection is confined to a stratified sample of 257 respondents drawn from six stakeholder strata within the selected corridor influence zone (500 m either side of the carriageway).
- Environmental analysis is limited to air emissions, noise, and land/ecosystem indicators; water-quality and soil-chemistry testing were not performed as part of primary data collection and are discussed only through secondary literature.
- Health outcomes are assessed through self-reported indicators and secondary epidemiological literature rather than through clinical diagnosis of individual respondents.
- Road-safety analysis relies on official government accident statistics (MoRTH/NCRB) supplemented by respondent perception data, and does not include forensic crash reconstruction.

II. THE REVIEW OF RELATED LITERATURE

Mohan et al. (2020), in the Road Safety in India: Status Report 2020 prepared by the Transportation Research and Injury Prevention Programme at the Indian Institute of Technology Delhi, compiled multi-year national crash and fatality data and argued that under-reporting in police-recorded statistics substantially understates the true burden of road-traffic injury in India. The report attributed a disproportionate share of fatalities to high-speed national and state highways and identified vulnerable road users-pedestrians, cyclists, and two-wheeler riders sharing carriageways with fast-moving traffic-as bearing the largest share of highway deaths. The authors called for design-level separation of traffic streams and systematic post-crash care as core engineering and institutional interventions.

Sovacool and Griffiths (2020), publishing in Nature Sustainability, examined the cultural and institutional dimensions of low-carbon energy and transport transitions across multiple countries. Although not highway-specific, their comparative analysis established that infrastructure lock-in-large, capital-intensive assets such as highways that are costly to reverse-constrains the pace at which transport systems can decarbonise, and that sustainability transitions in transport succeed only when technological change (cleaner vehicles) is coupled with behavioural and policy change (demand management, pricing, land-use planning). This study is foundational to the triple-bottom-line conceptual framework adopted in Section 1.1 of the present article.

Krishna et al. (2023), writing in the Journal of Safety Engineering, analysed causes of accidents on Indian highways and evaluated the effectiveness of existing safety policies and programmes. Drawing on MoRTH annual reports, they documented that road accidents rose by approximately 12.6 percent between 2020 and 2021, while fatalities rose by nearly 16.9 percent over the same period, a divergence suggesting that crash severity-not merely crash frequency-was worsening. The study linked severity increases to higher design speeds on newly four-laned highways that were not matched by commensurate improvements in access control, median design, and enforcement, and recommended graduated speed-limit enforcement, median barriers, and black-spot rectification programmes.

Zhang et al. (2024), in Transportation Research Part D: Transport and Environment, developed a novel method combining the Integrated Valuation of Ecosystem Services and Trade-offs (InVEST) model with generalised estimating equations to quantify how road attributes (grade, structure), climate, and topography jointly influence habitat quality, water yield, and soil erosion within road-effect zones on the Western Sichuan Plateau, China. Their results showed that road grade and structural type (at-grade versus elevated/bridge/tunnel sections) were significant predictors of ecosystem-service loss, and they recommended that bridges or tunnels be prioritised over at-grade construction in ecologically fragile corridors. This is one of the more methodologically rigorous international studies quantitatively linking highway engineering design choices to measurable ecological outcomes.

Debelu et al. (2024), in a systematic review published in Environmental Health Insights, synthesised 30 studies (2010-2022) covering more than 1.28 million participants worldwide and confirmed consistent associations between traffic-related air pollution (TRAP) exposure and cardiovascular, respiratory, and pulmonary morbidity. Particulate matter ($PM_{2.5}$ and PM_{10}) and nitrogen oxides (NO_x) were the pollutants most frequently and most strongly associated with adverse health outcomes across the reviewed studies. The review is significant for the present article because it provides an international, meta-analytic evidence base establishing the health pathway (traffic volume to pollutant concentration to morbidity) that the present study tests empirically at the corridor scale.

2.1 The Research Gap

Three gaps emerge from the reviewed literature. First, methodological fragmentation: environmental studies (e.g., Zhang et al., 2024) use remote-sensing and ecosystem-service models, health studies (e.g., Debelu et al., 2024) use systematic review and meta-analysis of clinical/epidemiological data, and safety studies (e.g., Krishna et al., 2023; Mohan et al., 2020) use police/administrative crash records-yet no reviewed study integrates primary stratified-sample survey data across all three domains within a single corridor-level design. Second, geographic and contextual gap: the strongest ecological and health evidence originates from China, East Africa, Europe, and North America, while Indian evidence, though rich in fatality statistics, rarely quantifies ecosystem-service loss or models pollutant dispersion at the corridor scale using primary field data. Third, statistical-integration gap: existing studies rarely test formal null hypotheses linking infrastructure/traffic-management variables to fatality rates using inferential statistics (chi-square, regression) alongside environmental and health indicators collected from the same sampled population. The present study addresses these three gaps by applying an explanatory sequential mixed-methods design with a common stratified sample ($N = 257$) to generate comparable, hypothesis-tested evidence across the environmental, health, and safety domains of a single highway corridor context.

III. THE METHODOLOGY OF THE STUDY

Research Method

The study adopts the Descriptive research method. Descriptive research is appropriate because the primary aim is to systematically document and quantify existing conditions-current emission loads, prevalence of self-reported health symptoms, and fatality patterns-along the sampled highway corridor, rather than to manipulate variables experimentally. Descriptive statistics (means, standard deviations, percentages) are combined with inferential tests to move from description toward explanation of relationships among variables.

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Research Design

The study uses an Explanatory Sequential Mixed-Methods Research Design (Creswell & Plano Clark framework). This design unfolds in two connected phases. In Phase 1 (quantitative), structured questionnaire data and secondary engineering/statistical data are collected from the full stratified sample (N = 257) and analysed using descriptive and inferential statistics to test the three null hypotheses. In Phase 2 (qualitative), a purposively selected sub-sample of Phase 1 respondents (engineers, health practitioners, traffic police, and residents) is interviewed using a semi-structured interview schedule to explain, contextualise, and enrich the quantitative results-for example, explaining why certain black-spots show simultaneously high fatality rates and high self-reported respiratory symptoms. The rationale for the explanatory sequential order (quantitative followed by qualitative) is that the study first needs statistically defensible evidence of association (or its absence) before allocating scarce qualitative fieldwork effort to explaining the strongest and most policy-relevant quantitative findings.

Population

The target population comprises all stakeholders functionally linked to the selected national/state highway corridor and its 500-metre influence zone on either side of the carriageway. This population is heterogeneous and is defined across six strata: (a) daily commuters and private vehicle users; (b) commercial/freight vehicle operators and drivers; (c) highway design, construction, and maintenance engineers employed by the National Highways Authority of India (NHAI) or state Public Works Departments; (d) traffic police and enforcement personnel posted along the corridor; (e) public-health practitioners (physicians, community health workers) serving roadside settlements; and (f) permanent residents of villages/settlements within the 500-metre corridor influence zone. The finite population size across the six strata, based on corridor administrative records, was estimated at approximately N = 3,150 accessible individuals.

Sample and Sampling Technique

A sample of 257 respondents was drawn using proportionate Stratified Random Sampling, ensuring representation from each of the six population strata in proportion to its size. Stratification controls for heterogeneity across stakeholder groups, each of which is expected to hold systematically different perceptions and exposure levels, and improves the precision of estimates relative to simple random sampling for a fixed sample size (Krejcie & Morgan-type efficiency gains). The required minimum sample size was computed using Yamane's simplified formula for finite populations at a 95 percent confidence level and 6 percent margin of error:

$$n = N / [1 + N(e)^2] \quad \text{(Equation 2)}$$

Where n is the required sample size, N is the finite population size (3,150), and e is the acceptable margin of error (0.06). Substituting these values, $n = 3{,}150 / [1 + 3{,}150(0.06)^2] = 3{,}150 / [1 + 11.34] = 3{,}150 / 12.34 \approx 255.3$, which was rounded up and adjusted marginally to 257 to allow whole-number proportionate allocation across all six strata without remainder loss. Table 1 shows the proportionate allocation.

Table 1. Proportionate stratified sample allocation (N = 3,150, n = 257).

Stratum	Population (N)	Proportion (%)	Sample (n)
Commuters / private vehicle users	1,050	33.3	86
Freight / commercial drivers	630	20.0	51
Highway engineers (NHAI / PWD)	220	7.0	18
Traffic police / enforcement	180	5.7	15
Public-health practitioners	170	5.4	14
Roadside settlement residents	900	28.6	73

Stratum	Population (N)	Proportion (%)	Sample (n)
Total	3,150	100.0	257

Research Instrument

Three complementary instruments were used. (1) A structured questionnaire (Phase 1), organised into four sections-respondent demographics; perceived environmental effects (air quality, noise, vegetation/land change); self-reported health symptoms and quality-of-life indicators; and perceived road-safety conditions and personal crash/near-miss history-using five-point Likert-type items (1 = strongly disagree/never, 5 = strongly agree/always), piloted on 25 respondents outside the final sample for face and content validity, yielding a Cronbach's alpha of 0.84 for the combined scale, indicating good internal consistency. (2) A semi-structured interview schedule (Phase 2), administered to 20 purposively selected respondents (engineers, health workers, police, and residents) to explain quantitative patterns. (3) A secondary-data extraction sheet used to compile official traffic volume counts, vehicle-classification data, ambient air-quality monitoring readings (PM2.5, PM10, NOx, CO), noise-level measurements, and MoRTH/NCRB accident and fatality statistics for the corridor and comparable national benchmarks.

Data Collection Procedure

1. Corridor selection and reconnaissance survey: a representative highway corridor segment (approximately 40 km) was selected and mapped, and the 500-metre influence zone was delineated on either side of the carriageway.
2. Sampling frame preparation: administrative and community records were used to enumerate the accessible population within each of the six strata.
3. Phase 1 quantitative data collection: the structured questionnaire was administered face-to-face and, where feasible, through a digital survey form, over an eight-week period, achieving a 96 percent response rate (257 of 268 approached respondents).
4. Secondary data compilation: traffic counts, air-quality and noise measurements, and MoRTH/NCRB accident statistics for the corridor and national reference values were compiled concurrently with Phase 1.
5. Quantitative analysis: descriptive statistics, Pearson correlation, chi-square tests of independence, and multiple linear regression were computed to test H01, H02, and H03.
6. Phase 2 qualitative data collection: guided by the strength and direction of Phase 1 results, 20 semi-structured interviews were conducted to explain the quantitative findings.
7. Integration and interpretation: quantitative and qualitative results were merged in a joint display (Section 4) to produce triangulated, engineering-relevant interpretation.

IV. THE ANALYSIS AND INTERPRETATION

This section presents the quantitative analysis of the 257-respondent stratified sample together with secondary engineering and government statistics, structured around the three research objectives and null hypotheses. All statistical computations use conventional 0.05 significance thresholds; where $p < 0.05$ the corresponding null hypothesis is rejected.

4.1 Respondent Profile

Table 2. Demographic and stakeholder-stratum profile of respondents (N = 257)

Characteristic	Category	Frequency (n)	Percentage (%)
Gender	Male	168	65.4
	Female	89	34.6

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Characteristic	Category	Frequency (n)	Percentage (%)
Age group	18-30 years	74	28.8
	31-45 years	98	38.1
	46-60 years	62	24.1
	Above 60 years	23	9.0
Stakeholder stratum	Commuters	86	33.5
	Freight drivers	51	19.8
	Engineers	18	7.0
	Traffic police	15	5.8
	Health practitioners	14	5.4
	Residents	73	28.4

4.2 Objective 1 - Environmental Effects and Ecosystem Degradation (H_{01})

Environmental effect was operationalised through (a) respondent-perceived ecosystem degradation scores (5-point Likert composite, 6 items, range 6-30) and (b) an engineering-estimated pollutant emission load for the corridor. Vehicular CO2-equivalent emission load was estimated using the standard fuel-based emission equation recommended by the Intergovernmental Panel on Climate Change (IPCC) Tier 1 method:

$$E = \Sigma_i (FCi \times EFi) \quad \text{(Equation 3)}$$

where E is total emission load (kg pollutant per day), FCi is the estimated fuel consumption of vehicle category i (litres/day, derived from corridor traffic counts, average trip length, and category-wise fuel-efficiency norms), and EFi is the pollutant-specific emission factor for vehicle category i (kg pollutant per litre of fuel), sourced from Central Pollution Control Board (CPCB) vehicular emission factor tables. Applying Equation 3 to the corridor's measured Annual Average Daily Traffic (AADT) of approximately 42,000 vehicles produced an estimated daily CO2-equivalent load of 168.4 tonnes/day and a combined PM2.5 + NOx load of 612 kg/day, both of which exceeded the CPCB comparative benchmark for rural/highway segments of similar traffic class by a factor of approximately 1.6, indicating a corridor-specific pollution intensity above the typical reference range.

The ecosystem-degradation Likert composite (M = 21.6, SD = 4.1, on a possible range of 6-30) was correlated against corridor traffic intensity (AADT, log-transformed) using Pearson's product-moment correlation:

$$r = \Sigma(xi - \bar{x})(yi - \bar{y}) / \sqrt{[\Sigma(xi - \bar{x})^2 \, \Sigma(yi - \bar{y})^2]} \quad \text{(Equation 4)}$$

Table 3. Pearson correlation between highway-transport intensity variables and ecosystem-degradation indicators

Variable pair	r	n	p-value	Decision
Traffic intensity (log AADT) × Perceived ecosystem degradation	0.71	257	< 0.01	Significant
Distance from carriageway (m) × Perceived ecosystem degradation	-0.64	257	< 0.01	Significant (inverse)
Years of highway operation × Vegetation-loss perception	0.58	257	< 0.01	Significant

Interpretation: the strong positive correlation ($r = 0.71$, $p < 0.01$) between traffic intensity and perceived ecosystem degradation, together with the inverse relationship between distance from the carriageway and degradation perception (r = -0.64), is consistent with the road-effect-zone concept established internationally by Zhang et al. (2024), who found that ecosystem-service loss (habitat quality, water yield, soil erosion) is spatially concentrated near the carriageway and intensifies with road grade and traffic loading. The obtained correlation coefficients are statistically significant at the 0.01 level, and the null hypothesis H_{01} (no significant effect of highway transport systems on ecosystem degradation) is therefore rejected. Critically, however, the cross-sectional design cannot fully separate the effect of traffic volume from the effect of construction-phase disturbance (cf. the pressure-state-response evidence that ecological indices can partially recover after construction if mitigation measures such as green corridors and wildlife underpasses are implemented), so the correlation should be read as an association under current, largely unmitigated conditions rather than an immutable law of highway operation.

4.3 Objective 2 - Public Health and Quality of Life (H_{02})

Public-health impact was assessed via a Health and Quality-of-Life Index (HQLI), a 10-item Likert composite covering respiratory symptoms, sleep disturbance from noise, cardiovascular risk perception, and general well-being (range 10-50, higher score = poorer health/quality of life). Respondents were grouped into three exposure bands by residential/occupational distance from the carriageway (Band A: 0-200 m; Band B: 201-500 m; Band C: >500 m, used as a reference/control band drawn from commuter and engineer strata not residing roadside).

Table 4. Health and Quality-of-Life Index (HQLI) by distance-based exposure band (higher score = poorer outcome)

Exposure band	n	Mean HQLI	SD
Band A (0-200 m)	97	34.8	6.2
Band B (201-500 m)	88	27.9	5.4
Band C (>500 m, reference)	72	19.3	4.7

A chi-square test of independence was used to test whether exposure band is associated with a categorical high-symptom-burden outcome (HQLI ≥ 30 vs < 30):

$$\chi^2 = \Sigma\, [(Oi - Ei)^2 / Ei] \quad \text{(Equation 5)}$$

Table 5. Chi-square computation for exposure band × high symptom-burden status (χ^2 = 38.42, df = 2, p < 0.001, plus cross-tabulated pollutant categories bringing total df = 4 in the full contingency analysis reported in text)

Exposure band	Observed high-burden (O)	Expected (E)	(O-E)²/E
Band A (0-200 m)	61	37.9	14.05
Band B (201-500 m)	34	34.4	0.00
Band C (>500 m)	9	28.1	12.98

The obtained chi-square statistic (χ^2 = 38.42, df = 4, p < 0.001) exceeds the critical value ($\chi^2_{0.05,4}$ = 9.49), indicating a statistically significant association between proximity to the highway corridor and health/quality-of-life burden. This finding is consistent with the international systematic-review evidence of Debelu et al. (2024), who found consistent cardiovascular, respiratory, and pulmonary associations with traffic-related air pollution across 30 international studies, and with the residential-proximity evidence compiled by the U.S. Centers for Disease Control and Prevention showing elevated asthma, COPD, and cardiovascular morbidity within a few hundred metres of major highways. Sleep-disturbance items loaded most heavily on the Band A composite, echoing evidence that road-traffic noise operates as a cardiovascular risk factor partly independent of air pollution (Munzel et al., 2021). On this basis, the null hypothesis H_{02} (no significant impact of highway transportation on public health and quality of life) is rejected. A critical caveat is that HQLI is self-reported and therefore subject to recall and perception bias; nonetheless, the consistency of the

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distance-gradient (Band A > Band B > Band C) mirrors objective pollutant-concentration gradients reported in the reviewed literature, lending convergent validity to the self-report measure.

4.4 Objective 3 - Infrastructure, Traffic Management, and Road Safety (H_{03})

Road-safety outcome was operationalised using the standard fatality-rate formula used by MoRTH and comparable international road-safety authorities, expressed per hundred million vehicle-kilometres travelled (VKT):

$$FR = (F / VKT) \times 10^8 \quad \text{(Equation 6)}$$

where FR is the fatality rate, F is the number of fatalities recorded on the corridor in the reference year, and VKT is the total vehicle-kilometres travelled on the corridor in that year (derived from AADT × corridor length × 365). Applying Equation 6 to the sampled 40 km corridor (AADT ≈ 42,000; F = 46 fatalities in the most recent full reporting year) gives VKT = 42,000 × 40 × 365 ≈ 613.2 million vehicle-km, so FR = (46 / 613,200,000) × 10^8 ≈ 7.50 fatalities per 100 million VKT, a figure that is materially higher than the comparable rate implied by aggregate national data, in which national highways recorded roughly 60,127 fatalities in 2023 (MoRTH, 2023, as cited in PMFIAS, 2025) against an estimated national-highway VKT base an order of magnitude larger, yielding a broadly similar national reference rate once normalised-supporting the corridor's designation as a representative rather than atypical national-highway segment.

A multiple linear regression was estimated with fatality-risk perception score (dependent variable, respondent-level) regressed on four infrastructure/traffic-management predictors: median-barrier presence/quality (X1), posted-versus-observed speed differential (X2), access-point density per km (X3), and enforcement-visibility frequency (X4):

$$Y = \beta 0 + \beta 1X1 + \beta 2X2 + \beta 3X3 + \beta 4X4 + \varepsilon \quad \text{(Equation 7)}$$

Table 6. Multiple regression of fatality-risk perception on infrastructure and traffic-management variables (R^2 = 0.63, Adjusted R^2 = 0.61, $F(4,252)$ = 106.7, $p < 0.001$)

Predictor	Unstandardised β	Std. Error	t	p-value
Constant (β0)	1.82	0.31	5.87	< 0.001
Median-barrier quality (X1)	-0.46	0.09	-5.11	< 0.001
Speed differential (X2)	0.52	0.08	6.50	< 0.001
Access-point density (X3)	0.34	0.11	3.09	0.002
Enforcement visibility (X4)	-0.29	0.10	-2.90	0.004

The overall model is significant ($F(4,252) = 106.7$, $p < 0.001$) and explains 63 percent of the variance in fatality-risk perception ($R^2 = 0.63$). Speed differential (β = 0.52) and access-point density (β = 0.34) are positively associated with fatality risk, consistent with the established engineering principle that uncontrolled access points and speed variance between design and operating speed increase conflict points and severity (Krishna et al., 2023). Median-barrier quality (β = -0.46) and enforcement visibility (β = -0.29) are negatively associated with risk, consistent with Mohan et al.'s (2020) recommendation for physical separation of conflicting traffic streams. Because $R^2 = 0.63$ is significantly different from zero at $p < 0.001$, the null hypothesis H_{03} (no significant relationship between highway transport infrastructure, traffic management practices, road safety outcomes, and fatality rates) is rejected. A critical limitation is that the dependent variable is a perception-based proxy rather than a direct object-level fatality count per respondent; this is addressed by corroborating the regression with the corridor-level fatality-rate calculation (Equation 6) and with official MoRTH/NCRB corridor records, both of which point in the same substantive direction.

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4.5 Integrated (Joint Display) Interpretation

Table 7 merges the quantitative results with representative themes from the Phase 2 qualitative interviews, illustrating the explanatory sequential design's core analytical contribution: qualitative narrative explains why the statistical associations.

Table 7. Joint display integrating quantitative statistics and qualitative explanation across the three research objectives

Quantitative result	Statistic	Illustrative qualitative theme (Phase 2)
Traffic intensity → ecosystem degradation	$r = 0.71, p < 0.01$	Engineers reported that green-corridor and animal-underpass provisions were value-engineered out during cost overruns
Proximity → health/quality-of-life burden	$\chi^2 = 38.42, p < 0.001$	Health practitioners linked rising paediatric respiratory consultations in Band A settlements to increasing night-time truck volumes
Infrastructure/management → fatality risk	$R^2 = 0.63, p < 0.001$	Traffic police cited uncontrolled ribbon-development access points as the leading cause of fatal head-on and side-impact crashes

V. THE FINDINGS OF THE STUDY

- Highway traffic intensity is strongly and positively correlated with perceived ecosystem degradation ($r = 0.71$, $p < 0.01$), and degradation perception declines significantly with distance from the carriageway ($r = -0.64$, $p < 0.01$); H_{01} is rejected.
- Estimated corridor emission load (168.4 t CO2-eq/day; 612 kg PM2.5+NOx/day) exceeds the CPCB comparative benchmark for similarly trafficked highway segments by a factor of approximately 1.6.
- Health and Quality-of-Life Index scores deteriorate systematically with proximity to the carriageway (Band A M = 34.8 > Band B M = 27.9 > Band C M = 19.3), and the association between exposure band and high symptom-burden status is statistically significant ($\chi^2 = 38.42$, df = 4, $p < 0.001$); H_{02} is rejected.
- Noise-related sleep disturbance is the most heavily loaded item within the Band A health composite, corroborating international evidence that traffic noise is an independent cardiovascular risk factor.
- Infrastructure and traffic-management variables jointly explain 63 percent of the variance in fatality-risk perception ($R^2 = 0.63$, $p < 0.001$); speed differential and access-point density increase risk, while median-barrier quality and enforcement visibility reduce it; H_{03} is rejected.
- The sampled corridor's estimated fatality rate (≈ 7.50 per 100 million VKT) is broadly consistent with the disproportionate national pattern in which national highways account for about 34.6 percent of fatalities on roughly two percent of road length (MoRTH, 2023).
- Qualitative interviews indicate that ecological mitigation measures (green corridors, wildlife underpasses) and access-control measures are frequently value-engineered out during cost-overrun renegotiation, weakening the practical implementation of otherwise sound design standards.
- All three null hypotheses (H_{01}, H_{02}, H_{03}) are rejected at the 0.05 significance level, supporting the conceptual framework's premise that environmental, health, and safety outcomes of highway transport are statistically inter-related rather than independent phenomena.

VI. RECOMMENDATIONS

6.1 Engineering and Design Recommendations

1. Mandate wildlife underpasses/overpasses and continuous green corridors in ecologically sensitive alignments, and prohibit their removal during cost-overrun value-engineering without independent environmental-clearance review, in line with Zhang et al.'s (2024) finding that bridge/tunnel sections reduce ecosystem-service loss relative to at-grade construction.
2. Install low-noise pavement surfaces and noise barriers within the 0-200 m high-exposure band identified in this study, prioritising stretches adjacent to residential settlements and schools.
3. Redesign access-point spacing using access-management standards (minimum spacing norms) to reduce the access-point-density predictor identified as significant in the fatality-risk regression (Table 6).
4. Install continuous median barriers of appropriate design (semi-rigid or rigid, per design speed) on divided highway sections showing high speed-differential and head-on/side-impact crash history.

6.2 Public Health Recommendations

5. Establish routine ambient air-quality and noise monitoring stations at fixed intervals along high-AADT corridors, with public reporting comparable to CPCB urban air-quality dashboards.
6. Integrate roadside-settlement respiratory and cardiovascular screening into existing primary health-centre outreach programmes, targeting the 0-200 m exposure band identified as highest-burden in this study.
7. Encourage setback zoning and vegetative buffer planting between new highway alignments and existing/planned residential development to reduce future exposure.

6.3 Traffic Management and Enforcement Recommendations

8. Deploy speed-enforcement cameras and variable message signs at locations where posted-versus-operating speed differentials are highest, since speed differential was the strongest positive predictor of fatality-risk perception in this study.
9. Strengthen post-crash emergency response along identified black-spots, consistent with Mohan et al.'s (2020) recommendation for improved trauma-care access.
10. Institutionalise periodic road-safety audits that jointly assess environmental, health, and safety indicators using the Highway Sustainability Index framework proposed in Section 1.1, rather than safety audits alone.

6.4 Policy Recommendations

Adopt a corridor-level Highway Sustainability Index (Equation 1) as a standard reporting requirement for new highway projects and major rehabilitation works, integrating environmental, health, and safety sub-indices into project appraisal. Align highway development planning with Sustainable Development Goals 3, 11, and 13 and the UN Decade of Action for Road Safety 2021-2030 through binding environmental and social safeguard clauses in project contracts.

VII. CONCLUSION

This study set out to examine, within a single explanatory sequential mixed-methods design, the environmental, public-health, and road-safety dimensions of highway transport systems using a stratified sample of 257 respondents together with secondary engineering and government statistics. The results demonstrate that highway transport intensity is significantly associated with ecosystem degradation, that proximity to highway corridors is significantly associated with poorer self-reported health and quality of life, and that specific, modifiable infrastructure and traffic-management variables significantly predict fatality-risk outcomes. All three null hypotheses were rejected, confirming the conceptual premise that environmental, health, and safety outcomes of highway transport are interdependent rather than isolated engineering, epidemiological, or enforcement problems. The convergence of the present corridor-level findings with international evidence (Debelu et al., 2024; Zhang et al., 2024; Munzel et al., 2021) and Indian national statistics

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(Mohan et al., 2020; Krishna et al., 2023; MoRTH, 2023) strengthens confidence that the observed patterns are not artefacts of a single local context but reflect a broader, generalisable pattern of highway-transport sustainability deficits. Critically, however, the cross-sectional and largely self-reported nature of the primary data means that causal directionality-particularly for health outcomes-cannot be established with the same confidence as the well-controlled engineering measurements of emission load and fatality rate; longitudinal and objectively monitored follow-up studies are recommended. Ultimately, the study argues that sustainable highway transport requires simultaneous, integrated attention to ecological design, public-health safeguarding, and safety engineering-operationalised through tools such as the Highway Sustainability Index-rather than sequential or siloed remediation after infrastructure is already in place.

REFERENCES

1. Boogaard, H., Patton, A. P., Atkinson, R. W., Brook, J. R., Chang, H. H., Crouse, D. L., Fussell, J. C., Hoek, G., Hoffmann, B., Kappeler, R., Kutlar Joss, M., Ondras, M., Sagiv, S. K., Samoli, E., Shaikh, R., Smargiassi, A., Szpiro, A. A., Van Vliet, E. D. S., Vienneau, D., . . . Forastiere, F. (2022). Long-term exposure to traffic-related air pollution and selected health outcomes: A systematic review and meta-analysis. *Environment International*, *164*, Article 107262. https://doi.org/10.1016/j.envint.2022.107262
2. Centers for Disease Control and Prevention. (2013). Residential proximity to major highways - United States, 2010. *Morbidity and Mortality Weekly Report*, *62*(3), 46–50. https://www.cdc.gov/mmwr/preview/mmwrhtml/su6203a8.htm
3. Debelu, D., Mengistu, D. A., Aschalew, A., Mengistie, B., & Deriba, W. (2024). Global public health implications of traffic related air pollution: Systematic review. *Environmental Health Insights*, *18*, 1–18. https://doi.org/10.1177/11786302241272403
4. Deka, G., & Ranganathan, S. (2022). Road safety issues in India. *Journal of Student Research*, *11*(3). https://doi.org/10.47611/jsrhs.v11i3.2709
5. Guo, L., Xu, J., & Zhao, S. (2025). Assessment of the impact of road construction on the ecological environment: A case study of two expressways in China. *Remote Sensing*, *16*(23), 4478. https://doi.org/10.3390/rs16234478
6. Hanse Chinthong, K., Baruah, J., & Phukan, I. (2023). Road traffic injuries and their associated risk factors in Dibrugarh district, Assam: A cross-sectional study. *International Journal of Community Medicine and Public Health*, *10*(8), 2839–2844. https://doi.org/10.18203/2394-6040.ijcmph20232374
7. Hopkins, D. (2020). Sustainable mobility at the interface of transport and tourism. *Journal of Sustainable Tourism*, *28*(2), 129–143. https://doi.org/10.1080/09669582.2019.1683007
8. Krishna, C. M., Singh, A., & Jha, K. N. (2023). Safety improvement on Indian highways. *Journal of Safety Engineering*, *12*(1), 1–12. https://doi.org/10.5923/j.safety.20231201.01
9. Ministry of Road Transport and Highways. (2023). *Road accidents in India 2022*. Government of India, Transport Research Wing.
10. Mohan, D., Tiwari, G., & Bhalla, K. (2020). *Road safety in India: Status report 2020*. Transportation Research and Injury Prevention Programme, Indian Institute of Technology Delhi.
11. Munzel, T., Sorensen, M., & Daiber, A. (2021). Transportation noise pollution and cardiovascular disease. *Nature Reviews Cardiology*, *18*(9), 619–636. https://doi.org/10.1038/s41569-021-00532-5
12. PMFIAS. (2025). *Road safety in India: Status and statistics*. https://www.pmfias.com/road-safety-in-india/
13. Sovacool, B. K., & Griffiths, S. (2020). Culture and low-carbon energy transitions. *Nature Sustainability*, *3*(9), 685–693. https://doi.org/10.1038/s41893-020-0519-4
14. Tavera Busso, I., Rodriguez, H., & Carreras, H. (2025). Short-term associations of traffic-related air pollution with cardiorespiratory outcomes among low-income residents from a US-Mexico border community. *Atmosphere*, *16*(2), 153. https://doi.org/10.3390/atmos16020153

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15. World Health Organization. (2023). *Road traffic injuries* [Fact sheet]. https://www.who.int/news-room/fact-sheets/detail/road-traffic-injuries
16. Zhang, H., Xu, X., Zhang, C., Fu, Z.-P., & Yang, H.-Z. (2024). Novel method for ecosystem services assessment and analysis of road-effect zones. *Transportation Research Part D: Transport and Environment*, *129*, Article 104120. https://doi.org/10.1016/j.trd.2024.104120
17. Zheng, J., Liu, S., Peng, J., Peng, H., Wang, Z., Deng, Z., Li, C., Li, N., Tang, L., Xu, J., Li, J., Li, B., Zhou, Y., & Ran, P. (2022). Traffic-related air pollution is a risk factor in the development of chronic obstructive pulmonary disease. *Frontiers in Public Health*, *10*, Article 1036192. https://doi.org/10.3389/fpubh.2022.1036192

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