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Behavioral dimensions of rural road accident vulnerability in the Garhwal region of Uttarakhand: A behavioral and disaster management perspective

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ABSTRACT

The Garhwal Himalaya of Uttarakhand presents a distinctive road-safety environment in which difficult terrain, unstable slopes, variable weather, narrow and winding roads, and highly seasonal traffic interact with human and institutional factors. Pilgrimage, tourism, commercial transport, and local mobility place substantial and uneven pressure on mountain road corridors, particularly during peak travel periods. In such a setting, accident vulnerability cannot be understood adequately through road engineering alone. Behavioral factors—including speeding, fatigue, distraction, impaired driving, risk perception, overconfidence, and the normalization of hazardous conditions—may interact with environmental and infrastructural constraints to influence both accident occurrence and severity. This exploratory paper examines the behavioral dimensions of rural road accident vulnerability in the Garhwal region using secondary evidence from peer-reviewed research, national road-safety literature, disaster-management material, and region-specific studies. The review focuses on behavioral risk, temporal and seasonal patterns, environmental exposure, institutional preparedness, emergency response, and the interaction among these dimensions. Particular attention is given to evidence from Uttarakhand and the Garhwal Himalaya, alongside national evidence used for contextual comparison. On the basis of the reviewed literature, the paper proposes the Sustainable Accident Reduction Model (SARM), a conceptual framework in which accident vulnerability is viewed as the result of interactions among behavioural risk, environmental exposure, infrastructure, enforcement, community preparedness, and emergency-response capacity. The framework does not treat any single intervention as sufficient. Instead, it emphasizes coordinated prevention, mountain-specific driver training, risk communication, climate- and hazard-sensitive infrastructure planning, enforcement, community participation, and timely trauma and rescue systems. The paper concludes that future research should complement this secondary-source synthesis with district-level accident databases, driver and community surveys, geospatial analysis, and longitudinal evaluation of interventions.

Keywords: Risk perception, Transport governance, Road accidents, Garhwal Himalaya, Disaster management, Mountain transport, Behavioral safety, Rural vulnerability

1. Introduction

Road transport is indispensable to the social and economic life of the Garhwal Himalaya. Roads connect rural settlements with markets, schools, health facilities, administrative centres, pilgrimage destinations, and tourism economies. At the same time, the physical and environmental setting of the region creates a road-safety context that differs substantially from that of the plains. Steep slopes, sharp curves, elevation changes, unstable geological formations, landslide-prone sections, fog, rainfall, falling debris, and limited road width can reduce the margin for driver error and complicate emergency response. The expansion of tourism and pilgrimage has added another layer of complexity. Traffic volumes can increase substantially during peak periods, including the Char Dham Yatra season. Commercial drivers may face pressure to complete trips within constrained schedules, while private drivers and visitors may have limited experience of mountain-road conditions. These circumstances create a setting in which exposure, behavior, infrastructure, and environmental hazards may reinforce one another.

The central issue examined in this paper is therefore not simply whether roads are physically adequate. It is how people behave within a hazardous transport environment and how that behavior interacts with road geometry, weather, traffic pressure, enforcement, and institutional preparedness. A driver who is speeding on a dry road may face one level of risk; the same behavior on a wet, poorly visible, sharply curved road may have substantially different consequences. Similarly, an accident that is survivable when emergency services can reach the site quickly may become fatal when terrain and distance delay rescue or trauma care. The be

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havioral perspective is particularly relevant because repeated exposure to hazardous conditions can change risk perception. Drivers who routinely use the same roads may become familiar with hazards and consequently perceive them as less threatening. Familiarity may support skill development, but it can also contribute to overconfidence and the gradual normalization of unsafe practices. The present paper therefore treats behavior not as an isolated individual characteristic but as one component of a wider socio-technical and environmental system.

The paper is exploratory and based on secondary evidence. It synthesizes behavioral road-safety literature with evidence concerning hill-road accidents, disaster risk, environmental vulnerability, and transport governance. It also proposes a conceptual framework—the Sustainable Accident Reduction Model (SARM)—to integrate these dimensions for future empirical testing.

2. Statement of the problem

Improved connectivity and continuing investment in mountain roads do not automatically eliminate accident vulnerability. Road widening, surface improvement, and improved connectivity may reduce certain physical constraints while simultaneously increasing traffic volumes, operating speeds, or exposure. During construction and maintenance, temporary road conditions may also create additional hazards. Consequently, changes in infrastructure need to be evaluated together with changes in traffic behavior, enforcement, environmental exposure, and emergency preparedness. In rural Garhwal, the problem is compounded by the spatial distribution of settlements and services. Long distances, difficult terrain, limited lighting, and the possibility of landslides or road blockage can delay emergency assistance. Weather can change road conditions rapidly, reducing visibility and traction. These characteristics mean that prevention and post-crash response are closely connected: reducing unsafe behavior may prevent crashes, while improving rescue and trauma systems may reduce the severity of outcomes when crashes occur. A further concern is the relative lack of integrated behavioral analysis at the regional level. Road safety discussions often separate engineering, enforcement, driver behavior, disaster management, and ecological vulnerability. The present paper seeks to bring these dimensions together and to identify how they can be incorporated into a practical framework for rural mountain transport safety.

3. Research objectives

1. To examine how behavioral factors influence rural road accident vulnerability in the Garhwal Himalaya.
2. To examine reported accident patterns in relation to time of day, season, road condition, and driving behavior.
3. To identify behavioral factors repeatedly associated with fatal and non-fatal accident outcomes in the reviewed literature.

4. Review of literature

4.1 Behaviour and human factors in road safety

Road-safety research increasingly recognises that crashes result from interactions among road users, vehicles, infrastructure, traffic conditions, and the wider transport system. Mohan (2002) [1] highlighted the distinctive road-safety challenges of less-motorised and developing-country environments, where diverse road users and heterogeneous traffic interact with infrastructure that may not have been designed for contemporary mobility patterns. Mohan *et al.* (2009) [2] similarly emphasised the importance of behavioural, enforcement, infrastructure, and post-crash-care dimensions in road-traffic injury prevention.

Driver behaviour is also shaped by risk perception and individual differences. Shinar (2017) [3] synthesised extensive evidence on human behaviour in traffic safety, including driver capacities, driving style, temporary impairments, distraction, and crash causation. Drivers may

not always perceive objective hazards in proportion to their actual risk. Repeated exposure to a hazardous environment may alter the subjective perception of risk. In mountain settings, this mechanism may be relevant to the routine acceptance of blind curves, steep gradients, narrow road sections, unstable slopes, or reduced visibility. Such normalisation does not imply that experienced drivers necessarily behave unsafely; rather, it identifies a behavioural mechanism through which familiarity may influence perceived risk.

Fatigue, distraction, impaired driving, speeding, and risky overtaking are important behavioural factors in road safety. Their relevance may increase during long-distance travel and periods of elevated traffic demand. Research on young and novice drivers has additionally highlighted the importance of individual differences, driving behaviour, risk perception, and behavioural responses to the driving environment (Shinar, 2017) [3]. These factors are potentially relevant to the Garhwal context, particularly where commercial, tourist, and pilgrimage-related transport operate under seasonal and traffic-pressure conditions.

4.2 Evidence from hilly and Himalayan terrain

Region-specific evidence is particularly important because national averages cannot fully represent the distinctive characteristics of mountain-road environments. Joshi *et al.* (2014) [4], in a retrospective study conducted at a tertiary-care centre in Srinagar Garhwal, Pauri Garhwal, examined road-traffic accidents in a hilly region of northern India. The study considered accident patterns, fatalities, injuries, severity, and disability and therefore provides region-specific evidence concerning the interaction between road accidents, injury severity, and the difficult terrain of Uttarakhand. The evidence should nevertheless be interpreted within the design and time period of the original study. Joshi *et al.* (2014) [4] examined cases recorded during December 2009–November 2011; therefore, its findings cannot be treated as a complete representation of all Garhwal districts or contemporary traffic conditions. Its principal value for the present analysis is as region-specific evidence that complements broader road-safety literature.

4.3 Ecological vulnerability and disaster risk

Road safety in the Himalaya is closely connected with environmental and disaster risk. The Indian Himalayan Region is exposed to hazards including landslides, earthquakes, flash floods, intense rainfall, and associated environmental disturbances. Such hazards can affect road safety by damaging road surfaces, destabilising slopes, obstructing carriageways, reducing visibility, and delaying emergency access. From a transport perspective, these environmental conditions should be analysed together with road design, traffic exposure, vehicle characteristics, and human behaviour. Environmental and infrastructure factors should not, however, automatically be interpreted as direct causes of individual crashes. The relationship between environmental degradation, slope instability, road development, and accident occurrence requires location-specific empirical investigation. Road development and widening in fragile mountain environments have also generated concerns regarding slope stability and environmental vulnerability. Such concerns should be distinguished from accident statistics: environmental disturbance or slope instability may increase exposure to hazards, but the magnitude and direction of their effect on particular accident patterns cannot be established without appropriate empirical data.

4.4 Governance, enforcement, and scale of the problem

National road-accident statistics provide an important context for understanding the scale of road-safety challenges in India. The National Crime Records Bureau's *Accidental Deaths & Suicides in India (ADSI) 2023* provides nationally reported information on accidental deaths, including traffic accidents and their temporal distribution (NCRB, 2024). The ADSI dataset is an official national statistical source maintained by the National Crime Records Bureau under the Ministry of Home Affairs.

These national data are useful for contextual comparison, but they should not be interpreted as direct estimates of Garhwal-specific risk because road environments, traffic composition, population characteristics, exposure levels, and reporting conditions differ among regions. Governance affects road safety through enforcement, signage, speed management, road maintenance, weather-related communication, emergency response, and coordination among relevant agencies. The WHO road-traffic injury prevention framework similarly emphasises risk-factor assessment, evidence-based prevention, post-crash care, multisectoral collaboration, and road-safety policy. In mountain areas, institutional capacity may have particular importance because the consequences of a crash can depend not only on whether an accident occurs but also on how rapidly rescue and medical services can reach the location.

5. Research Methodology

The study adopts an exploratory qualitative research design based on secondary-source analysis. It does not claim to generate a new accident-rate estimate or causal coefficient. Instead, it synthesises evidence from road-safety research, region-specific studies, national statistical reports, disaster-management literature, environmental vulnerability assessments, and transport-related material relevant to Uttarakhand and the Garhwal Himalaya. The analytical framework was organised around eight recurring dimensions: (i) speeding and aggressive driving, (ii) driver fatigue, (iii) mobile-phone distraction and other attention-related behaviours, (iv) night and low-visibility travel, (v) weather and environmental hazards, (vi) road geometry and infrastructure, (vii) institutional preparedness and enforcement, and (viii) community awareness and emergency response. These dimensions are consistent with the broader multidisciplinary approach to road-injury prevention, which considers human, environmental, infrastructural, enforcement, and post-crash factors together (Mohan, 2002; Shinar, 2017; WHO, 2006) [1, 3].

The evidence was interpreted thematically rather than through *meta-analysis*. Where the reviewed material provides numerical statistics, these are reported as source-specific findings. Where the literature in-

dicates a qualitative pattern but does not provide a comparable dataset, the paper describes that pattern without presenting an invented numerical estimate. Any conceptual or illustrative figure is therefore distinguished clearly from an official accident count or statistically estimated index. This approach has an important limitation: secondary-source synthesis cannot establish causal relationships for the Garhwal region with the same confidence as a longitudinal, district-level empirical study. The proposed Sustainable Accident Reduction Model (SARM) framework should consequently be treated as a conceptual model requiring validation through primary and longitudinal data.

6. Accident vulnerability patterns in the Garhwal region

6.1 Temporal and year-wise vulnerability

The reviewed material suggests that accident vulnerability is temporally uneven and can be affected by major environmental events, changes in traffic volume, infrastructure works, and tourism or pilgrimage activity. The source literature discusses several periods, including 2013, 2017, 2019, 2022, and 2023–24, in relation to significant environmental, infrastructural, or traffic-related pressures in the broader Uttarakhand/Garhwal context. However, these years should not be interpreted as a statistically validated ranking of annual accident rates without a harmonised district-level accident database. Accordingly, the present study treats them as periods associated with notable risk-related events or pressures rather than as a verified annual accident time series. This interpretation is consistent with the study's exploratory secondary-source design and avoids converting heterogeneous historical evidence into an unsupported numerical trend. Where year-wise patterns are presented graphically, the figure should therefore be labelled as an **illustrative or conceptual synthesis** rather than an official accident-count series. Such a presentation is intended to demonstrate the temporal concentration of risk-related pressures identified in the reviewed literature and not to estimate the actual annual accident burden of Garhwal.

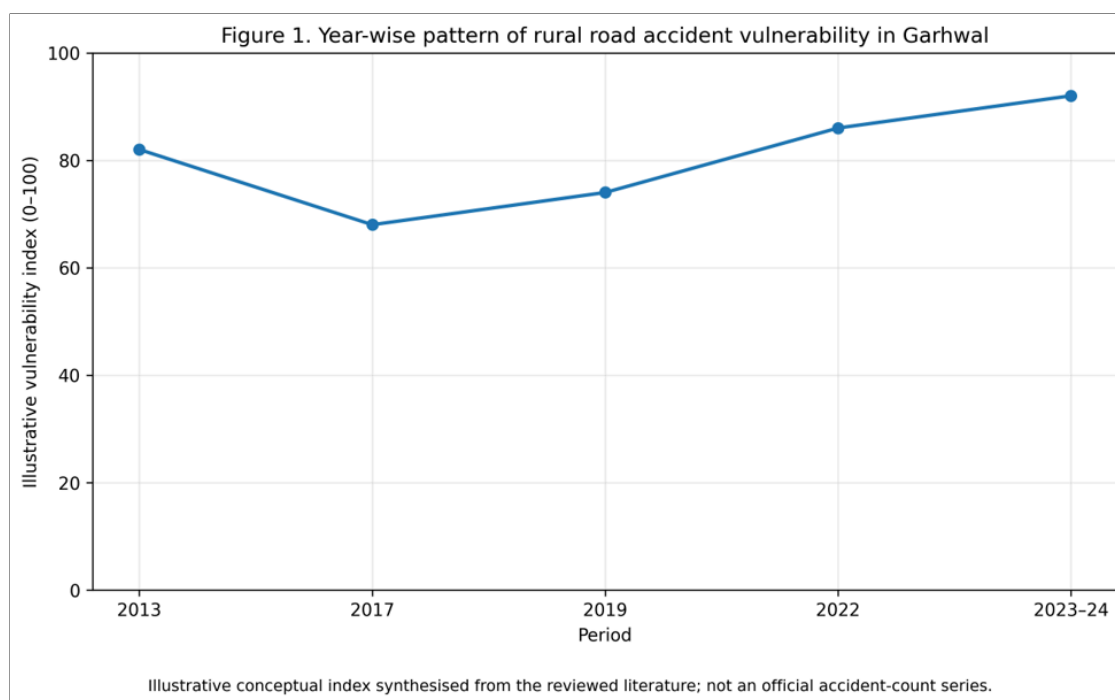


Figure 1. Year-wise pattern of rural road accident vulnerability in Garhwal — illustrative conceptual figure only; not an official accident-count series.

6.2 Seasonal vulnerability

Monsoon conditions are an important component of mountain-road vulnerability. Rainfall can reduce pavement friction, increase the likelihood of debris on carriageways, trigger or reactivate landslides, and

reduce visibility through fog and intense precipitation. The source material identifies July–September as a period of elevated vulnerability and notes an additional traffic-related pressure during the May–

June pilgrimage period. These two mechanisms are conceptually different: monsoon conditions increase environmental exposure, whereas peak pilgrimage traffic increases traffic density and travel demand.

Their effects may overlap in years when high traffic coincides with unstable weather.

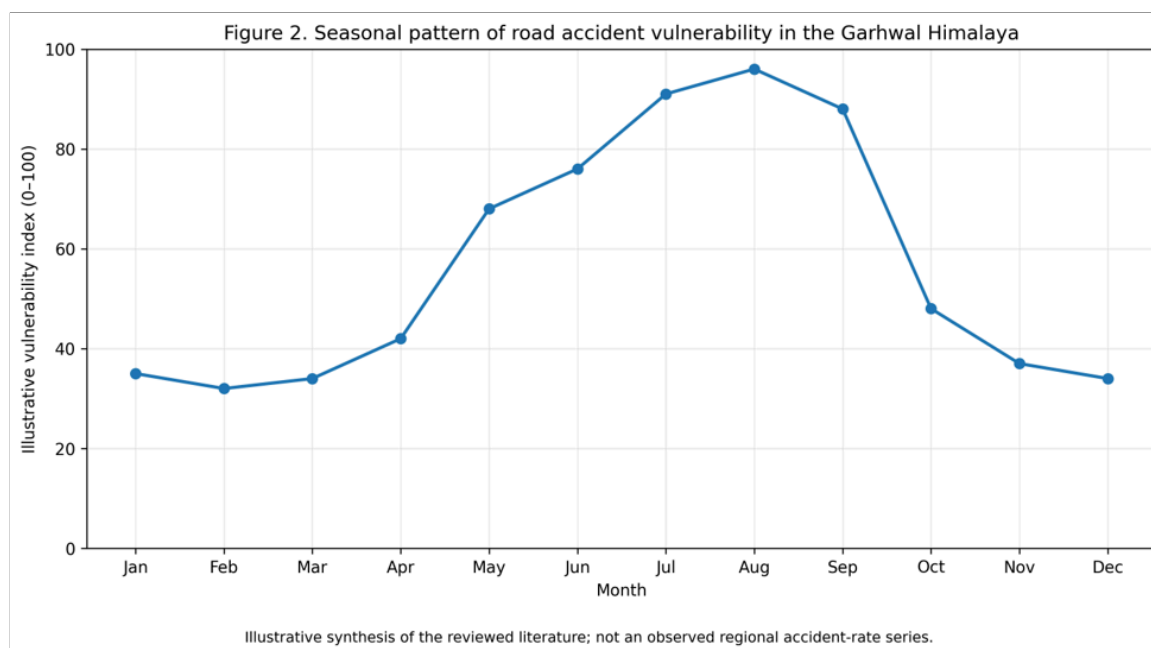


Figure 2. Seasonal pattern of road accident vulnerability in the Garhwal Himalaya — illustrative synthesis of the reviewed literature.

6.3 Time-of-day vulnerability

Time of day is relevant because visibility, fatigue, traffic composition, and driving behaviour change over a 24-hour period. The source material highlights evening and night travel as periods of concern and uses NCRB's national 2023 distribution as contextual evidence. According to the source draft, the 6:00–9:00 p.m. period represented 20.7% of reported accidents nationally, followed by 3:00–6:00 p.m. at

17.3%. These values are national rather than Garhwal-specific and should therefore be used only as contextual comparison. For Garhwal, the risk implications of night travel may be amplified by unlit road sections, limited sight distance, fatigue, weather, and the consequences of leaving the carriageway on steep terrain. A regional time-of-day estimate would require district-level accident records with reliable time-of-occurrence fields.

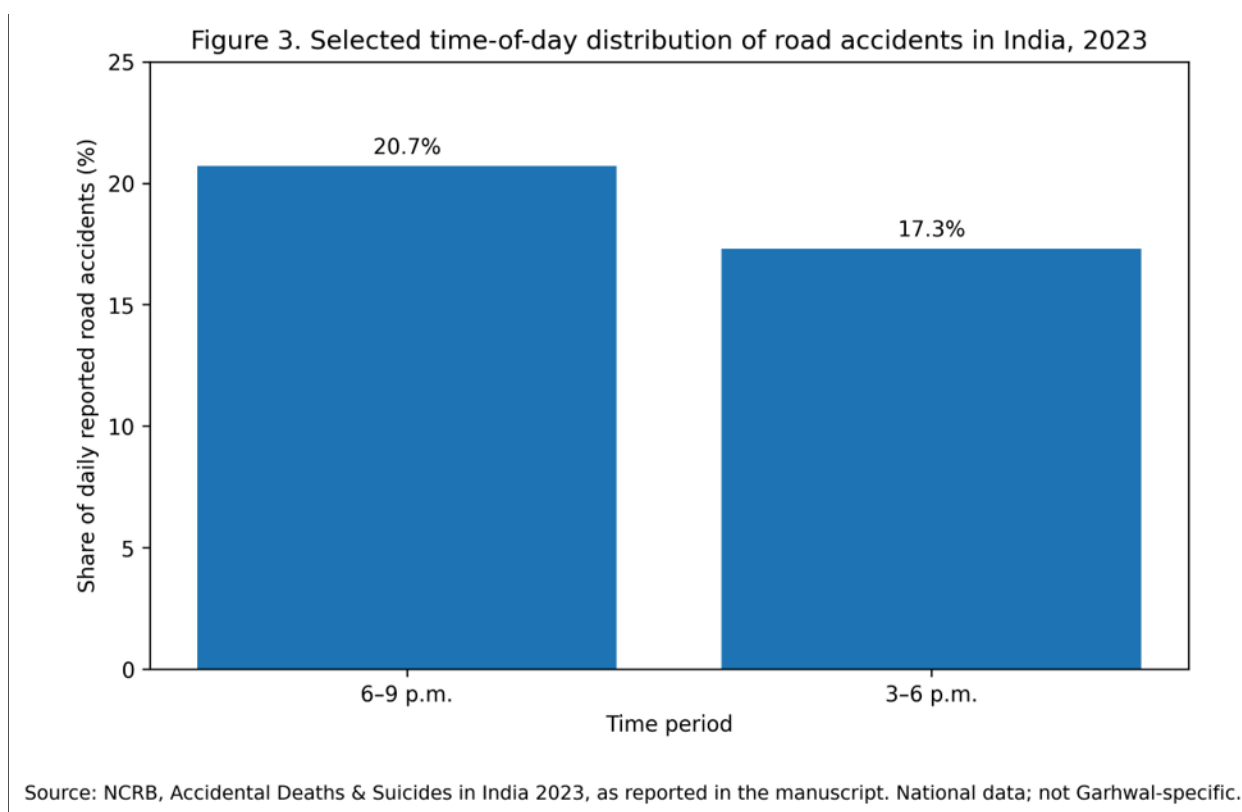


Figure 3. Time-of-day distribution of road accidents in India, 2023 — reproduce only from the NCRB 2024 source table when preparing the final journal version.

7. Fatal and non-fatal accident characteristics

The reviewed evidence indicates that severe outcomes in hill-road crashes can be associated with over speeding, loss of vehicle control, falls from elevated roads, impaired driving, and travel under low-visibility conditions. The physical geography of Garhwal can increase the severity of a crash because a vehicle leaving the road may encounter a steep slope or gorge, while rescue may be delayed by terrain and access constraints. Non-fatal crashes may include skidding, low-speed collisions, and incidents associated with wet or unstable road surfaces. The distinction between fatal and non-fatal outcomes is analytically useful because severity is influenced not only by crash occurrence but also by impact conditions, roadside environment, vehicle protection, seat-belt or helmet use, rescue time, and access to trauma care. Therefore, accident prevention and post-crash response should be considered as complementary components of road-safety policy.

8. Sustainable Accident Reduction Model (SARM)

The Sustainable Accident Reduction Model (SARM) is proposed as a conceptual framework for understanding accident vulnerability in Himalayan transport systems. It is based on the premise that accident

risk is dynamic rather than fixed. A road segment can become more or less hazardous depending on the interaction of driver behavior, traffic exposure, environmental conditions, infrastructure, enforcement, and emergency preparedness. The model contains two broad sets of interacting factors. The first comprises risk-increasing conditions: speeding, fatigue, distraction, impaired driving, night travel, high traffic pressure, adverse weather, unstable slopes, and hazardous road geometry. The second comprises protective capacities: driver education and mountain-specific training, speed management and enforcement, appropriate road design and maintenance, hazard communication, community preparedness, rapid rescue, and timely trauma care.

Conceptually, SARM can be represented as:

$$\text{Accident Vulnerability} = f(\text{Behavioral Risk} + \text{Environmental Exposure} + \text{Traffic Pressure} + \text{Infrastructure Constraints} + \text{Community Preparedness})$$

This expression is not a statistical equation and should not be interpreted as a quantitative estimator. It is a conceptual representation of the paper's central argument: vulnerability emerges from interacting risk and protective factors rather than from a single cause.

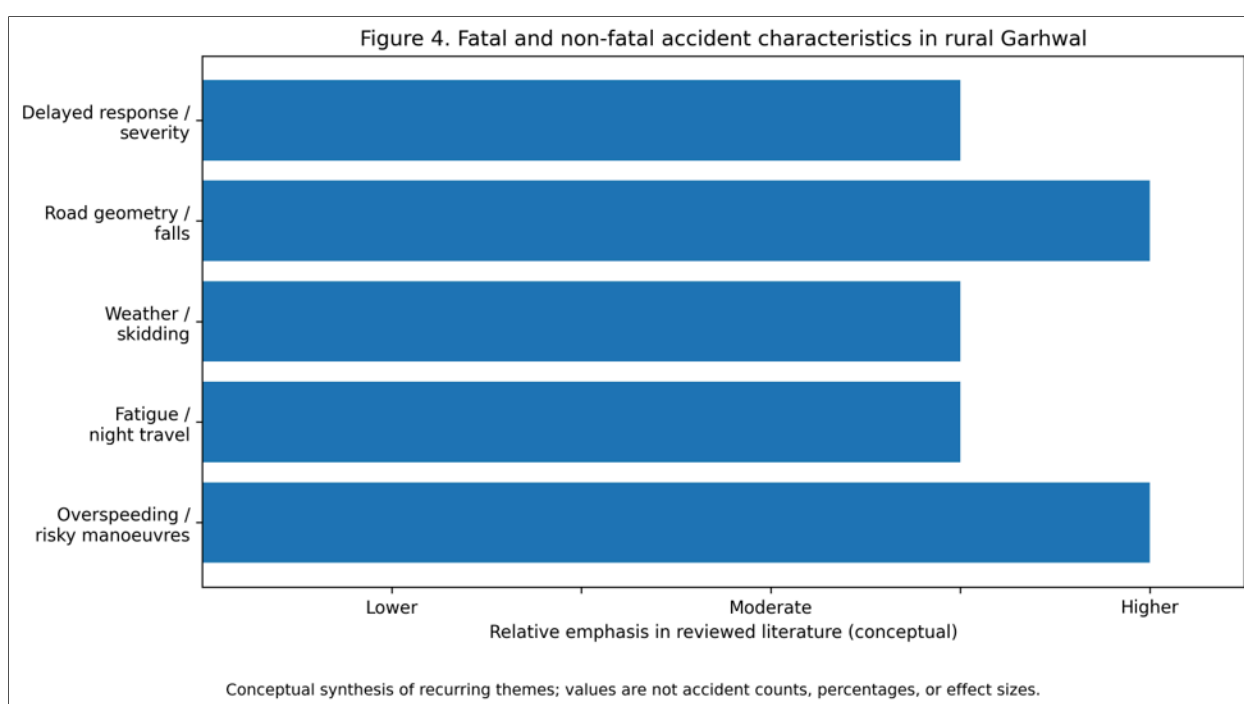


Figure 4. Fatal and non-fatal accident characteristics in rural Garhwal — conceptual synthesis based on the reviewed literature; not a statistical composition of all regional crashes.

The practical value of SARM is its systems perspective. A technically improved road may still experience serious crashes if speed management is weak or drivers are fatigued. Conversely, behavioral compliance may reduce risk but cannot eliminate hazards created by unstable slopes, inadequate barriers, or severe weather. Sustainable accident reduction therefore requires simultaneous attention to prevention, infrastructure, governance, community preparedness, and emergency response.

9. Behavioural dimensions of vulnerability

Risk perception is a central behavioural dimension. Drivers may underestimate hazards when they are familiar with a route, when traffic is moving normally, or when previous journeys have been completed without incident. Such experience can create confidence, but excessive confidence may reduce compliance with safe speeds, overtaking restrictions, or visibility-related precautions (Shinar, 2017) [3]. Speeding is particularly important on mountain roads because available stopping distance is constrained by curves, gradients, road width, visibility, and roadside drop-offs. A small increase in speed may

therefore have consequences disproportionate to the numerical increase itself. Dangerous overtaking and abrupt manoeuvres can similarly become critical on blind curves or narrow sections (Mohan, 2002; Shinar, 2017) [1, 3]. Fatigue is another major concern, especially during long-distance and high-demand travel. Prolonged driving, irregular schedules, congestion, and night travel can reduce attention and reaction time. During pilgrimage seasons, commercial drivers may face intensified work demands. Driver scheduling, rest opportunities, and monitoring are therefore behavioural as well as organisational issues (Mohan *et al.*, 2009; Shinar, 2017) [2, 3].

Distraction, including mobile-phone use, can reduce visual, manual, and cognitive attention. In a mountain environment, where hazards may emerge suddenly around a curve or after a change in weather, divided attention can be particularly consequential. Impaired driving is also a critical safety concern and requires appropriate enforcement and preventive communication (Shinar, 2017; WHO, 2004) [3]. Finally, normalisation of risk deserves specific attention. Shinar's (2017) [3] discussion of risk perception provides a useful theoretical basis for understanding how repeated exposure can reduce perceived danger. For Garhwal, the implication is not that local drivers are in

herently careless, but that safety programmes should actively refresh risk awareness among people who spend long periods driving in the same hazardous environment (Shinar, 2017) [3].

10. Institutional vulnerability

Institutional capacity influences both the probability of crashes and the severity of their consequences. Key elements include road inspection and maintenance, guardrails and crash barriers, signage and delineation, speed enforcement, weather warnings, landslide monitoring, traffic management, rescue coordination, ambulance access, and trauma-care availability (Mohan *et al.*, 2009; WHO, 2004) [2]. Emergency response is especially important in mountainous areas.

Difficult access, road blockage, steep terrain, and long travel distances can increase response time. The evidence cited in the source material regarding on-site mortality in hill-road accidents illustrates why rescue and trauma systems should be treated as part of road-safety planning rather than as an entirely separate health-sector issue (Joshi *et al.*, 2014) [4]. Institutional risk also arises when responsibilities are fragmented across agencies. Effective mountain-road safety requires coordination among transport authorities, police, road agencies, disaster-management institutions, health services, local governments, tourism and pilgrimage administrations, and community organisations. Shared protocols and interoperable communication systems can improve the transition from crash detection to rescue and medical treatment (WHO, 2004; Mohan *et al.*, 2009) [2].

Figure 5. Sustainable Accident Reduction Model (SARM): conceptual framework

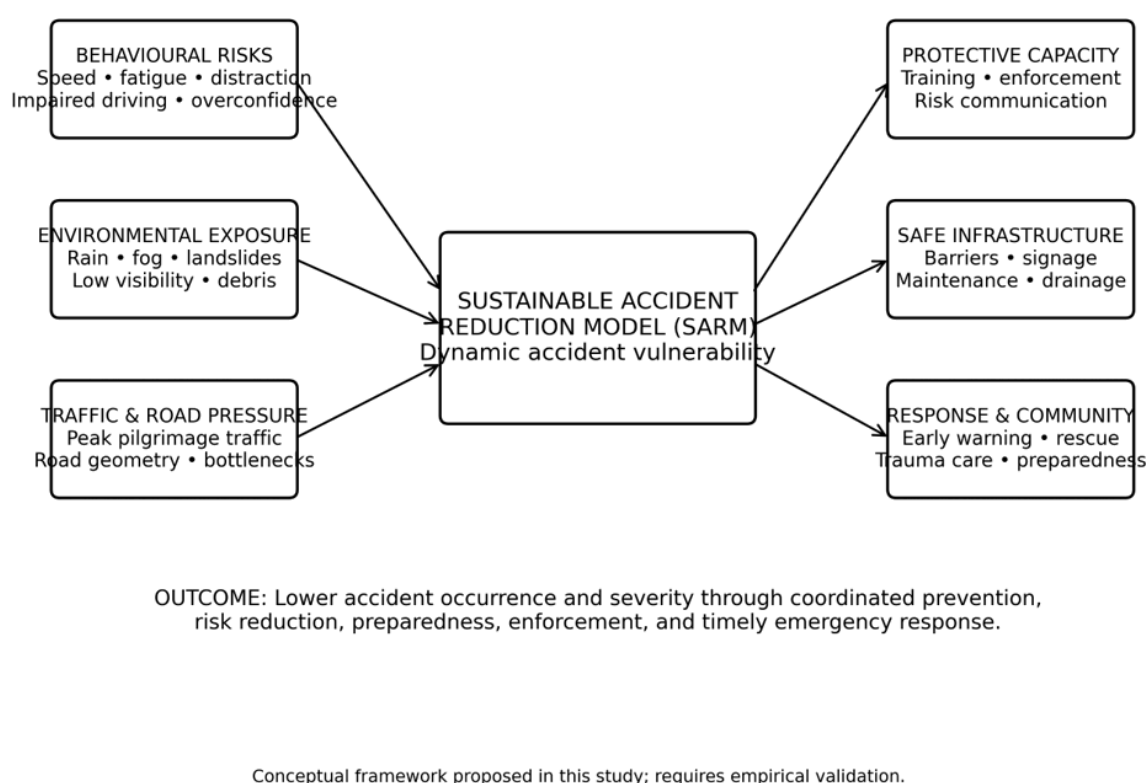


Figure 5. Sustainable Accident Reduction Model (SARM) — conceptual framework integrating behavioral, environmental, infrastructural, institutional, and community factors.

11. Findings and Discussion

- Behavioural and environmental factors should be analysed together** because their effects are interactive rather than independent. A systems-based approach to road safety recognises that human behaviour interacts with road design, vehicle conditions, environmental exposure, and institutional arrangements (Mohan, 2002; Shinar, 2017) [1, 3].
- Speeding, fatigue, impaired driving, distraction, and risky overtaking** are repeatedly identified in road-safety literature as important behavioural risk factors and are relevant to mountain-road conditions (Mohan, 2002; Mohan *et al.*, 2009; Shinar, 2017) [1, 2, 3].
- Monsoon conditions can increase exposure** through reduced friction, poor visibility, debris, and slope instability; peak pilgrimage periods introduce a separate source of traffic pressure. In the Himalayan context, environmental hazards and changing weather conditions can further complicate road accessibility and emergency response (Gupta *et al.*, 2024) [5].

- Night and evening travel deserves targeted attention** because fatigue and reduced visibility can coincide with difficult road geometry. Driver visibility, fatigue, and risk perception are recognised components of human-factor road safety (Shinar, 2017) [3].
- Region-specific evidence supports the importance of driver-related factors**, but available studies do not justify treating behaviour as the sole or universally dominant cause of accidents across Garhwal. Evidence from Srinagar Garhwal demonstrates the relevance of driver-related and injury-related characteristics in a hill-road setting, but the study's geographic and temporal scope limits its generalisation to the entire Garhwal region (Joshi *et al.*, 2014) [4].
- Emergency-response capacity can influence accident severity and survival**, making rescue and trauma access important components of transport vulnerability. This is particularly relevant in mountainous regions where terrain, road blockages, and travel distances can delay access to medical facilities (Joshi *et al.*, 2014; WHO, 2004) [4].

7. **The available secondary evidence is insufficient for a statistically validated Garhwal-wide risk index;** future work should therefore prioritise harmonised primary and administrative data. Differences in geographical coverage, definitions, reporting periods, and study methodologies limit direct aggregation of existing evidence (NCRB, 2024; Joshi *et al.*, 2014) [4].

12. Policy and management recommendations

i. Sustained behavioural programmes

Implement year-round road-safety communication in rural Himalayan communities rather than relying exclusively on short seasonal campaigns. Messages should address speed, fatigue, distraction, impaired driving, seat-belt and helmet use, and mountain-specific hazards (Shinar, 2017; WHO, 2004) [3].

ii. Mountain-specific driver training

Introduce competency-based training for commercial, public-transport, tourist, and pilgrimage-route drivers, including hazard perception, controlled downhill driving, curve negotiation, weather response, fatigue management, and emergency procedures. Such training should be adapted to the specific demands of mountain-road environments (Mohan *et al.*, 2009; Shinar, 2017) [2, 3].

iii. Speed and fatigue management

Use targeted speed enforcement, trip scheduling, rest requirements, and monitoring during periods of high traffic demand. Commercial operators should be encouraged to adopt documented driver-rest protocols (Shinar, 2017; WHO, 2004) [3].

iv. Climate- and hazard-sensitive infrastructure

Integrate landslide susceptibility, drainage, slope stability, visibility, roadside protection, and climate exposure into road planning, maintenance, and widening decisions. The Himalayan region's exposure to climate-related and geological hazards makes environmental risk assessment an important component of infrastructure planning (Gupta *et al.*, 2024) [5].

v. Early warning and communication

Strengthen weather, landslide, road-closure, and traffic information systems. AI-supported tools may be considered where adequate historical and real-time data are available, but their accuracy and operational reliability should be validated before deployment. Early warning and timely dissemination of hazard information are important components of disaster-risk reduction and transport resilience (Gupta *et al.*, 2024) [5].

vi. Emergency response and trauma care

Improve rescue access, ambulance coordination, first-response capacity, communication networks, and referral pathways in high-risk mountain corridors. The importance of timely post-crash care is particularly relevant to geographically difficult hill environments (Joshi *et al.*, 2014; WHO, 2004) [4].

vii. Community-based preparedness

Train communities located along major corridors in first response, safe incident reporting, evacuation procedures, and basic emergency support, while ensuring that community roles complement rather than replace professional rescue services. Community participation and multisectoral coordination are recognised components of effective injury-prevention and emergency-response systems (WHO, 2004).

viii. Integrated governance

Establish coordination mechanisms among road agencies, police, transport departments, disaster-management authorities, health services, local governments, and pilgrimage/tourism administrations. A coordinated institutional approach is consistent with the multidisciplinary framework recommended for road-traffic injury prevention (Mohan *et al.*, 2009; WHO, 2004) [2].

ix. Evidence-based monitoring

Develop a harmonised district-level accident database containing location, time, road geometry, weather, vehicle type, behavioural factors, injury severity, emergency-response time, and outcome variables. Such a database would permit empirical testing of SARM and improve comparability between districts and time periods (NCRB, 2024).

13. Limitations and future research

The principal limitation of this paper is its reliance on secondary evidence. The reviewed studies differ in design, geographic coverage, sample size, definitions, reporting periods, and outcome measures. Consequently, their findings cannot be combined into a single regional accident rate without additional standardisation. Some statements in the literature concern road safety generally, whereas others are specific to Uttarakhand or hill districts; these levels of evidence should not be treated as interchangeable (Joshi *et al.*, 2014; NCRB, 2024) [4]. A second limitation concerns the use of illustrative conceptual figures. Such figures are useful for communicating patterns emerging from qualitative synthesis, but they are not substitutes for official accident statistics. In the final journal submission, every numerical figure should be reconstructed from an identifiable dataset, with source, year, population, denominator, and method clearly stated. Future research should collect district-level accident data and combine them with GIS-based road characteristics, rainfall and landslide records, traffic-volume measurements, driver surveys, emergency-response times, and hospital or trauma-centre records. Multivariate analysis could then test the relative contribution of behavioural, environmental, infrastructural, and institutional variables. Longitudinal studies could also evaluate whether driver training, enforcement, warning systems, or infrastructure interventions produce measurable reductions in crashes and fatalities (Mohan *et al.*, 2009; WHO, 2004) [2].

14. Conclusion

Road accident vulnerability in the Garhwal Himalaya is a multidimensional problem. The evidence reviewed in this paper indicates that behavioural factors such as speeding, fatigue, distraction, impaired driving, risk misperception, and the normalisation of hazardous conditions can interact with difficult road geometry, weather variability, traffic pressure, ecological instability, and institutional constraints (Mohan, 2002; Shinar, 2017; Gupta *et al.*, 2024) [1, 3, 5]. The resulting vulnerability cannot therefore be adequately represented as a simple engineering problem. At the same time, the evidence does not support attributing accidents to driver behaviour alone. Roads, vehicles, environmental hazards, traffic exposure, enforcement, emergency response, and access to trauma care all influence outcomes. A systems approach is consequently more appropriate for rural mountain transport safety (Mohan *et al.*, 2009; WHO, 2004) [2]. The Sustainable Accident Reduction Model (SARM) offers a conceptual structure for this systems approach. It places behavioural risk and environmental exposure alongside protective capacities such as infrastructure quality, enforcement, community preparedness, and emergency response. The model is intended as a basis for empirical testing rather than as a validated predictive model. Its principal contribution is to frame accident reduction as a coordinated process involving people, infrastructure, institutions, and the mountain environment. For policy and practice, the central implication is that road development should be accompanied by mountain-specific driver training, evidence-based speed and fatigue management, hazard-sensitive infrastructure, reliable warning systems, community preparedness, and rapid rescue and trauma care (Mohan *et al.*, 2009; WHO, 2004) [2]. Future empirical research can determine which combinations of these measures produce measurable improvements in safety across the diverse districts and corridors of Garhwal.

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