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Delineating road accident risk along mountain roads

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Abstract

Purpose – The purpose of this paper is to attempt to put forth an innovative geographic information system (GIS)-based methodology for demarcating stretches of mountain roads with differential probability of road accidents. The proposed methodology has been tested in a sample road network of Uttarkashi district in Uttaranchal (India) and exhibits potential of reducing the frequency of road accidents by adopting suitable site-specific measures along accident-prone stretches.

Design/methodology/approach – The paper is based on the hypothesis that road accidents in the mountain roads are largely due to the three basic road parameters that distinguish mountain roads from those in the plains; sinuosity, gradient, and width. The sinuosity of the road is calculated for every 500 meter stretch of the road map layer while for delineating the gradient of the road topographic data of Survey of India maps have been used. The paper utilises GIS-based environment for correlating these parameters and delineating accident-prone road stretches.

Findings – The proposed new methodology for delineating differential accident risk in mountain roads has been utilised for demarcating road stretches with differential probability of road accidents and the output has been correlated with the actual road accident database of Uttarkashi district in Uttaranchal. The correlation exhibits the potential of this methodology for practical mitigative planning-related purposes. The same can also be utilised for better aligning the planned roads.

Research limitations/implications – Human factor is the most important determinant of road accidents and non-incorporation of this parameter is the biggest limitation of the proposed methodology. Further, the effectiveness of the proposed methodology is the function of the validity of the hypothesis. The methodology is, however, highly flexible and has ample scope for accommodating other parameters as well. The effectiveness of the output is, however, a function of the accuracy of the input maps. Road layer considered in this paper has been prepared from the maps available with the State Government Department (Public Works Department) and their alignment does not depict the ground details. Input road layer prepared with precision Geographical Positioning System (GPS), preferably differential, mapping would produce more realistic results. The positions of the past accident sites for the purpose of correlations are taken from the data provided by the State Police Department and these are not very accurately determined. GPS-based database of the accident locations would help in effective correlations.

Practical implications – The methodology proposed in this paper is an attempt to scientifically delineate differential accident-prone stretches of the mountain roads. This would pave the way for implementation of site-specific measures for reducing probability of road accidents and better aligning of the proposed roads.

Originality/value – Previously a large number of workers have used GIS-based techniques for delineating hazard and risk related largely to landslides, floods and earthquakes but the same has never been employed for delineating road accident risk. The methodology is simple, unique, original and functional and has immense practical utility for reducing the menace of road accidents in mountain roads.

Keywords India, Mountains, Road safety, Road accidents, Accident prevention

Paper type Research paper

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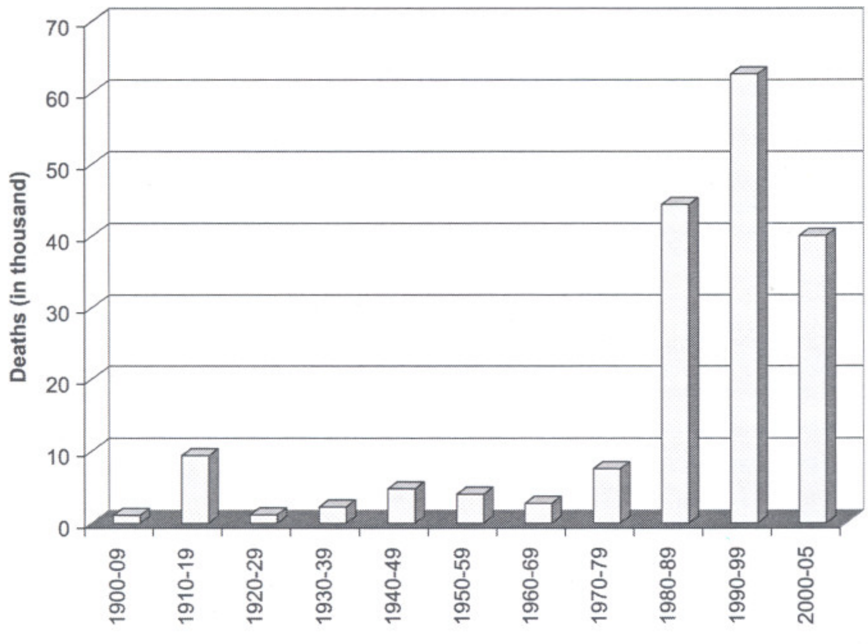
Road accidents: a cause of concern

In the post-Industrial Revolution era the world has witnessed many new modes of transport and with increasing transport traffic there has been a sharp rise in human toll of transport accidents in the previous decades (Figure 1) as against reducing global human toll of natural disasters. Increasing incidences of road accident and the associated loss of human lives and loss of workforce due to the disability caused by these, together with the economic losses that these inflict upon the society is a cause of global concern. Road accident as a cause of death has been placed at ninth position in 1990 amongst a comprehensive list of more than one hundred separate causes of death (World Health Organisation, 1996, 1999). The forecasts made with the analysis of data and trends suggest that by the year 2020 this would move up to sixth place. In terms of "years of life lost" and "disability-adjusted life years" the road accidents would reach at second and third place respectively by 2020. Ghee and others (1997) have analysed the worsening road accident scenario and the global death toll of road accidents in 1998 is estimated to be 1.17 million (World Health Organisation, 1999). Data on road accidents for the previous 30 years (1970-2001) for India indicate that these have gradually increased from 1,14,100 to 3,94,800 in this period; registering a 3.5 fold increase. Annual road fatalities in this period have increased from 14,500 to a staggering 80,000 and the number of people injured in accidents has risen from 70,100 to 3,82,700 (MORTH, n.d.).

Fatality Index (FI) defined as the ratio of fatalities in road accidents to the people injured in accidents, gives important clues on the nature of road accidents (Rautela and Sharma, 2004). FI studies for the mountainous state of Uttaranchal in India show that



Source: CRED database of EM-DAT; http://ww.em-dat.net

Figure 1. Decadal global human death toll due to transport accidents

the road accidents on the mountainous terrain are relatively more fatal. Together with the terrain the fatalistic nature of road accidents is attributed to the delay in response and the lack of post accident medical care for the victims.

Fast burgeoning human and economic toll of the road accidents and their adverse societal implications warrant serious interventions for reducing the same. As is a common observation some stretches of road are more prone to accidents than the others and this simple fact invokes a line of research requiring in depth investigations for identifying crucial factors (apart from human error and negligence) that make these road stretches accident prone. Once these factors have been established and analysed the road stretches exhibiting these factors can well be deduced to be risk prone. This strategy aims at quick identification of accident prone road stretches so as to design necessary mitigative strategy.

This article is an attempt to identify parameters that make mountain roads prone to accidents and to devise a methodology for delineating differential accident risk prone road stretches based upon mutual correlation of the causative factors under GIS environment. The results can then be correlated with the actual accident data in order to test the efficacy of the methodology.

A practical strategy can subsequently be proposed for reducing the probability of accidents in mountain roads and this could comprise of both structural and non-structural measures. Besides saving precious human lives and reducing trauma of the road accident victims, these interventions would at the same time promote tourism in the Himalayan states that would boost their economy.

Factors influencing road accidents in mountainous terrain

The comparison of hill roads with those in the plains needs to be undertaken in detail for better understanding the constraints of hill driving. Topography is the main factor differentiating mountains from plains. The topography promotes rectilinear road alignment in plains while the mountain roads, even without any gradient, are sinuous as these have to negotiate ridge-valley topography. Sinuosity of the mountain roads is thus a compulsion put forth by the topography of the terrain and this factor differentiates mountain roads from those in the plains.

The sinuosity of the road increases with the terrain becoming more rugged and this is responsible for:

- limiting visibility across the curves and thus increasing probability of the driver being surprised by a speeding vehicle approaching him or an obstruction on the road;
- the speeding vehicle not being able to negotiate curves and thereby losing control; and
- the fatigue in negotiating recurrent curves during long hill driving and the ensuing loss of control of the vehicle. The sinuosity of the roads is a major factor responsible for road accidents in the hills and it can be hypothesized that accident proneness of the mountain roads increases with increasing sinuosity of the roads.

The roads in the plains follow more or less a given topographic level but a large number of compulsions forbid mountain roads from being contour aligned. These include:

- bringing habitations located at different elevations under the road cover;
- avoiding bridges so as to make the roads cost effective;
- geo-technical considerations of avoiding certain zones; and
- physiographic constraints.

Thus the mountain roads cannot always be contour aligned and have to negotiate different altitudes. This makes some stretches of these roads particularly steep. Steepness or the gradient of the road is another physical parameter that is distinct to the hill roads and it together with the sinuosity makes hill driving prone to hazards. The hypothesis can thus be expanded to include that the accident proneness of the mountain roads increases with increasing gradient of the roads.

The mountainous terrain does not always have the space required for accommodating the road and therefore the hill slope has to be excavated for road construction. Geo-technical as also economic constraints limit the width of the mountain roads and it is not always feasible to make these roads as wide as those in the plains. The excavation of the hill slope often renders hill roads prone to landslides and shooting stones. Width of the road is however directly related to physical and mental fatigue of the person driving the vehicle and under similar traffic density conditions the risk of accidents on a narrow road is more than on a well paved and wide road.

Some roads in the Himalayan terrain, particularly National Highways, are well paved and maintained with necessary safety precautions but this is not the case with many other connecting roads whose maintenance is not adequate. Poor maintenance and lack of safety precautions along the road is another factor responsible for road accidents in the hills.

Visibility is one of the most important factors influencing road accidents. Weather conditions in the hills limit visibility during the rainy season as also during winters when the terrain witnesses thick fog and this is often responsible for accidents. Many accidents take place during nights and this is attributed to relative lack of visibility, and also lapses due to fatigue.

It is an observation that large proportion of accidents in the hills involve drivers that are not used to hill driving and therefore the experience of the driver in hill driving is a major factor influencing road accidents.

It is asserted that the road accidents in the hills are relatively more fatal (Rautela and Sharma, 2004) and it is therefore important to dwell upon factors that make accidents fatal. The major ones include:

- high relative relief of the area due to which the vehicles often land up in gorges and the impact is responsible for serious injuries and consequent deaths;
- non-availability of trained, highly mobile and well equipped search and rescue personnel at crucial locations often cause delay in rescue operations that reduce the probability of survival of the accident victims; and
- non-availability of adequate post-accident medical care for the accident victims often results in deaths. The victims are referred to far off medical colleges or referral hospitals and seriously injured accident victims are usually unable to cope up with this.

Parameters considered for road accident analysis

This communication attempts to put forth a GIS-based methodology for the identification of the stretches of mountain roads that are relatively more prone to accidents so as to prepare a comprehensive mitigative strategy. Some characteristic parameters have to be identified for the purpose of GIS-based analysis from amongst the various factors that make hill driving prone to accidents. Besides having a major influence upon the occurrence of accidents, these parameters have to be objective and well quantifiable. Three parameters that qualify these conditions have been identified for the purpose of analysis under GIS environment. These include: sinuosity of the road; gradient of the road; and width of the road. For the purpose of quantification and further analysis these parameters are defined below.

Sinuosity of the roads. The sinuosity of the roads is one factor that makes the mountain roads stand out distinctly against the roads in the plains and it is an important factor influencing the road accident frequency in the hills.

For the purpose of GIS based analysis the ratio of the road length and the aerial distance between any two given points is defined as the sinuosity index (SI):

Sinuosity Index (SI) = Road distance between two points/Aerial distance between the two points

The SI is unity for any given rectilinear road stretch and its value increases with the roads becoming increasingly sinuous (Figure 2).

The terrain. Terrain defines the gradient, i.e. the angle of ascent or descent of the roads that is a major parameter influencing road accidents in the hills. Terrain is measured in degrees relative to the horizontal base level. Based upon the slope the terrain is defined as plain (0-5.7°), rolling (5.7-14°) and mountainous (14-31°) as per the Hill Road Manual (1998).

Width of the road. On the basis of their formation width and width of the painted surface, roads are classified as National (NH) and State Highway (SH), Main District Road (MDR), Other District Road (ODR) and Village Road (VR).

NH is double lane with formation width of 10 meters and painted width of 7 meters while SH together with MDR and ODR is single lane with formation width of 5.95 meters and painted width of 3.75 meters. The VR has formation width of 5.95 meters

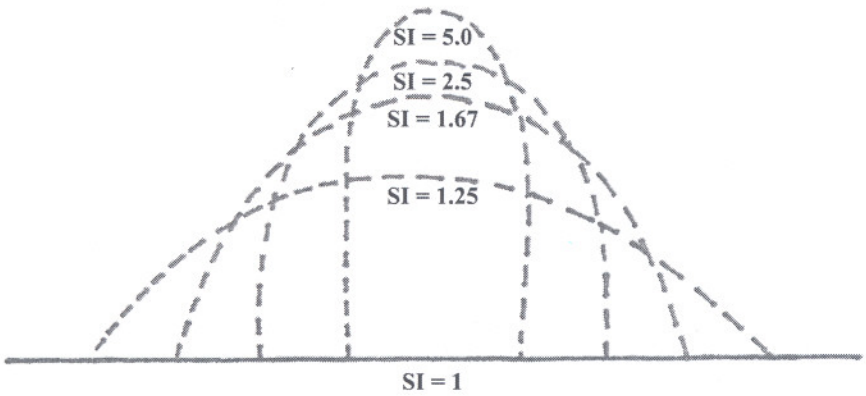


Figure 2. Schematic diagram depicting increase of Sinuosity Index (SI) with increasing sinuosity

with painted width of 3.20 meters. For the purpose of the GIS-based analysis the roads can be categorised into three classes; NH, SH + MDR + ODR and VR.

GIS-based methodology for determining differential accident risk

For the purpose of analysis under GIS environment Uttarkashi district of Uttaranchal (Figure 3) that shows the highest Fatality Index (>1) (Rautela and Sharma, 2004) is taken up for pilot studies. The terrain of the district is highly rugged with high relative relief. The road infrastructure of the district considered for GIS-based analysis is shown in Figure 4 along with other infrastructure facilities and habitations. The district has three NHs; Rishikesh-Gangotri (NH 108), Dharasu-Yamunotri (NH 94) and Harbartpur-Barkot (NH 123). These, together with the MDRs in the district, have been taken up in this analysis. Of the total road length considered for the analysis, 87.82 percent is accounted for by NH.

The SI for the roads under consideration is calculated for consecutive 500 meter stretches of the road length under GIS environment. The output map depicting SI values along the road is resampled into three classes; low sinuosity, moderate sinuosity and high sinuosity based upon bounding limits of the three SI classes (Table I). Major portion of the road length under consideration (76.74 percent) falls under low sinuosity class while 15.96 percent falls under moderate sinuosity class with the rest (7.30 percent) falling under high sinuosity class. The resampled map (SI class map) is then utilised for the purpose of further analysis.

Terrain information from the toposheets of the Survey of India (at 40 meters contour interval) is utilised for making a digital elevation model (DEM) of the area under GIS environment. Elevation data for points 500 meters apart along the road alignment is extracted from the DEM. Elevation of the consecutive points together with rectilinear distance between these has been used for calculating gradient of the intervening 500

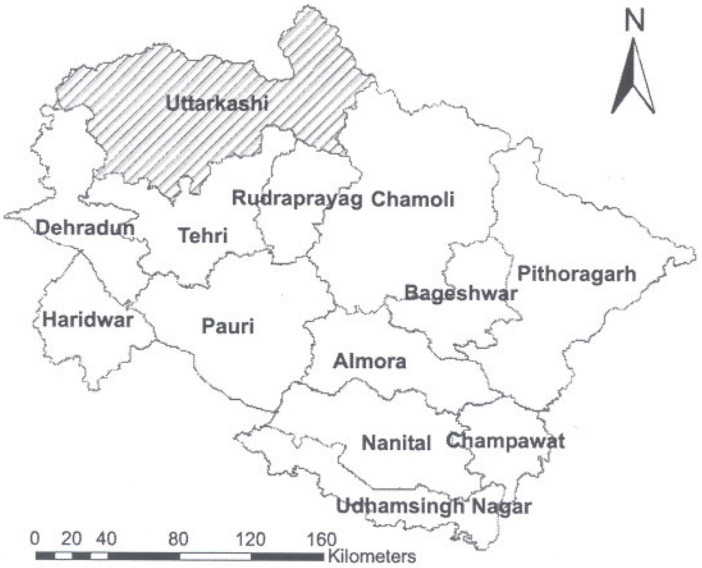


Figure 3.
Location of Uttarkashi district (Uttaranchal, India) taken up for GIS-based analysis

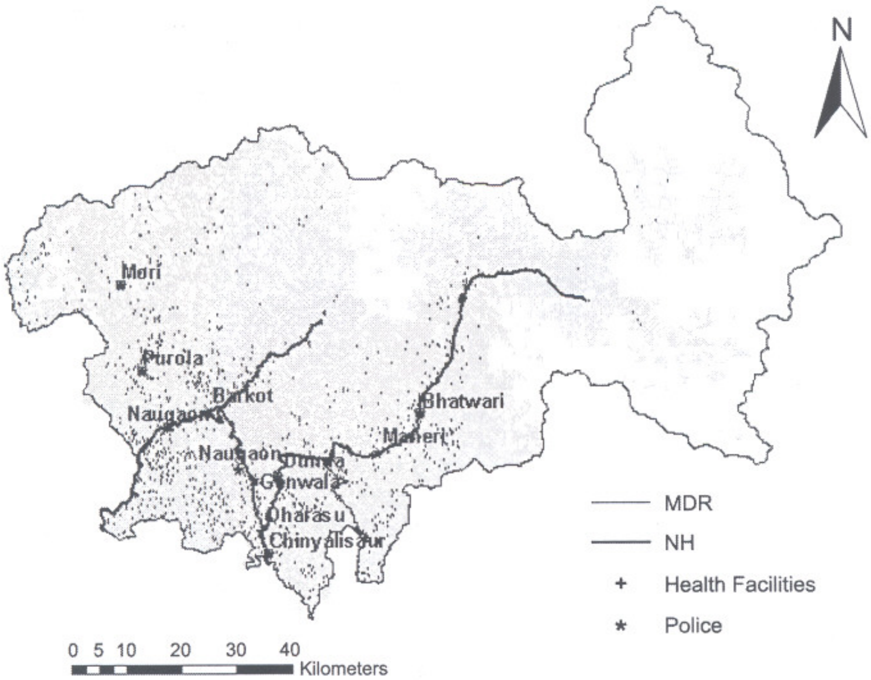


Figure 4.
Map showing the road network in Uttarkashi district (Uttaranchal, India) taken up for GIS-based analysis together with drainage network and habitations

Table I.
The bounding limits of the sinuosity index classes for preparing sinuosity index class map

Sinuosity index class	Low sinuosity index	Moderate sinuosity index	High sinuosity index
Sinuosity index value	1-1.25	1.25-1.67	>1.67

meters of road stretch. After the analysis the road map with gradient values (in °) is resampled for three terrain classes; plain, rolling and mountainous based on Table II. The three gradient classes are as per the classification suggested in *Hill Road Manual* (1998): 69.42 percent of the road under consideration falls under plain terrain class, while 18.42 percent falls under rolling and the rest (12.16) under mountainous terrain class.

Mutual correlation of the terrain class and the SI class maps has been utilized for preparing accident hazard class map in accordance with Table III. This map classifies the entire road into stretches of low, moderate and high accident hazard class; 70.10

Table II.
The bounding limits of the gradient along the road for preparing terrain class map

Terrain class	Plain	Rolling	Mountainous
Gradient value (in °)	0-5.7	5.7-14	14-31
Ratio	1:10	2.5:10	6:10

percent of the road stretch under consideration falls under low accident hazard class, while 14.95 percent falls under moderate accident hazard class and 14.95 percent falls under high accident hazard class.

The output of the correlation of terrain class and SI class maps, i.e. the accident hazard class map is then correlated with the road map having two classes (NH, SH + MDR + ODR). Table IV has been utilised for this correlation that gives the road accidents risk class map for the road network in question. In total, 14.95 percent of the road falls under low road accidents risk class while 61.91 percent falls under moderate road accidents risk class and 23.13 percent falls under high road accidents risk class.

In accordance with the proposed methodology, high road accident risk class delineates road stretches that have relatively high probability of accidents.

The actual road accident scenario

Road accident sites in Uttarkashi district between December 2004 and October 2005 (as per the records of the State Police) for which exact locations were available were mapped under GIS environment. This map is then correlated with the road accident risk class map. It was observed that 94.4 percent of the accidents along the NHs under consideration take place in road stretches with high and moderate road accident risk with the high road accident risk prone stretches accounting for 44.4 percent. The correlation suggests that 85 percent of the accidents take place along the road stretches falling under high and moderate road accidents risk class; 50 percent falling in high road accidents risk class. This correlation validates the efficacy of the methodology put forth in this paper.

Practical implications

With the input layers of road network and elevation the proposed methodology delineates differential accident risk. This analysis can then be used for prioritization of safety and mitigation strategy that could be initiated on the following lines.

	Sinuosity index class		
Terrain class	Low	Moderate	High
Plain	Low	Moderate	High
Rolling	Low	Moderate	High
Mountainous	High	High	High
		Road accident hazard class	

Table III. Correlation table utilized for preparing accident hazard class map on the basis of the correlation of terrain class and the SI class maps

	Road accident hazard class		
Road type	Low	Moderate	High
NH	Low	Moderate	High
SH + MDR + ODR	Low	High	High
VR	Moderate	High	High
		Road accident risk class	

Table IV. Correlation table used for preparing accident risk class map

Awareness. The information regarding the road stretches identified as being prone to high risk of accidents should be disseminated amongst the drivers, policy makers and those responsible for ensuring safety regulations along the road.

For making the tourists aware of the high accident risk these stretches can be shown with red colour in all tourist guide maps of the region. Sign boards and hoardings can also be put up along these road stretches for making the people conscious of the risk.

Structural measures. After demarcating high accident risk prone road stretches special site specific structural measures can be resorted to for avoiding fatal accidents. If possible bypass roads for averting these zones can be planned.

Regulations. Strict regulations need to be formulated for managing the road accidents in the hills. Night driving should be banned and the vehicular traffic without fog lights should not be allowed during rainy and winter season.

Monitoring. Strict monitoring has to be adhered to in the hills, especially in the stretches falling in the high accident risk prone stretches for ensuring abidance of driving and together with the speed regulations. Mobile monitoring teams can be established in these zones for this purpose.

Planning future road alignments. The proposed methodology can be used while planning new road alignments so as to avoid high road accident risk prone stretches where ever possible by suitably realigning the proposed road. Where realignment is not feasible adequate mitigative measures should be incorporated in the road during its first construction.

Managing accident response. In the aftermath of any accident, the effectiveness of the response has an important bearing upon the casualty rates. With the help of the road accident risk map, appropriate sites could be located for setting up search and rescue centres. Based upon the exercise carried out for Uttarkashi district, the search and rescue teams can be stationed at Dharasu, Badethi, Bishanpur and Chhatanga. These search and rescue centres would cover almost all high road accident-prone stretches and cater to the needs of all the three NHs in the district. These scientifically located search and rescue centres have, however, to be staffed with highly mobile, skilled, adequately equipped and motivated search and rescue workers together with medical staff, ambulance and other infrastructure facilities.

Under the prevailing circumstances, the villagers in the vicinity of the site of the accident are the first responders and with thorough knowledge of the terrain conditions they often discharge the rescue work very effectively. With the help of the road accident risk map the habitations falling in the vicinity of high accident risk prone stretches can be identified and efforts for training volunteers from these villages in the art of search, rescue and first aid can accordingly be initiated. Dhanpur, Badethi, Kumrara, Kishala, Barnigad and Sanglai include some of the villages identified in Uttarkashi district along the NHs for this purpose. This option of raising a grassroots level cadre of search and rescue volunteers is a highly cost-effective option for tackling the menace of road accidents in the hills.

Existing medical facilities in the vicinity of a cluster of search and rescue centres can be upgraded for managing major emergencies. The existing medical infrastructure at Uttarkashi and Chinyalisaur can accordingly be upgraded for this purpose.

The methodology is intended to pave way for minimising and better managing road accidents in the mountainous terrain so as to make driving in the hill roads safe.

Depending upon the local ground realities the process can be adequately modified and more input parameters can be incorporated for the identification of the high accident risk prone road stretches. This exercise, together with the implementation of the mitigative measures around high accident risk zone, would be making the Himalayan roads safer. The terrain houses a number of famous tourist, adventure sports, and pilgrimage centers that attract large numbers of people from across the country and abroad. Improved road safety conditions in the region would help in boosting tourism, that is one of the main sources of revenue for the Himalayan states. Not leaving everything to the government, the organizations involved in insurance, tourism, hospitality and the like need to come forward for promoting road safety awareness, as also for propagating the message in favour of safer mountain roads amongst their clients, highlighting the efforts being made by the state. This would improve the economy of the region besides reducing road accident losses and thus contributing to the prosperity of the region.

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