New methodology for demarcating high road accident risk-prone stretches in mountain roads

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There is a growing global concern over burgeoning road accident-induced losses. Terrain conditions in the mountainous regions make roads prone to fatal accidents. Sinuosity (high curvature), gradient and width of the hill roads are identified as major factors making these roads accident-prone and based upon mutual correlation of these basic road parameters, a methodology is evolved for delineating high accident risk-prone stretches of mountain roads. This methodology is used for demarcating differential probability of accident risk along the National Highway and Main District Road network of Uttarkashi District, Uttarakhand (India) and the results are correlated with real road accident database. Application of the proposed methodology thus exhibits potential for reducing the frequency of road accidents by adopting suitable site-specific measures at high accident risk-prone road stretches. These could be in the form of bringing forth awareness and by initiating suitable changes in the techno-legal regime for controlling vehicular traffic as also initiating structural measures and providing for quick post-accident search, rescue and relief facilities. These would reduce frequency of road accidents and provide quick relief to accident victims and at the same time reduce economic and human toll of road accidents.

Keywords: Gradient, mountain roads, road accidents, sinuosity.

IN the previous decades there has been a sharp rise in vehicular traffic density and this has been accompanied by increasing incidences of road accidents and associated human deaths (Figure 1). Together with the loss of workforce due to disability caused by these and the economic losses that they inflict upon society, road accidents have become a cause of concern the world over. Road accident as a cause of death has been placed at the ninth position in 1990, amongst a comprehensive list of more than one hundred separate causes of death[1,2], and the forecasts 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'[1,2], road accidents would reach the second and third place respectively, by 2020. Research has highlighted worsening road accident scenario[3] and the World Health Organization (WHO) has estimated[2] global death toll due to road accidents in 1998 to be 1.17 million. Data on road accidents for the previous more than 30 years (1970–2004) for India indicate that the number of road accidents increased from 114,100 to 429,800 in this period, registering a 3.8-fold increase[4]. During this period, annual road fatalities increased from 14,500 to a staggering 92,500, and the number of people injured in accidents rose from 70,100 to 464,600.

With 'fatality index' defined as the ratio of fatalities to people injured in accidents, it has been shown that road accidents in mountainous terrain are relatively more fatal[5]. This communication is an attempt to identify objective and quantifiable parameters that make mountain roads prone to fatal accidents and to put forth a methodology for demarcating high accident risk-prone road stretches, so that site-specific and adequate remedial measures are adopted for reducing human misery.

Sinuosity (high curvature) of the roads together with steepness, road width, road condition, negligence of driver, road worthiness of vehicles, overloading and overspeeding are identified as causes of road accidents in the hills. Among these, sinuosity, steepness and road width are recognized as objective and quantifiable, and have thus been used here for identification of high accident-prone road stretches.

Sinuosity of the mountain roads is a compulsion put forth by the topography of the hills. Sinuosity of the road increases with the terrain becoming more rugged. This is responsible for (i) constraining visibility across the curves, (ii) speeding vehicles not being able to negotiate the curves, and (iii) fatigue caused in negotiating recurrent curves. Sinuosity of the roads is thus a major factor responsible for road accidents in the hills.

The ratio of the length of a given road stretch and the aerial distance between the end-points of the same road

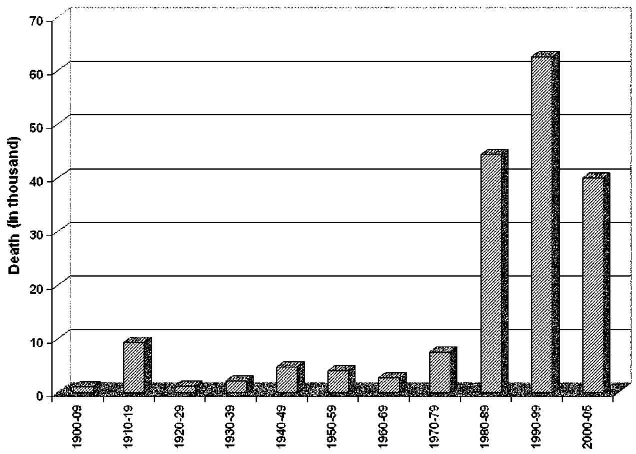

Figure 1. Bar diagram depicting decadal global human death toll due to transport accidents (source: CRED database of EM-DAT; http://ww.em-dat.net).

*For correspondence. (e-mail: piyooshrautela@hotmail.com) stretch is defined as sinuosity index (SI) (Figure 2). SI would be unity for a straight road stretch and its value would keep on increasing with roads becoming increasingly sinuous (Figure 3). The road map under consideration is split into successive stretches of 500 m each and the straight-line distance between the end-points of the successive stretches is then considered. SI is calculated for each road stretch (500 m/aerial distance in m) and values are assigned to the respective road stretches. Based upon the SI values so calculated, the road map is resampled into three classes: low sinuosity, moderate sinuosity and high sinuosity to prepare SI class map. The bounding limits of the three SI classes are given in Table 1.

The hilly terrain forbids mountain roads from being contour-aligned and major compulsions for this include (i) bringing habitations located at different elevations under the road cover, (ii) avoiding bridges so as to make the roads cost-effective, (iii) geo-technical considerations of avoiding certain zones, and (iv) physiographic constraints. This results in some road stretches being rendered particularly steep which makes them prone to accidents.

Terrain information from the toposheets of the Survey of India is utilized for extracting elevation details of the ends of each 500 m road stretch used earlier for calculating SI. The elevation details together with aerial distance between the ends of the road stretches are utilized for calculating the gradient of the particular road stretch, θ.

$$\theta = \tan^{-1}((|h_1 - h_2|)/\text{aerial distance}),$$

where h_1 and h_2 are the elevations of the end-points of the given road stretch and θ (in degrees) depicts the gradient of the road stretch from the horizontal (Figure 2). The gradient values obtained using this relationship are assigned to the respective road stretches. This map of the road network depicting gradient values (in degrees) for every 500 m stretch is then resampled into three terrain classes: plain, rolling and mountainous (based upon Table 2) to prepare a terrain class map of the road network under consideration. The three gradient classes are according to the classification suggested in the *Hill Road Manual*[6].

In the hills, valley slope has to be excavated for accommodating roads, and both geo-technical and economic constraints limit the width of the roads. Road width is directly related to physical and mental fatigue and under similar traffic density conditions, risk of accidents on a narrow road is more than on a well-paved wide road. According to their width and the width of the painted surface, roads are classified as National Highway (NH), State Highway (SH), Main District Road (MDR), Other District Roads (ODR) and Village Road (VR). NH is a double-lane road with formation width of 10 m and painted width of 7 m. SH together with MDR and ODR are single-lane roads with formation width of 5.95 m and painted width of 3.75 m. VR has a formation width of 5.95 m with painted width of 3.20 m. In the present analysis, roads are categorized into three classes, i.e. NH, SH + MDR + ODR and VR. The road map under consideration is accordingly classified into three categories. Poor maintenance and lack of safety precautions along the roads is another factor responsible for road accidents in the hills. The road width map accounts well for this parameter as NH is well maintained and VR is the least maintained.

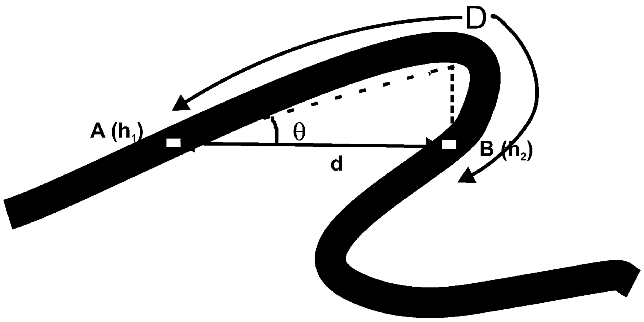

Figure 2. Definition of sinuosity index (SI). Elevations of end-points of a road stretch of length D are h_1 and h_2 respectively, while aerial distance between these is d. SI = D/d, while $\theta = \tan^{-1}((|h_1 - h_2|)/d)$.

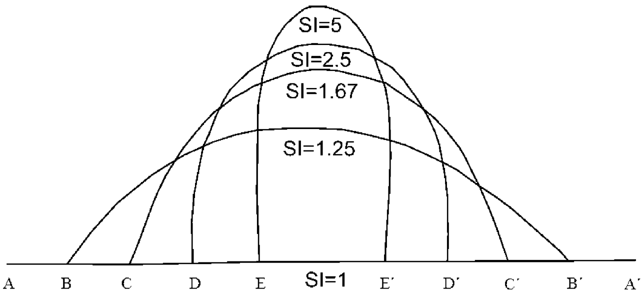

Figure 3. Schematic diagram depicting increase of sinuosity index (SI) with increasing sinuosity (curvature) of a given road stretch. SI values for road stretches of equal length increase with reducing aerial distance between their ends (*A–A′*, *B–B′*, *C–C′*).

Table 1. Bounding limits of sinuosity index classes for preparing sinuosity index class map

Sinuosity index class	Low sinuosity index	Moderate sinuosity index	High sinuosity index
Sinuosity index value	1–1.2	1.2–1.7	>1.7

Table 2. Bounding limits of the gradient along the road for preparing terrain class map

Terrain class	Plain	Rolling	Mountainous
Gradient value (in degrees)	0–5.7	5.7–14	14–31
Ratio of vertical difference in altitude to road length	1 : 10	2.5 : 10	6 : 10

Other important parameters influencing road accidents are weather conditions, experience of the driver, negligence, non-abidance to safety and driving norms, etc. All these are hard to quantify and therefore are not considered for the present analysis. Sinuosity, terrain (gradient) and road class are the three well-quantifiable parameters considered here. Based on these, three different maps of the road network under consideration are prepared, i.e. SI class map, terrain class map and road width map.

For the purpose of classification and analysis, we have used facilities available in ILWIS Geographic Information System (GIS). Other GIS software can well be used for this purpose. Road and contour maps are used as the primary input layers. Digital elevation model of the area is prepared with the help of the contour map and the same is utilized for extracting elevation details of the end-points of the successive road stretches. SI class map and terrain class map of the road network under consideration are correlated under GIS environment (based upon the relations given in Table 3) to prepare the accident hazard class map (Figure 4). This map classifies the entire road stretch into low, moderate and high road accident hazard classes. The accident hazard class map is then correlated with the road class map (based upon the relations given in Table 4) to prepare the accident risk class map (Figure 4) that has three classes of risk, i.e. low, moderate and high for the road network under consideration.

Based upon the above methodology, accident risk class map for Uttarkashi district that shows the highest fatality index (>1) in Uttarakhand[5] is prepared (Figure 5). The actual sites of road accidents in Uttarkashi District in the year 2005 (according to the records of the State Police) along the roads considered for the present analysis are correlated with accident risk class map. It is observed that 84.2% of the accidents along the NH under consideration take place in road stretches with high and moderate road accident risk, with 21.1% taking place in high road accident risk-prone stretches. The correlation suggests that 80% of the accidents take place along the road stretches falling under high and moderate road accidents risk class with 20% falling in the high road accidents risk class. This correlation validates the efficacy of the methodology put forth here.

With the input layers of road network and contours, the proposed methodology delineates differential accident risk along the considered road network that can be used for prioritizing road safety-related initiatives and preparing a mitigation strategy which could be initiated on the following lines.

Information regarding the road stretches identified as being prone to high risk of accidents needs to be disseminated amongst drivers of vehicles, policy makers and those responsible for ensuring safety regulations along the roads. For making tourists aware of the high accident risk, these stretches can be shown with red colour in all tourist guide maps. Sign boards and hoardings can also be put up along these road stretches, making the drivers conscious of the risk.

Site-specific and appropriate structural measures (crash barriers) can be erected in high accident risk-prone road stretches for avoiding fatal accidents. If possible, bypass roads for averting these zones may be planned.

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

Strict monitoring has to be adhered to for ensuring abidance of driving regulations. Mobile monitoring teams can be established in high accident risk-prone road stretches for this purpose.

Table 3. Correlation table utilized for preparing accident hazard class map on the basis of correlation of terrain class and SI class maps

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

Table 4. Correlation table utilized for preparing accident risk class map

	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		

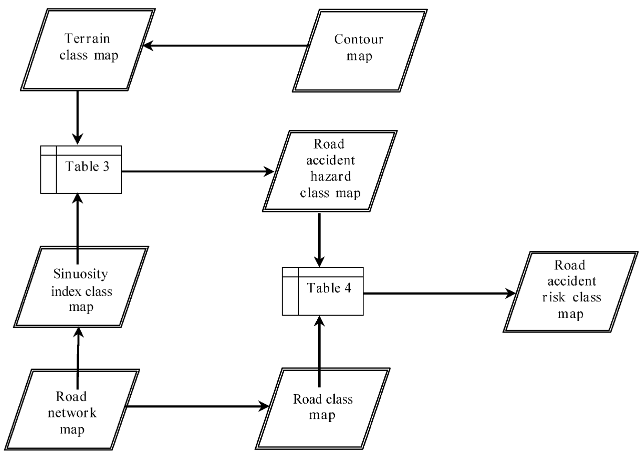

Figure 4. Flowchart depicting methodology for road accident risk class map preparation. Road network and contour maps are the required inputs in this scheme.

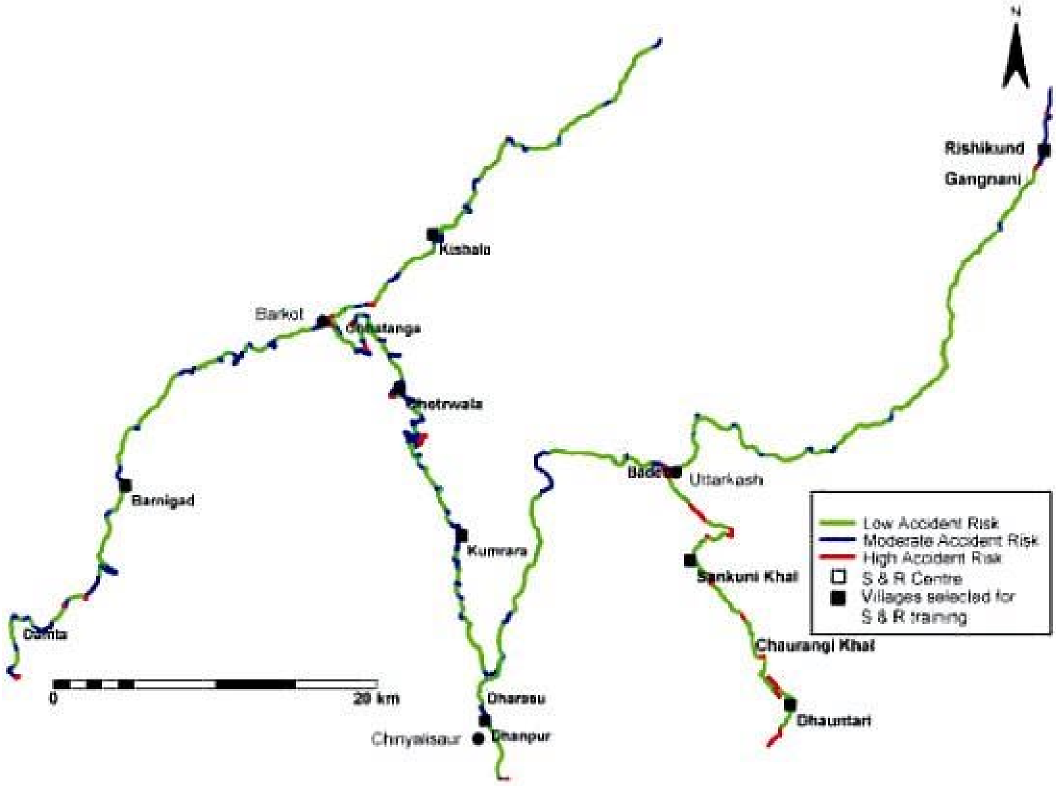

Figure 5. Road accident risk class map of the National Highway and Main District Road network of Uttarkashi district (Uttarakhand) showing location of the proposed search and rescue centres.

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

On the aftermath of any accident, the effectiveness of response has an important bearing upon casualty rates. The road accident risk map can be utilized for selecting appropriate sites to set up search and rescue centres. Based upon the exercise carried out for Uttarkashi District, Gangnani, Badethi, Chaurangi Khal, Dharasu, Chhatanga and Damta are identified as appropriate sites for setting up search and rescue centres (Figure 5). These centres would cover almost all high road accident-prone stretches and would cater to the needs of all the three NHs in the district. However, these centres would have to be staffed with highly mobile, skilled, adequately equipped and motivated search and rescue workers, together with medical staff, ambulance and other infrastructure facilities.

Villagers in the vicinity of any accident site are generally the first responders and armed with thorough knowledge of the terrain conditions, they satisfactorily discharge the rescue work. Need for training village volunteers in the art of search and rescue has been highlighted and the State Government of Uttarakhand has already started imparting such training. The road accident risk map can be utilized for prioritizing the habitations to be covered under such training. In Uttarkashi District, volunteers from Rishikund, Sankuni Khal, Dhanpur, Kumrara, Kishala, Chetrwala and Barnigad can be imparted such training (Figure 5).

Lack of immediate and appropriate post-accident medical care is the main cause of high accident fatality rates in the hills. The road accident risk map can be utilized for selecting medical centres in the vicinity of a cluster of search and rescue centres that require immediate upgradation for managing major emergencies. Upgradation of existing medical infrastructure at Uttarkashi, Barkot and Chinyalisaur would be highly effective.

The proposed methodology is intended to pave the way for minimizing and better managing road accidents in 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 identification of high accident risk-prone road stretches. This exercise together with implementation of site-specific and appropriate mitigative measures around identified high accident risk zones would make the Himalayan roads safer. The terrain houses a number of famous tourist, adventure-sports and pilgrimage centres that attract a large number of people from across the country and abroad. Improved road safety conditions in the region would boost tourism, which is one of the major sources of revenue for the Himalayan States and thus contribute to the welfare of the masses.

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The past 26,000 years evolutionary history of Keoladeo National Park (Ghana), Rajasthan

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Pollen analysis of a 4.4 m trench dug out from the Keoladeo National Park (Bharatpur district, Rajasthan) situated on the western edge of the Gangetic Plains has revealed that around 26,000 yrs BP, the area was a thick forest dominated by *Holoptelea* under moist climate and good monsoon, reflecting an interstadial period. The next phase between 20,000 and 14,000 yrs BP had witnessed a barren zone with no trace of any pollen deposition. This could be attributed to poor preservation of pollen during the course of sedimentation, most likely due to the drying of the lake during the Last Glacial Maximum period. This was followed by favourable humid conditions and good vegetation cover in the region. Gradually this huge lake turned into a wetland.

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Keywords: Keoladeo National Park, monsoon variability, palaeoclimate, vegetation change, World Heritage Site.

RAJASTHAN in western India is known for its vast stretch of desert. Initiation of desert conditions and temporal change in its geographical coverage has always invited the attention of geologists, palaeoclimatologists, ecologists and geomorphologists. Quaternary vegetation succession and corresponding climatic fluctuations in the region are known through various studies[1–10].

Most of the work carried out in the region covers the western part of the Rajasthan desert. Eastern Rajasthan has not received due attention for similar Quaternary palaeoclimatic studies despite the fact that there exist a number of potential lake sites. The present communication provides palaeoclimatic proxy data and vegetation succession in the region reflecting climatic changes covering the past 26,000 yrs or so, inferred through the investigated sediment profile from the Bharatpur Bird Sanctuary (Keoladeo National Park) wetland – a World Heritage Site, which lies at the western edge of the Gangetic Plains. The Keoladeo National Park (27°7′6″–27°6′2″N and 77°29′5″–77°33′9″E) is about 2 km southeast of Bharatpur, 50 km west of Agra and 150 km south of Delhi (Figure 1). The wetland or the natural sanctuary depression covers about 29 sq. km area, of which 11 sq. km is marshy land and the rest is scrubby with a thick growth of grass.

The wetland of the sanctuary turned completely dry during 1999–2002, probably for the first time in its history, because of successive monsoon failure. This made it feasible to dig out a 4.4 m deep trench at the selected site for palynological investigations.

Vegetation of Rajasthan[11–17] covering Bharatpur and its nearby forested Park region[18–20], has been thoroughly worked out. The Park is a protected forest area and the vegetation comprises mostly scrub woodland, littered with shrubby thickets, climbers and medium-sized arboreal elements to make it a savannah-type open grassland. The luxuriance of the wetland vegetation is reflected through copious growth of free-floating, rooted amphibious and marshy taxa[21]. About 400 species of flowering plants are recorded from the Bharatpur region, of which nearly one-fourth inhabits the wetland area[22].

The Bharatpur region experiences moderate climatic conditions typical to the upper Gangetic Plains. The temperature varies from 5 to 45°C – the minimum in December–January and maximum in May–June. Onset of monsoon brings down the summer temperature to as low as 27°C, which generally continues till October. Average rainfall in the area calculated for the past 100 yrs is 655 mm, showing gradual decline as demonstrated by the annual rainfall witnessed during the last one decade which now stands only at 496 mm.

A 4.4 m deep trench was dug out from the completely desiccated main wetland (Figure 2) in order to expose the sediment profile. In all 44 samples were collected from