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An assessment of landslide hazard along alternate road alignment in the Mussoorie Hills, Uttaranchal, India

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ABSTRACT

The Dehradun-Mussoorie area comprises a combination of the Krol-Tal formations of the doubly plunging Mussoorie Syncline. The limestone belonging to the Krol C stage of the Krol Formation is being extensively mined in the west and southwest of Mussoorie. The Main Boundary Thrust (MBT) and a large number of folds and faults affect the rocks exposed all along the Dehradun-Mussoorie Highway. There are many landslides along the highway particularly near the Kalagad *Nala* and Nalota *Nala*. These cause obstruction and problems for tourists and mine traffic along the highway.

In order to ensure uninterrupted traffic and safety of tourists it became necessary to explore alternate routes for transporting the mine produce. Two of the alternate alignments identified are the Dehradun-Kiarkuli alignment and the Dehradun-Kimiari (Lambhidhar) alignment. Different levels of landsliding indices for sections of these routes were assessed and calculated on the basis of evaluation of various parameters such as lithological variation, folds and faults affecting the rock formations, hill slope angle, density of vegetation, orientation of discontinuities and extraneous activities of mining and mining traffic.

The methodology adopted included assigning numerical values for various landslide hazard levels: the highest and the lowest levels being assigned 100 and zero values respectively. The Index of Landsliding for a particular section was arrived at by averaging different values assessed for these parameters. Thus, an Index of Landsliding in the range of 91-100 represents a zone of open forests where the geological formations are thinly bedded, and/or highly jointed, dip steeply (20°-45°) and have suffered disturbance due to faulting, mining and truck traffic. A lower Index of Landsliding represents correspondingly more stable status of hill slopes.

The MBT affects the rock formations along the Dehradun-Kiarkuli alignment and Dehradun-Kimiari alignment near Punkulgaon and Galjwari respectively. Phyllite, shale and quartzite exposed along parts of these alignments have suffered excessive shattering and the highest level (91-100) of landsliding. The level of Landsliding Index is also of higher order in the vicinity of the mine areas near Kiarkuli and Lambhidhar.

In the context of extensive landsliding in the vicinity of the MBT and the mines, it is advisable that an equitable distribution of transport load is made over these alignments to save not only these routes but also the Dehradun-Mussoorie Highway from excessive destabilisation and degradation.

INTRODUCTION

The Dehradun-Mussoorie area of the Himalayan region in India represents a unique geomorphic entity that is characterised by a wide synclinal, inter-montane, closed valley merging with Mussoorie foot hills. The foothills gain about 1,500 m in height over a short distance of approximately 15 km from Dehradun. A combination of the Krol-Tal formations belonging to the doubly plunging Mussoorie Syncline is exposed in the Dehradun-Mussoorie area. Intense folding, faulting and the Main Boundary Thrust have affected these formations. These tectonic features have also affected the inherent strength of rocks as is evidenced by the landslides at Kalagad *Nala*, Nalota *Nala* and numerous other streams along the Dehradun–Mussoorie Highway.

Various geological formations lying between Dehradun and Mussoorie include sandstone, slate, phyllite, quartzite, and limestone and occasionally marble bands. Dehradun – Mussoorie area has more than 400 million tonne reserves of all grades of limestone (Mehta et al. 1959). The rocks belonging to the Krol C stage of the Krol Formation with NW–SE trend are being mined at many places lying towards west and southwest of Mussoorie. Better grade limestone is located and mined in the vicinity of Mussoorie. The mine produce is largely transported along the Dehradun-Mussoorie Highway. The highway has a limited load carrying capacity, having been originally designed to carry only tourist traffic to Mussoorie. The additional truck traffic carrying mine production has adversely affected the highway slope and triggered instability and incidences of landslides. To facilitate movement of mine produce and also ensure safety of tourist traffic, two alternate routes viz the Dehradun-Kimiari (Lambhidhar) alignment and the Dehradun-Kiarkuli alignment were identified.

GEOLOGIC AND GEOMORPHOLOGICAL SET-UP OF DEHRADUN-MUSSOORIE AREA

Geologically, Dehradun-Mussoorie area comprises the Pre-Tertiaries, Tertiaries, Old Dun Gravel, Younger Dun Gravel and Miscellaneous Alluvial deposits. The Pre-Tertiaries comprise the Chandpurs, the Nagthats, the Blainies, the Infra-Krols and the Krols in different parts of the area, representing, ortho-quartzites, phyllites, slates, shales, limestones and conglomerates (Auden 1934).

The Tertiaries represent sandstones and conglomerates of the Siwalik Group. The Old Dun Gravel is seen as massive conglomerate, whereas the Younger Dun Gravel is represented by piedmont valley deposits that originate from the Pre-Tertiaries and the Siwalik (Fig. 1). Various fluvial sediments spread over the terraces, floodplains and channel bars are included in the Miscellaneous Group that largely comprises alluvial deposits (Geological Survey of India 1981).

The rocks of Siwalik Group, which show open type of folds, flanks the structurally controlled Dun Valley. The neotectonic activity in the area has affected Dun gravel and hence brought these in juxtaposition with the Siwalik (Fig. 1). The Mussoorie Syncline which exposes the Krol Nappe (Auden 1934), is doubly plunging with NW-SE regional strike and is separated from the Siwalik rocks by the Main Boundary Thrust (MBT). Three common fold patterns, two sets of fault and three sets of joint are known to affect the strength of rocks exposed in the area between Dehradun and Mussoorie. Pore water pressure and open discontinuities have a direct relationship with the indices of landsliding in different parts of the area.

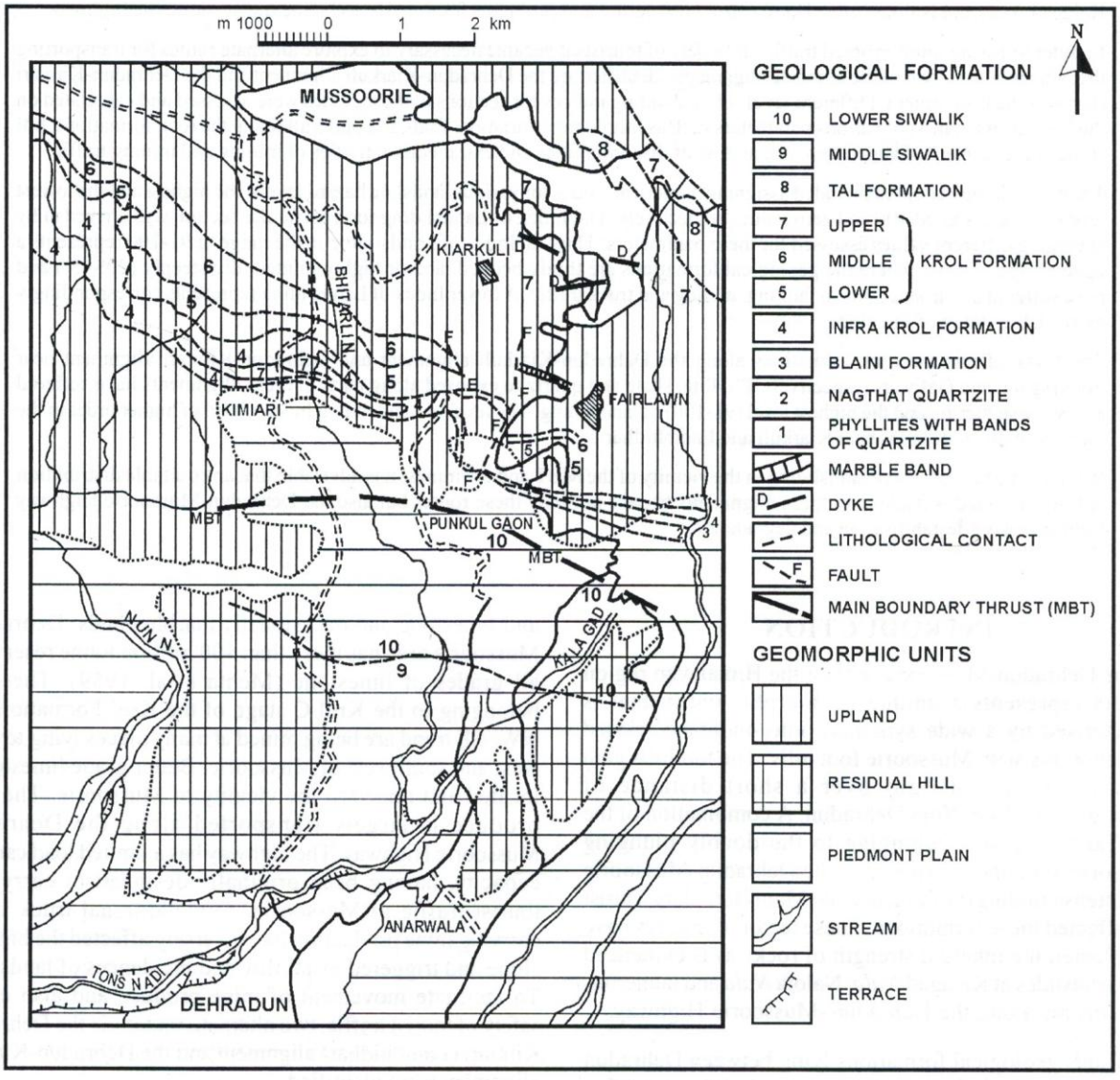

Fig. 1: Geological and geomorphological map of parts of Dehradun-Mussoorie area, Uttanchal, India (after Geological Survey of India 1981)

Geomorphologically, the Dehradun-Mussoorie area has been divided into three important geomorphic units such as the Mussoorie Upland, the Dun Valley and the Residual hills (Fig. 1). The ridge running from Cloud End in the West, through Mussoorie and extending further east represents the watershed from southern slopes of which the major part of the valleyward drainage originates.

GEOENVIRONMENTAL PARAMETERS AFFECTING INDICES OF LANDSLIDING

The geoenvironmental parameters such as lithology, slope angle, structural attributes of rocks and density of vegetation that have direct bearing on the safety of the road and stability of the hills, were identified and an attempt was made to work out the indices of landsliding for different alignments. The extraneous influences of cut slopes, location of the waste dumps or slide dumps lying over hill slopes and the vibrations due to truck traffic were also taken into account while working out the indices along the alignments. The details of the various parameters considered for evaluating the indices of landsliding are summarised below (Roy 1999).

Lithology

When a sequence comprising thinly alternating bands of different rocks suffer differential weathering, the status of slope stability becomes extremely poor, sometimes even critical, leading to frequent landslides. Numerical value for this level of sliding is assessed in the range of 100 whereas for hard and massive rocks the value is taken as zero.

Joints

The limestone of the Dehradun-Mussoorie belt at places, is marked by a high density of jointing. Similarly the Chandpur phyllites and shales sometime show high degree of fissility and the sandstones are extremely friable. These structural attributes render them far more susceptible to weathering processes and the conditions of landsliding are thereby aggravated. The numerical value for higher density of jointing and closely spaced fissility or bedding planes of the rock types was assessed at 100, whereas for massive rock without perceptible joints or bedding planes, a numerical value of zero was assigned.

Folds and faults

The rocks that are affected by faults, fold and thrusts often get crushed and shattered in the process and thus become extremely sensitive to the extraneous influences of traffic induced vibrations, rock cutting for mining and road construction. The area in the vicinity of the structural disturbances suffers from many instabilities, irrespective of the rock type and slope angle. The incidence of landsliding in the vicinity of highly shattered rocks nearby the faults were assigned a numerical value of 100 as against the zero value for rocks that have not been faulted or folded.

Slope angle

When the hill slope exceeds 30°, it lends itself to landsliding. However, where the rocks are massive and compact and have not been affected by fault, the hill slopes were quite stable even at 60°. For dip slopes, the sliding stabilises only after the angle of repose of the shattered rock mass is attained. For the purpose of working out the Index of Landsliding along the road alignment, the slopes were categorised into: (a) less than 5°: low, (b) between 5- 20°: medium (c) between 20-45°: high and (d) more than 45° : very high. Thus, a numerical value of 100 was assigned for very high level slope and the dip slopes onto the road aligned along the strike as against the zero level for low angle slopes abutting against the dip of the beds.

Density of vegetation

Low density or lack of vegetation, particularly where the rocks have prominent fissility planes, joints etc. leads to landslides even at slopes as low as 15° to 20°. Being a vital input towards stability of the hill side slopes, the density of vegetation was categorised as (a) Closely spaced forests – Thick or Dense (b) Widely spaced forests – Medium, and (c) Open forests and shrubs – Thin. Thus numerical value assessment of 100 has been made for landsliding in the barren country comprising highly jointed/ fissile rock types as against the zero value in case of closely spaced dense forests.

Extraneous influences

Such as the location of a mine, and mining traffic: location of waste dumps over hill slopes, rock – cut slopes and mining traffic, in an area, otherwise sensitive to sliding, adds to the ecological imbalance and increases the intensity and frequency of sliding. The absence of mining and rock – cut slopes in an area otherwise having no history of landsliding was assigned a numerical value of zero as against the mine area with known incidences of landsliding where a numerical value of 100, was assigned.

LANDSLIDE HAZARD ALONG THE DEHRADUN-KIARKULI ALIGNMENT

Dehradun-Kiarkuli road alignment is an extension of the Dehradun-Punkulgaon road and serves as a link road to the adjoining hinterland. The road section from Dehradun to Anarwala represents slightly undulating terrain and is marked by well-compacted gravel, sandstones, quartzites embedded in silt/ silty clay of Younger Dun Gravel. The Landsliding Index along this section is assessed at less than 10- level. The hill slope ranges between 20-25° near Anarwala and around the periphery of Old Dun Gravel hill of Rajpur (Fig. 2, Table 1). Old Dun Gravel comprises pebbles and cobbles of sandstones, quartzites and shales. The habitations here are rather sparse and the forest density of medium order. The Landsliding Index from Anarwala to Chandrauti and in the vicinity of Nalota *Nala* is of the order of 31-50 (Table 1).

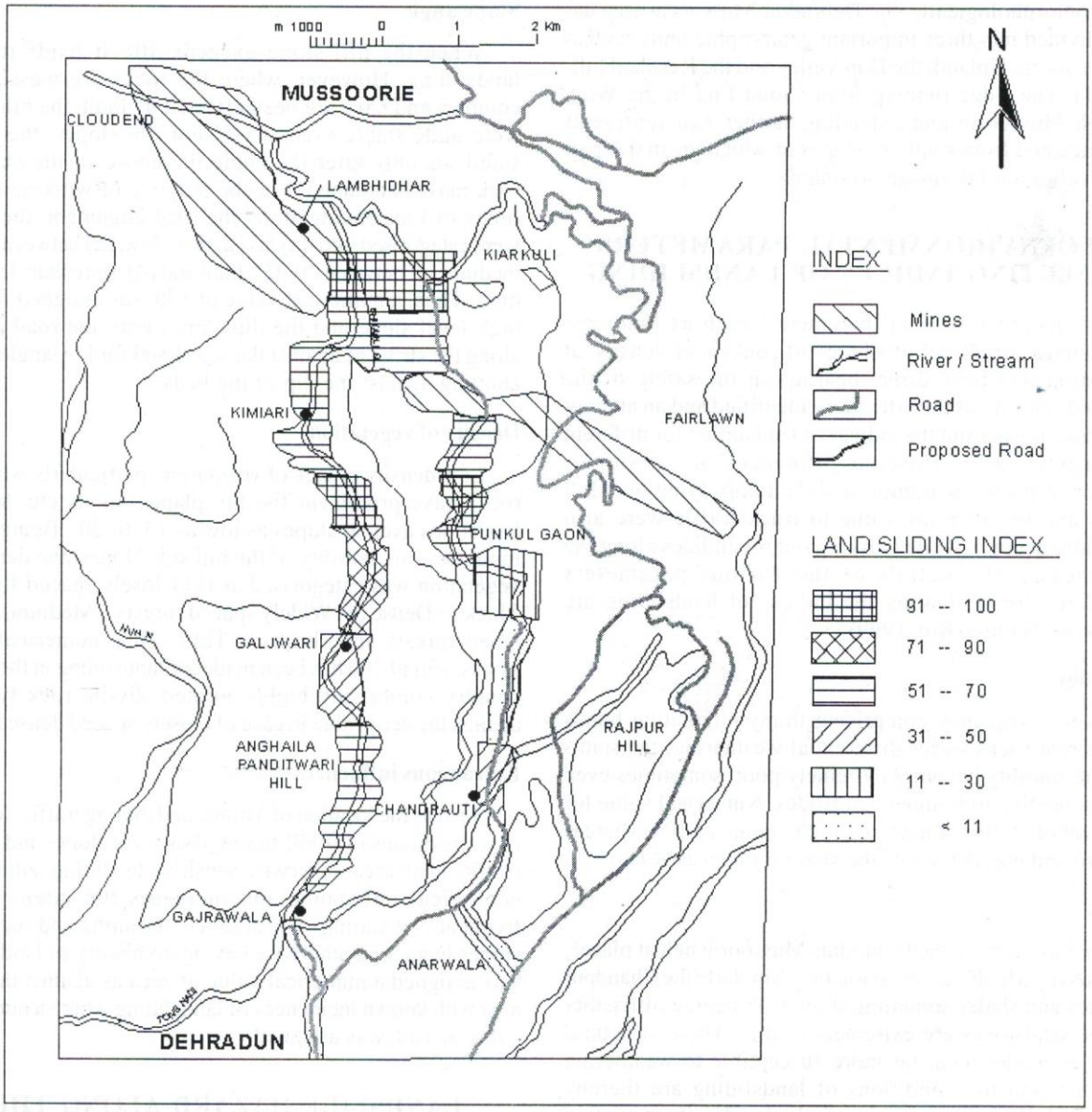

Fig. 2: Landslide Indices along parts of alternate road alignment in Dehradun-Mussoorie area, Uttaranchal, India

Northwards, the road runs over the flat summit parts of the extended ravines that represent the hill vicinity of the piedmont deposits in the valley, where the Landsliding Index is very low (less than 10 level). Further north the road passes through well compacted and stratified gravel deposits: and has a slope range of 3-5° upto Punkulgaon. The Landsliding Index for these parts is in the range of 11-30 level (Table 1).

Friable sandstone is exposed along a part of the jeepable track extending for a distance of about a km from Punkulgaon. The slope of the adjoining hills varies between 15-20°. The hill slopes are bare for most part of the road length from Punkulgaon to Kiarkuli *Nadi* where the Landsliding Index is of the order of 51-70. Adjoining the river, quartzites are exposed that are followed by highly fragile/shattered dark grey/black shale/phyllite. The hill slope here ranges between 30-45° and the density of vegetation is of Low Order. The Index of Landsliding here has been assessed to be of the order of 91-100 (Table 1).

The area between Kiarkuli *Nadi* and the Cart Mckenzi road comprises various grades of limestone that suffers high degree of shattering due to mining at two locations. The two mining areas, one of which lies towards west of the Dehradun-Mussoorie highway near Fairlawn and the other towards west of Kiarkuli village, are connected to Dehradun-Mussoorie Highway by means of the Mine Approach Roads. The Index of Landsliding from the Kiarkuli *Nadi* to Kiarkuli Mining area may be of the order of 70 (Table 1).

Table 1: Showing the indices of landsliding along different parts of the Dehradun- Kiarkuli Road Alignment

	Road length	Slope angle (degree) of adjoining hill slope	Nature of rocks and faulting/jointing etc.	Density of vegetation	Extraneous influences	Index of Landsliding
	1	2	3	4	5	6
1	Dehradun-Anarwala	Flat terrain	Younger Dun Gravel	Medium density of habitation along the road. Open to widely spaced forests.	Medium vehicular traffic	Less than 10
2	Anarwala-Chandrauti (*Pucca* road)	Undulating topography. Hill slope ranges between 20-25°	Partly Younger Dun Gravel and partly Old Dun Gravel	Congested habitation of Anarwala. Medium density of forests	Medium vehicular traffic	31-50
3	Chandrauti-Punkulgaon (*Pucca* road)	Undulating topograaphy and ravine affected terrain hill slope range 5-10°	Partly Younger Dun Gravel and partly Pediment plains.	Agricultural/Farm land	Medium vehicular traffic	11-30
4	Punkulgaon-Kiarkuli *Nadi* (*Kutcha* road)	Hillslope range 15-30°	Friable sandstone	Open forests and Bare slopes	Nominal	51-70
5	Adjoining Kiarkuli *Nadi*	Hill slope range 30-45°	Highly crushed phyllite and quartzite because of a major fault (MBF)	Open forests and shrubs and Bare slopes	Nominal	91-100
6	Mine areas	Hill slope range 40-45°	Massive Limestone with minor joints	Only shrubs and bare slopes	Mining activity of high order: mining traffic of medium order	51-70

Table 2: Showing the indices of landsliding along different parts of the Dehradun- Kimiari Road Alignment

	Road length	Slope angle (degree) of adjoining hill slope	Nature of rocks and faulting/jointing etc	Density of vegetation	Extraneous influences	Index of Landsliding
	1	2	3	4	5	6
1	Dehradun-Gajrawala (*Pucca* road)	Flat terrain	Younger Dun Gravel and terrace (silt) material	Medium density of habitation. Open to widely spaced forests and farm land	Medium vehicular traffic	Less than 10
2	Gajrawala-Galjwari road section	Hill slope range 10-40°	Compacted Old Dun Gravel	Medium forest density	Mining traffic of medium order.	51-70
3	From Galjwari for 1km length	Hill slope range 10-25°	Friable and soft sandstone	Medium forest density	Mining traffic of medium order	31-50
4	For 1 km length from No.3	Hill slope range 25-40°	Highly friable and soft sandstone	Open forest: Medium density	Mining traffic of medium order	71-90
5	Just before Kimiari	Hill slope range 25-40°	Highly fragile, crushed carbonaceous shale and quartzite because of a major fault	Only shrubs	Mining traffic of medium order	91-100
6	Kimiari to Lambhidhar Hill road section	Hill slope range between 30-40°	Small thickness of quartzite, shale, limestone and Krol limestone marked by closely spaced jointing	Very low forest density; generally shrubs open forests	Mining traffic of medium order	51-70
7	Lambhidhar Hill and its vicinity	Hill slope range between 30-40°	Krol Limestone marked by jointing	Only shrubs and bare slopes	Mining traffic and mining activity of high order	91-100

STATUS OF LANDSLIDING ALONG DEHRADUN-KIMIARI (LAMBHIDHAR) ALIGNMENT

The road length from Dehradun to Gajrawala, passing through flat land/slightly undulatory terrain, cuts through different terrace levels of the Tons *Nadi* and gradually slopes down to the river level. The Index of Landsliding from Dehradun to Gajrawala is of less than 10 level (Fig. 2, Table 2). Northwards of Gajrawala, the alignment traverses along the periphery of the Anghaila Panditwari hill, where, for about 3 km length, it cuts through the compacted Old Dun Gravel. The roadside hill slope varies between 10-40° and the forest density is of medium order. The Index of

Landsliding from Gajrawala for some distance along the periphery of the hill lies in the range of 31-50, but further northwards upto Galjwari is of the order of 51-70 (Table 2).

For about a km, from near Galjwari, the alignment goes over the summit part of the hill, through friable and soft sandstone. Roadside walls are about 2-3 m high. The Index of Landsliding is of the order of 31-50 level (Table 2). Northwards, for another km distance from Galjwari, the road traverses through highly friable and soft sandstone and cuts through roadside hill slope of 20-40° and has a medium category of forest density. The Index of Landsliding in this part of the road is of the order 71-90 level (Table 2). In its immediate vicinity, highly fragile, crushed and shattered carbonaceous shale/phyllite and quartzite are exposed that are completely barren of vegetation with hill slope of 25-40°. The Index of Landsliding here is of the order of 91-100 level (Table 2).

In the vicinity of Kimiari, small thicknesses of different rock formations of quartzite, shale, limestone are exposed. This is followed by Krol limestone, marked by closely spaced jointing. The Index of Landsliding here is of the order of 51-70 level because of very low forest density, high angle of hill slope (30-40°) and medium strength of litho-units. This road leads to the mines of Punjab Lime and Limestone Company adjoining Uttar Pradesh State Mineral Development Corporation (UPSMDC) mine over Lambhidhar hill. The hill slopes are of about 30-40° and are almost completely devoid of vegetation. Intensive mining activity involving large-scale cutting, loading, blasting and transport of the material has raised the Index of Landsliding in the vicinity of the mine area to an order of 90.

A summarised account of the indices of landsliding along Dehradun-Kiarkuli and Dehradun-Kimiari (Lambhidhar) alignment is and given in the Table 1 and Table 2, respectively and also shown in Fig. 2.

CONCLUSION

The mine production from a large number of mines located towards west of Mussoorie and Cloud End is being transported along Dehradun-Mussoorie Highway, thereby putting excessive stress on the Highway that was constructed for movement of local population and the tourists.

In order to relieve the Dehradun-Mussoorie Highway of the excessive strain and to provide viable alternatives for transport of mine produce, an assessment of the Indices of Landsliding along Dehradun-Kimiari (Lambhidhar) alignment and the Dehradun-Kiarkuli alignment was made. It was found that the Indices of Landsliding are of 91-100 level in the vicinity of MBT, where the rocks have been badly shattered. The area is prone to excessive landsliding, and needs to be stabilised for safe truck traffic. Areas in the vicinity of Lambhidhar and Kiarkuli mines also suffer from 71-90 Index level of the Landsliding because of the presence of faults and need active protection measures. However, the status of Landsliding Indices along alternate alignments as also the Dehradun-Mussoorie Highway is quite comparable (Roy 1999). It is advisable, therefore, to permit only a limited flow of mine production along these alignments. However, it is necessary that measures are taken to metal and widen Dehradun-Kamiari alignment to accommodate the truck traffic from the mines and connect it to the Cart Mckenzi road via a bypass across the UPSMDC mine to make it functionally operative.

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