Facet based landslide hazard zonation of Kodaikanal hills, Dindigul district, Tamil Nadu

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Abstract

Rapid development is taking place in Kodaikanal Township - the second important hill station in Tamil Nadu and the surrounding areas. Landslide occurrence is a frequent and recurring phenomenon in the hill ranges housing Kodaikanal. Landslide Hazard Zonation which is the primary step towards landslide hazard management and mitigation is pursued to evaluate hazard status.

Landslide Hazard zonation of the area has been carried out adopting BIS Guidelines modified by GSI taking slope facet as the fundamental unit. Nine parameters have been evaluated to work out Total Estimated Hazard (TEHD) for the individual facets. During evaluation of the individual factors, the system proposed in the guideline is modified suitable to the study area considering the type of slides, causal planes, causative factors, etc. As, rain fall is the triggering factor, average annual rain fall is not considered.

1. Introduction:

Landslide occurrence in Kodaikanal Hills- the second important hill station in Tamil Nadu is a frequent and recurring phenomenon. Many a time landslides caused loss of lives, damage to roads, dwelling units, properties and agricultural lands. Road blocks due landslide and traffic disruption put the tourists and local people into hardship. In addition, rapid development is taking place in Kodaikanal Township and the surrounding areas. Hence, it was felt that the time is befitting to manage the landslide hazard for better planning and selection of suitable sites for future development and to suggest adequate slope protection measures.

With the objective of assessing hazard status, which is the primary step towards management and mitigation, landslide hazard (Susceptibility) mapping on macro scale was taken up in the Kodaikanal Hills and environs covering about 700sq.km area bounded by latitudes 10°01'00" N and 10°25'00" N and longitudes 77°17'00" E and 77°50'00"E falling in parts of Survey of India Topo sheets No.58 F/7,8,11,12&15.

2. Terrain Characterization:

Kodaikanal Hill Range - a narrow, long linear plateau trending in ENE – WSW is the eastern extension of Western Ghat, bounded by Anamalai in the west, Udumalpettai, Dindigul and Vaigai plains in the north, east and south respectively. The area is well connected by road from Palani in north, Batalagundu in south and Dindigul in east. The nearest Railway Station is Kodai Road located about 50km southeast of the area and Airport is Madurai.

Figure 1 Location Map.

3. Geomorphology:

The Kodaikanal Hills rises from Kamakkapatti pediment with the elevation of about 360m to 2500m above m.s.l. The highest peak present in the hill range is Vembadi Shola Peak with R.L 2502m above m.s.l. The hill is characterised by undulating plateau land form in the central part, deeply dissected fringe slopes with steep to very steep slope angles in the southern part. The plateau is subjected to extensive fluvial erosion evidenced by the presence of ridges and valleys, which is conspicuous in north and east sides. The most common trend of the ridges and moderately dissected valleys with steep slopes is NE-SW followed by NW – SE trend. Trellis and sub-trellis are the most prevalent drainage patterns with straight courses indicating the structurally controlled nature of majority of the drainages. Sub-dendritic pattern is also observed at places mainly in the undulating plateau areas. The hill range is bounded by Chatrapatti Shear in the north, Surliyar Shear in the south and Batalagundu- Idayakottai and Dharapuram shears in the east.

4. Geology:

The Kodaikanal hills are occupied by country rocks of Khondalite and Charnockite Groups, Peninsular Gneissic Complex with acidic and basic intrusives and capping sediments.

Country rocks: Quartzite, calc gneiss, charnockite, pyroxene granulite, pyroxenite, banded magnetite quartzite, hornblende- biotite gneiss, granite gneiss, garnetiferous quartzo feldspathic gneiss, dolerite and gabbro dykes, granites and quartz veins are the rock types exposed in the hill range. The regional foliation trends NE-SW, dip towards SE. The strike of the foliation swerves in NW-SE and E – W directions and dip in NW.

Three phases of folding and four sets of lineaments / faults are flexure and fracture tectonic fabrics deciphered from the rock mass present in the area. Antiformal valleys and synformal ridges are commonly observed. The four sets of joints/shears/faults present are 1. Strike N 55° to 60° E – S 55° to 60° W, dip 65° to 80° towards S 30° to 35° E, 2. Strike N 40° to 50° W – S 40° to 50° E, dip sub vertical, 3. Strike N 20° E – S 20° W, dip sub vertical and 4.Strike N 80° E – S 80° W, dip sub vertical.

Capping Material: In situ soil / rock detritus, alluvial, colluvial including slide debris and pediment materials constitute the capping material occurring over the bedrock in the Kodaikanal hills. The rock detritus consists of soil, lithomarge, saprolite and other products of weathering of bedrock. In situ residual lateritic loamy soil is the predominantly found in less or moderately dissected plateau areas. Lateritic soil is light yellow to reddish brown in colour and is generally noticed at the top of in situ soil profiles below humus layer. Three categories of lateritic loamy soils viz. lateritic soil with humus layer at the top, lateritic soil without humus layer and skeletal soil are recognized.

The skeletal soils are seen as patches at places in the upper most waxing parts of the slopes. The lowermost parts of the waning slopes and the narrow, linear and flat bottomed valleys are occupied by colluvial and alluvial soils. The visual estimation of thickness of the soil horizon based on the observation on slope cuts and well sections varies from 0.5 to the maximum of 15m. Humus soil (peaty) occurs as top horizon of the soil profile predominantly developed in densely vegetated forest and plantation areas (1 – 1.5 m thick) in the forest areas, whereas it is thin (about 0.5m) or absent in cultivated areas. Lithomargic clay zone is found between lateritic soil and weathered rock. Lithomarge is reddish/pinkish/mottled in colour and mainly developed in the undulating plateau.

5. Weathering and Accumulation:

Weathering processes in the Kodaikanal hills are mainly controlled by the altitude and to some extent composition of rock. Predominantly two types of weathering are noticed in the area viz physical and chemical weathering. Physical weathering is predominant below 1000 m level giving rise to sandy soils. Physical weathering particularly exfoliation type is also seen along escarpment slopes and in the barren hills in undulating plateau giving rise to exfoliation domes. Chemical weathering is predominant in the undulating plateau.

Picture 1 Lithomarge and top soil

Picture 2 Palaeo /Old Slide Debris

In order to find out the mechanical properties and to classify the soil, four undisturbed samples have been collected one each from top humus soil, in-situ khaki brown sandy soil, lithomarge and completely weathered and transformed slide debris. The samples have been tested at Geotechnical Laboratory, Southern Region, GSI, Hyderabad and results are given in the table 1.

Table1

S.No	MC %	Density gm/cm^3	Spg.	Gravel %	Sand %	Silt %	Clay %	LL %	PL %	SL %	C Kg/cm^2	φ°	Group class
UDS-1	27.44	1.45	2.63	0	24	66	10	62	46	38	0.40	30	MH
UDS-2	20.90	1.45	2.59	0	29	67	4	49	41	32	0.27	21	ML
UDS-3	22.81	1.56	2.64	5	37	36	22	55	39	32	0.29	24	MH
UDS-4	23.31	1.77	2.66	1	40	53	6	48	41	34	0.29	25	ML

Spg- Specific Gravity, MC-Moisture Content, LL- Liquid Limit, PL-Plastic Limit, SL-Shrinkage Limit, C-Cohesion, φ°-Angle of internal friction

The top humus soil and completely weathered and transformed slide debris are classified under ML (Sandy silt) type, whereas the khaki brown insitu soil and lithomarge are grouped under MH (Elastic silt with sand).

6. Average Annual Rain fall:

The western part of the Kodaikanal hill receives rains during both southwest and northeast monsoons. The eastern part gets rain fall mainly during northeast monsoon. The average annual rain fall in the western part varies from 1500mm to 2500mm. In the eastern part the average annual rain fall varies from 1000mm to 1500mm.

7. Landslide Hazard Assessment:

Landslide hazard zonation of the area has been carried out adopting Modified BIS Guidelines by GSI taking slope facet as the fundamental unit. A total of nine parameters for the individual facets have been evaluated and eight thematic maps have been prepared. Seven thematic maps are single parameter based and the eighth map is based on two parameters. While preparing the thematic maps, suitable modifications have been incorporated considering the type of slides, causal planes, causative factors, etc. specific to the area. The parameters considered for a comprehensive hazard evaluation are slope morphometry, rock outcrop – soil cover, soil/regolith thickness, relative relief, land cover, land use, hydrological conditions, landslide incidences and slope erosion. As, rain fall is the triggering factor, average annual rain fall has not been considered. Individual LHEF rating value for the parameters was assigned to each facet by superimposing the numbered facet map on the various thematic maps. The LHEF rating values are added to arrive at Total Estimated Hazard (TEHD) value for individual facets for assessing the hazard status and prepared final hazard (Susceptibility) map. The details including modifications incorporated of individual thematic maps are dealt hereunder:

7.1 Slope Morphometry Map:

Slope morphometry map is prepared applying image processing techniques. The data is extracted from SRTM images using Arc GIS 9.2-spatial analyst processing software. The slope is classified into five categories as given in the adopted code. In general the slope falls in very gentle slope to moderately steep slope categories in the undulating plateau, moderately steep to steep slopes in the moderately dissected valley slopes and steep to escarpment/ cliff category in the fringe areas.

7.2 Rock Outcrop – Soil Cover Map:

Rock outcrop – soil cover map is prepared instead of lithology map, as most of the slide incidences occurred are in over burden materials comprising soil, rock detritus and accumulated materials. While preparing the map the areas of rock exposures without or with capping materials up to 1m is given separate entity and shown as rock out crop and assessed accordingly. Rock exposures are observed in deeply dissected fringe areas, moderately dissected valley slopes and on the summits of the hills in undulating plateau areas. The exposed rock in valley slopes and on the summits of the hills in general is fresh to slightly weathered, where as it is moderately weathered in the fringe areas. Gneiss and charnockite are the rock types observed in the exposures and the value of 0.4 pertaining to gneiss is assigned for the purpose of Landslide Hazard Evaluation Factor (LHEF) rating for facets occupied by bed rock.

The insitu soil over the bed rock belongs to sandy silt (ML&MH –Unified Soil Classification) categories. Insitu soil is the predominant capping material present in the area. Colluvial and pediment materials are occurring over insitu soil. Most of the landslide occurrences recorded in the area is in lithomarge. Heterogeneous permeability is the characteristic of lithomarge. Water percolate through comparatively higher permeable pockets is blocked or not allowed to drain by low permeable pockets. Accumulation of water leads to building up of pore pressure that triggers failures. Hence the LHEF rating value for the clay rich lithomarge over the bed rock should be more than sandy soil over the bedrock instead of low rating value for clayey soil (0.8) than sandy soil (1.2) as given in the Code. Based on the experience in Kodaikanal, Nilgiri Hill and Western Ghat areas, the entire capping materials comprising insitu soil, colluvial, alluvial and pediment material are considered to be single unit and LHEF rating pertaining to poorly compacted lose material is assigned.

7.3 Regolith (Soil) Thickness Map:

The theme of soil thickness is taken for hazard evaluation for soil covered areas, whereas the disposition of the important/predominant discontinuities is considered for the rocky facets, particularly along road alignments. The thickness of the soil/regolith varies from 0m to 15 m. On the basis of the thickness of the soil the area has been classified into four categories as 0-1m, 1-5m, 5-10m, 10-15m instead of three as <5m, 5-10m, 10-15m. The LHEF rating pertaining to less than 5m is taken for1m-5m category. Planar and toppling failures have been noticed along structurally controlled weathered seams/joints on cut walls along road alignment in the deeply dissected fringe areas due to sub parallel disposition and removal of lateral support. Hence the disposition of prominent

discontinuities with the slope i.e., parallel or slightly askew (Unfavourable), moderately askew (Moderately favourable) and highly askew or perpendicular (Favourable) and dip towards (Unfavorable) or against the slope are taken for hazard evaluation of the rocky facets and facets with overburden up to 1m.

7.4 Relative Relief Map :

The thematic map of relative relief is also prepared applying image processing techniques. SRTM images and Arc GIS 9.2-spatial analyst software are used for data extraction and processing respectively. The categories of low, medium and high are the three categories demarcated as given in the code adopted. The relative relief in general belongs to low category in the undulating plateau, medium to high in the moderate – deeply dissected valley slopes and in the fringe slopes.

7.5 Land Cover Map:

In general, the areas exposing bedrock with or without thin overburden (<1m) are barren to sparsely vegetated. Barren and sparsely vegetated areas are found to occupy part of the facets. While preparing this thematic map, the category of the land cover which occupies more than 50% of the facet is assigned for the entire facet and the map is prepared accordingly. Agricultural land with seasonal crops is classified under barren category and with some trees and plants are categorized as sparsely vegetated.

7.6 Landuse Map:

While preparing the map of this theme, it is found to be difficult to follow the categories enumerated in the guidelines strictly. Hence, during categorization slight modification has been done in the guidelines in order to suit the site. The geomorphic location, extent of slope modifications particularly for the land used for road alignments and residential purposes, etc. are taken in to consideration. The details of modifications are as given in the following table 2.

Table 2

Sl. No	**Category descriptions as given in the BIS Code modified by GSI**	**Site suitable category descriptions adopted**
1	Agricultural land/populated flat land	Agriculture/plantation and forest land/populated areas in undulating plateau.
2	Moderately populated slope/village roads	Moderately populated/plantation and forest land/rural road in deeply and moderately dissected fringe/valley slope areas.
3	Thickly populated slope modified by large scale excavation	Thickly populated / important roads in undulating plateau
4	Major communication roots involving extensive slope cutting	Major / important roads in moderately and deeply dissected fringe/ valley slope areas.

7.6 Hydrological Condition Map:

During monsoon season wet condition prevails in soil covered slopes, whereas the rocky slopes, in general, are dry with occasional wet surface. Seepage is noticed at some places along the contact between bedrock and overburden, particularly, where the contact is day lighted. Springs with continuous water flow is rare in the area. During summer the entire area is dry. Groundwater is restricted mainly to overburden materials including highly weathered rock. Based on the above observation, only two hydrological condition categories- viz. wet and dry are considered. The rock outcrop areas are classified under dry category and the soil covered areas with more than 1m thick overburden are grouped as wet.

7.7 Slope Erosion Status Map:

The main preparatory causative factor of most of the landslides in the area is the removal of lateral support either by toe erosion by the streams or toe removal due to vertical/sub-vertical cutting for road alignment, for siting dwelling units and other structures. Hence, it is felt that the classification could be based on whether the slope facet is subjected to toe erosion / removal or not. Accordingly, the categories are modified slightly keeping the same LHEF rating. The details are as given in the table 3.

Table - 3

Sl. No	Category descriptions as given in the BIS Code modified by GSI	Site suitable category descriptions adopted
1	Deep gully erosion/rill erosion of hill slope	Slope subjected to neither toe erosion nor toe removal/cutting
2	Severe toe erosion by nala and river	Slope subjected to either toe erosion or toe removal/cutting

7.8 Landslide Incidence Map:

An inventory of 198 landslides and slope failures indicated that most of the landslides are soil/debris slide. Soil covered slopes of the undulating plateau under forest and plantation cover are devoid of contemporaneous landslide, whereas medium to small scale landslides are seen in the cultivated soil covered slopes that are affected by toe erosion. Debris flows and old landslide scars are present mainly on the fringe slopes and at some places on the moderately dissected valley slopes. Debris/soil falls, slips and slides are the cut slope failures seen along the roads in deeply dissected fringe and moderately dissected valley slopes. Shallow sheet failures are noticed at a few places on steep slopes with thin soil cover in the fringe areas.

No conspicuous landslides or scars are observed on the rocky slopes of exfoliation domes in the undulating plateau. Planar and toppling rock failures occurred in the moderately weathered rock mass on the cut walls along roads in the reaches with unfavourably

oriented weak planes. Foliation parallel joint with weathered seam is the causative plane for most of the planar failures. Occasionally, joint planes trending N40̊ to 60˚E – S40˚ to 60˚W are found to be the sliding surface. Only the foliation parallel joint planes are the causative planes for the toppling failures. A common map has been prepared merging slope erosion status map and landslide incidence map.

Picture 3 Perumalmalai Subsidence

Picture 4 Panrimalai Subsidence

Picture 5 Panneer Thottam Debris Slide

Picture 6 Geranium Farm Debris Slide

Picture 7 Alagarmadai Debris Flow

Picture 8 Murukkadi Shallow Sheet Slide

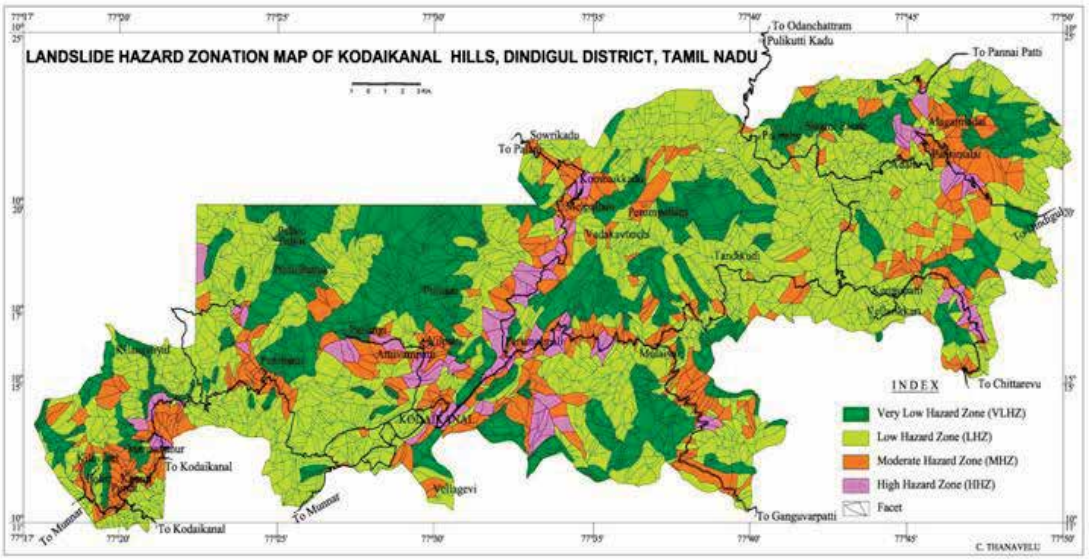
Picture 9 Alagarmadai Cutslope Slide

Picture 10 Tomtom parai Rock Slide

8. Conclusion:

The rocky slopes in undulating plateau are in general worked out to be low hazard with least hazard at some places. During finalization of the hazard map the hazard status is slightly modified as least hazard. The status worked out is retained for the rock exposed in the areas along road corridors. The neighbourhood areas of Kodaikanal Township, such as, Senbaganur, Vilpati and Attuvampatti, where the developmental activities are spreading are falling under high hazard. The slope around Mother Therasa College is found to fall in moderate hazard.

Well knitted surface and sub-surface drainage arrangements can stabilize the slide prone slopes to a large extent. In addition, designed slope cuts with adequate protection, for siting dwelling units and other structures will result in to positive change of the hazard status.



Major parts of the newly aligned Addukkam – Periyakulam road and select reaches of Ganguvarpatti – Kodaikanal and Perumalmalai – Palani - roads fall under high hazard category, which needs detailed studies for arriving at reach wise suitable preventive/ control and corrective measures. Debris flows are present along some of the streamlets in the fringe slopes mainly along Chiterevu – Thandikudi Road, which may be surmounted by increasing the bay width of the culverts to facilitate unhindered flow of debris.

Based on the studies,it is recommended to carry out landslide hazard zonation mapping of Kodaikanal Town on mesoscale covering the future developmental prospect areas; detailed study of the Mother Terasa College slope, Shanmukhapuram slope and Attuvampatti South and North slopes and detailed study and monitoring of Perumalmalai Subsidence above Kodaikanal road near the junction with Palani road.

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