Macro scale (1:50,000) landslide susceptibility mapping in parts of Kullu, Mandi, Chamba, Kangra and Lahaul & Spiti districts, Himachal Pradesh

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Abstract

The studied area is in parts of Kullu, Mandi, Chamba, Kangra and Lahaul & Spiti districts of Himachal Pradesh has been selected for susceptibility mapping because of its potentiality for resulting disastrous landslides. The study area exposes rocks of Vaikrita Crystallines with Manjir and Katarigali formations and Kullu and Rampur Groups with Vaikrita and Kullu thrusts.The susceptibility mapping involved preparation of geofactor maps and landslide inventory map to calculate Yule's Co-efficient and Landslide Occurrence Favourability Score (LOFS), determination of weightage for factor class by Weighted Multiclass-index Overlay Method for the susceptibility modelling in ArcGIS to obtain the susceptibility score map, and finally classified into 'high', 'moderate' and 'low' susceptibility zones in the study area. . Seven major high zones viz. (i) Sissu –Khoksar stretch (ii) Rohtang –Marhi stretch (iii) Solang –Vashist stretch (iv) Higherreaches near Manali town (v) Bara Garan-Barot stretch (vi) Pataku, Bara Garan –Baraot road stretch (vii) Manali –Babeli road stretch and several sporadic high zones haves been deciphered in the study area. Major landslides occurrences perceive in the area are Pagal Nala debris slide, landslides near Rohtang pass, landslide near Vashist village, landslide near Sissu village, subsidence near Raling village, landslide near Solang Village and landslide near Machhachas village

1. Introduction:

The study area covering toposheet nos.52D/16,52H/3 and 52H/4 which falls in parts of Kullu, Mandi, Kangra, Chamba and Lahaul & Spiti districts of Himachal Pradesh and forms part of Beas and Chandra River valleys. The area witnesses severe cold during winters and is moderately cool during summers. The northern part of the study area in Lahaul & Spiti, and Chamba exhibits predominance of glacial activities whereas majority of the southern part is manifested with mostly fluvial activities. Manali and Rohtang Pass are two important tourist destinations within the study area connected by National Highways (NH-21 and NH-154) which are of immense socio economic and strategic significance. The studied area in parts of Kullu, Mandi, Chamba, Kangra and Lahaul & Spiti districts of Himachal Pradesh has been selected for susceptibility mapping because of its potentiality for resulting disastrous landslides. The presence of towns and famous tourist spots such as Kullu and Manali, National Highway (NH-21) and other state roads make this area significant for landslide susceptibility modelling for providing a base map for regional land use planning, prioritising area for further detailed study and planning risk mitigation options.

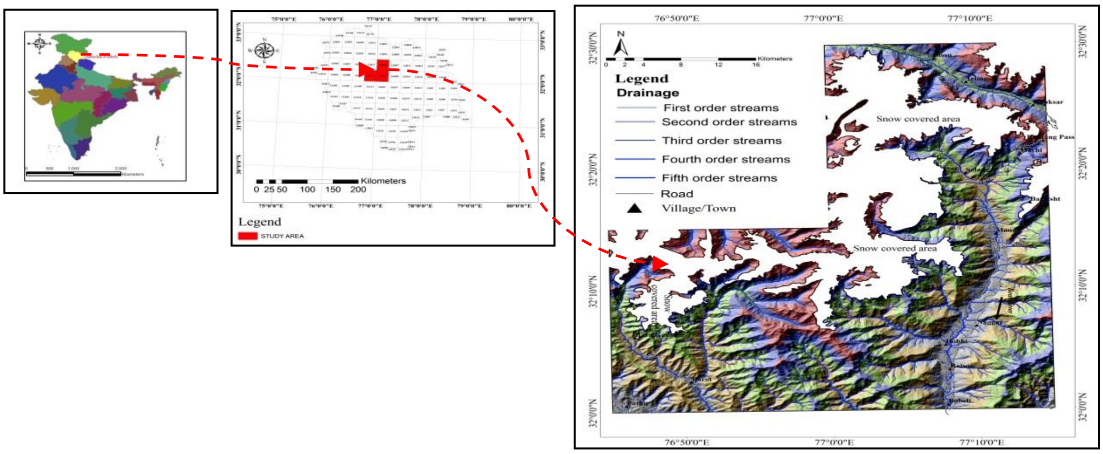

Figure 1 Location map of the study area (Toposheets: 52D/16, 52H/03 and 52H/04)

2. Geology and Geomorphology:

Geologically, the study area exposes high grade rocks of Higher Himalayan Crystalline (HHC), which are considered mainly exhumed frontal part of the range due to tectonic exhumation controlled by thrusting along the Main Central Thrust (MCT) and extension along the South Tibetan Detachment System (STDS) (P.H. Leloup et.al.) The study area exposes Vaikrita Crystallines with Manjir and Katarigali formations and rocks of Kullu and Rampur Groups respectively of Proterozoic ages. The Vaikrita Crystallines are the most dominant and comprise gneiss, schist and granitoids. The Vaikrita and Kullu thrusts are major tectonic features which almost run sub-parallel to the strike of the rock formations having NE hades.

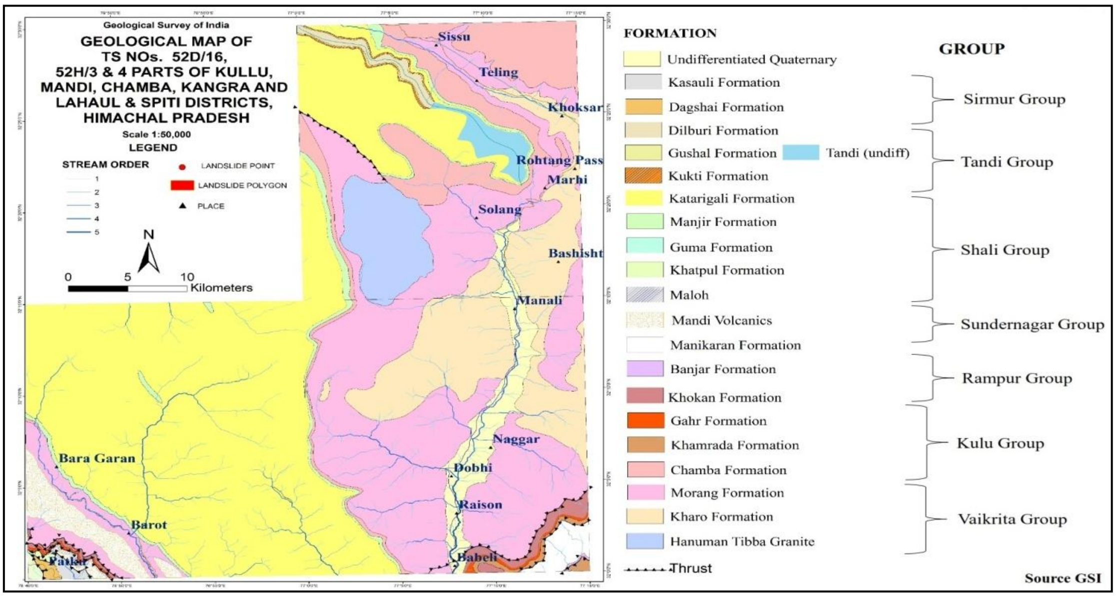

Figure 2 Geological map of the study area (Toposheets: 52D/16, 52H/03 and 52H/04) (Source: Geological Survey of India).

The major part of study area belongs to wet and green lower lands of Lesser Himalaya from the northern cold and arid highlands of Higher Himalayas and manifested by highly rugged mountainous terrain with U-shaped and V-shaped river valleys. Higher Himalaya is dominated by glacial and fluvio-glacial geomorphic processes whereas Lesser Himalaya by fluvial processes.

Table 1
Geological Sucession of the Study Area
(Ref: Geology and Mineral Resources of Himachal Pradesh Miscellaneous Publication No. 30: Part - XVII, Second Revised Edition)

Formation	Group	Age
Undifferentiated Quaternary		Recent
Kasauli Formation Dagshai Formation	Sirmur Group	Eocene e to Early Miocene
Dilburi Formation Ghushal Formation Tandi (Undifferentiated) Kukti Formation	Tandi Group	Permo-Triassic
Katargali Formation Manijir Formation Guma Formation Khatpul Formation Maloh Formation	Shali Group	Meso Proterozoic
Mandi Volcanics Manikaran Formation	Sundernagar Formation	Palaeo Proterozoic
Banjar Formation Khokan Formation	Rampur Group	
Ghar Formation Khamrada Formation Chamba Formation	Kullu Group	Palaeo Proterozoic
Moran Formation Kharo Formation Hanuman Tibba Granite	Vaikrita Group	Palaeo Proterozoic

3. Landslide occurrences:

Landslide has been a common hazard in the hilly regions of Himalayas causing numerous losses to life and properties since several year. Erosion of the country rock is a continuous process in mountainous terrain causing several types of landslides such as debris flows, debris slide, rock slides and rock falls which are natural as well as anthropogenic in nature. For the past many years landslide related studies in this area has gained attention of geologists mainly due to tourists influx in Man**a**li and strategic importance of NH-21. However, no systematic landslide susceptibility mapping was carried out by GSI in the study area. Only after certain events, post-disaster geological appraisals have been carried out. Some of the major landslide inventoried recorded by GSI in the past are Nehru Kund Landslide, Kullu district, Shanag village (Kaistha, M., 2008), Gulaba slide (Kumar Manoj and Kumar Sajin, 2007).Rahni Nala landslide (Singh et al., 2012), Landslide at 39.3 km RD (Singh et al., 2012) and Marhi Rock Fall, Kullu district (Kumar Manoj and Kumar Sajin, 2007). Major landslides occurrences perceive in the study area during field work are Pagal

Nala debris slide, landslides near Rohtang pass, landslide near Vashist village, landslide near Sissu village, subsidence near Raling village, landslide near Solang Village and landslide near Machhachas village. Landslide identification was carried out by visual estimation from multi-temporal Google Earth images (2014), toposheets, and from the published/unpublished reports of GSI with extensive field observation.

Field photograph of high susceptibility zones:

Photo 1 Landslide (debris flow) along Chandra River, Sissu village

Photo 2 Landslide (debris slide) along Rohtang Pass at Rani Nala.

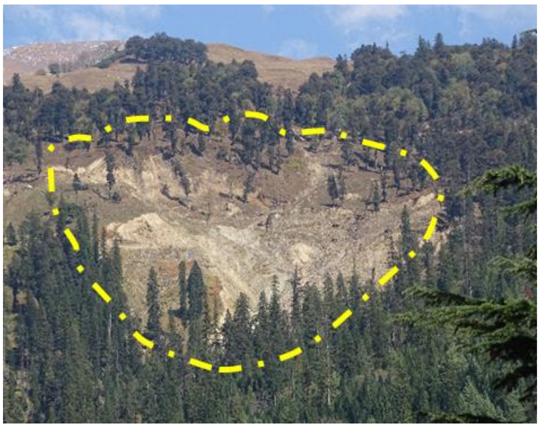

Photo 3 Landslide (debris slide) on steep slope, near Marhi village

Photo 4 Landslide (debris slide) near Vashist village.

Photo 5 Landslide (Rock fall) along Solang Nala, Solang village

Photo 6 Landslide (debris slide) near Barot village

4. Methodology :

The landslide susceptibility mapping is being carried out based on a knowledge driven integration technique known as the weighted multi class index overlay method, (Guzzetti et al.1999; van Westen et al., 2008, and Ghosh et al., 2011). The susceptibility mapping involved preparation of geofactor maps viz. slope, aspect, curvature and drainage (derived from Aster DEM), geomorphological, landuse and land cover map (LULC) (from Google Earth,), slope forming material map (SFM) (derived by crossing Geology, Geomorphology and LULC maps), fault/fracture map (from GSI published map of scale1:50K) and landslide inventory map (using multi temporal Google Earth imagery, existing toposheet and published and unpublished inventory data followed by field observations to calculate Yule's Co-efficient (YC) *(Yule,1912;Fleiss,199;Bonham-Carter,1994)* and Landslide Occurrence Favourability Score (LOFS), determination of weightage for factor class by Weighted Multiclass-index Overlay Method for the susceptibility modelling in ArcGIS to obtain the susceptibility score map, and finally classified into' high',' moderate' and' low' susceptibility zones in the study area.

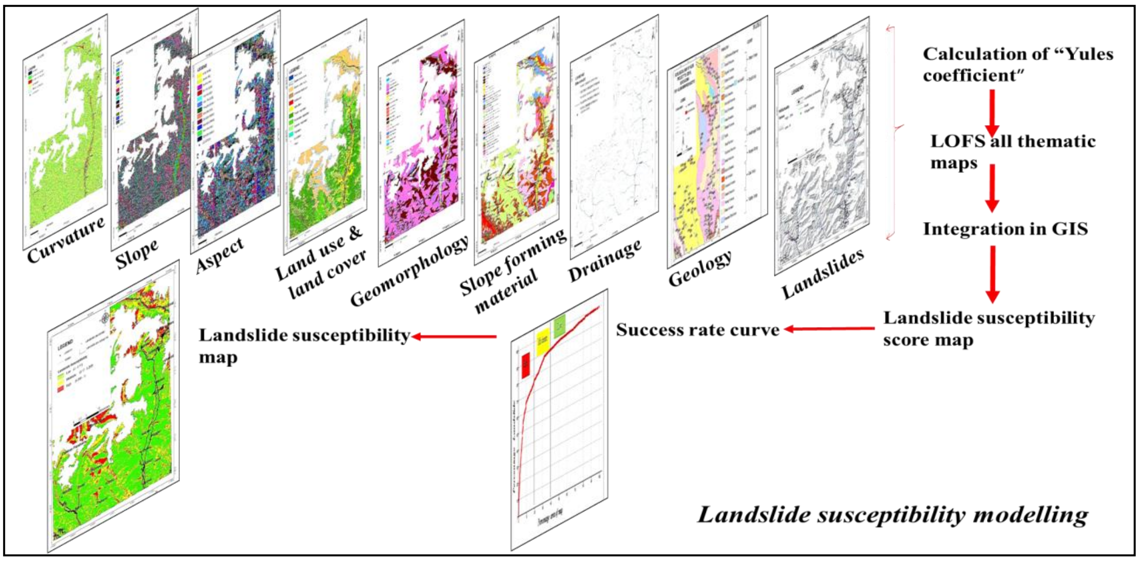

Figure 3 Flow diagram showing the process adopted for landslide susceptibility

The method is an improved bivariate statistical technique which uses landslide as a dependent variable to estimate the landslide susceptible areas.The landslide susceptibility map was prepared using pixel as a mapping unit, of 50m×50 m grid, by calculating Landslide Occurrence Favourability Score (LOFS) for all factor classes. For a particular mapping unit, the susceptibility score is calculated after adding the LOFS values of all factor maps except regolith thickness map and normalizing it by its weight. Geofactors maps are considered as in dependent variable were integrated with landslide incidences as a dependent variable to generate Yule's Co-efficient and Landslide Occurrence Favourability Score (LOFS).

Success rate curve, as proposed by Chung and Fabbri (1999) is used to subdivide the susceptibility scores into three classes of different landslide susceptibility (i.e., high, moderate and low).The cut-off boundaries are taken based on cumulative distribution of landslide percentage such that 80% landslides are contained within high susceptibility and 90% in moderate susceptibility.Using all the nine factor maps and a landslide susceptibility score map was generated, the obtained score map was combined with the landslide map and a success rate curve was generated in ILWIS 3.2 Chung and Fabbri (2003).

5. Landslide susceptibility analysis.

Landslide susceptibility mapping depends on multiple factors such as (i) assumptions, which is "the past and present are keys to the future", implying that landslides in the future will be more likely to occur under those conditions which led to past and present instability, (ii) landslide inventory that is the ability of the investigator to recognize existing and old landslides, to prepare a reliable and reasonably complete landslide inventory map, and to recognize the main causes of instability in the investigated area, (iii) factor map that is the availability and quality of relevant thematic and environmental data, including maps showing morphological, geological, and land use conditions prone to landslides, and (iv) susceptibility model, the type of modelling approach adopted for the susceptibility assessment (e.g., qualitative vs. quantitative, direct vs. indirect). Besides, it is equally important to select an appropriate terrain subdivision, i.e. a "mapping unit" for a reliable landslide susceptibility assessment (Hansen, 1984; Carrara et al., 1995; van Westen et al., 1993, 1997; Luckman et al., 1999).

In the study landslide susceptibility maps on scale 1:50,000 has been generated following a GIS-based approach and through development and use of site-specific/terrain-specific weights/ ratings using a landslide dependent statistical analysis.The input thematic maps and landslide inventory data have been prepared using both remote sensing and field inputs as describe in previous section. The input geofactor maps have been integrated through a knowledge-driven integration technique known as Multi-class Index Overlay method.Analysis and ratings after Multi-class Index Overlay of geofactor maps are emerge as Land use and land cover(LULC), Geomorphology, Slope forming material(SFM), Drainage, Slope, Aspect, Fault/Fracture and Curvature have the weights in decreasing order as 17, 16, 16, 12, 11, 8, 5 and 1 respectively.

6. Geofactor classes and association of landslide:

Slope morphometary indicate that the maximum distribution of landslide is within 30 º-35º followed by 25º to 40º slope classes, however, the 65º class constitutes the most vulnerable slope class. Landslide occurrences in the study area are mostly associated with SE (9%), SW (10%) slope directions. Landslides occur more frequently in those areas where the slopes are convex.Geomorphological geofactor indicates that landslides are mostly associated with denudational hill slopes followed by moderately dissected hill, lowly dissected hill, moderately dissected hills and colluvial foot slope. However, the highly dissected hill slope followed by escarpment and moderately dissected hill slope constitute vulnerable geofactor sub-classes. Land use and land cover geofactor indicate that landslide vulnerability is mainly associated with barren rocky slope. Slop forming martial geofactor shows that maximum numbers of landslide is associated with young loose debris followed by rock with thin slope wash and colluvium of the various bed rocks in which calcareous slate and phyllite are most vulnerable. The fault/fracture buffer zone analysis revealed presence of negligible landslide up to 500 m distance intervalthat gradual increases to maximum distance interval at 3 km. This indicates that maximum landslide occurrence are governed by geomorphic processes. The drainage analysis revealed that the maximum landslide records in the distance classes of 2 to 40 km. Generally, 2nd to 4th order perennial streams are most relevant to land sliding because field observations show that 1st order streams cause only limited erosion including shallow landslide.

Table 2
Predictor rating or weight of factor map

Sr. no	Geofactors	Min Y_c	Max Y_C	Absolute Difference	Weight
1	LULC	-1.00	0.7617	1.76	17
2	SFM	-1.00	0.6109	1.61	16
3	Geomorphology	-1.00000	0.61063	1.61	16
4	Slope	-1.00	0.15404	1.15	11
5	Drainage	-1.000000	0.239249	1.24	12
6	Aspect	-0.614991	0.19059	0.81	8
7	Fault fracture	-0.17050	0.30519	0.48	5
8	Curvature	-0.0488234	0.05232328	0.10	1

(Where, YC- Geofactor class and its Score or rating)

7. Landslide susceptibility map and venerable zones:

The susceptibility is expressed in terms of the relative proneness to initiation of a landslide in under the terrain conditions. The landslide susceptibility map at a glance gives an idea about the vulnerability to the land sliding for particular areas as demarcated in different zones as classes in bright and discerning colours (like red for ‘High’; yellow for ‘Moderate’ and green for ‘Low’ susceptibility).

Landslide susceptibility is a quantitative or qualitative estimate (e.g., a pixel, slope unit or facet) of the spatial distribution of landslides that exists or potentially may occur in an area. Although it is expected that landslide will occur more frequently in the most susceptible areas, yet in the susceptibility analysis, no time frame and magnitude of event can be predicated.

Landside susceptibility map of the study area was obtained using Weighted Multiclass Index Overlay method in ArcGIS. Seven major zones viz. (i) Sissu –Khoksar stretch (ii) Rohtang –Marhi stretch (iii) Solang –Vashist stretch (iv) Higherreaches near Manali town (v) Bara Garan-Barot stretch (vi) Pataku, Bara Garan –Baraot road stretch (vii) Manali –Babeli road stretch and several sporadic high zones haves been deciphered in the study area. Also high susceptibility zones are present along the streams and major rivers such as Chandra and Beas Rivers are due to the toe bank erosion of thick colluvial and alluvial cone or fan present along the course.

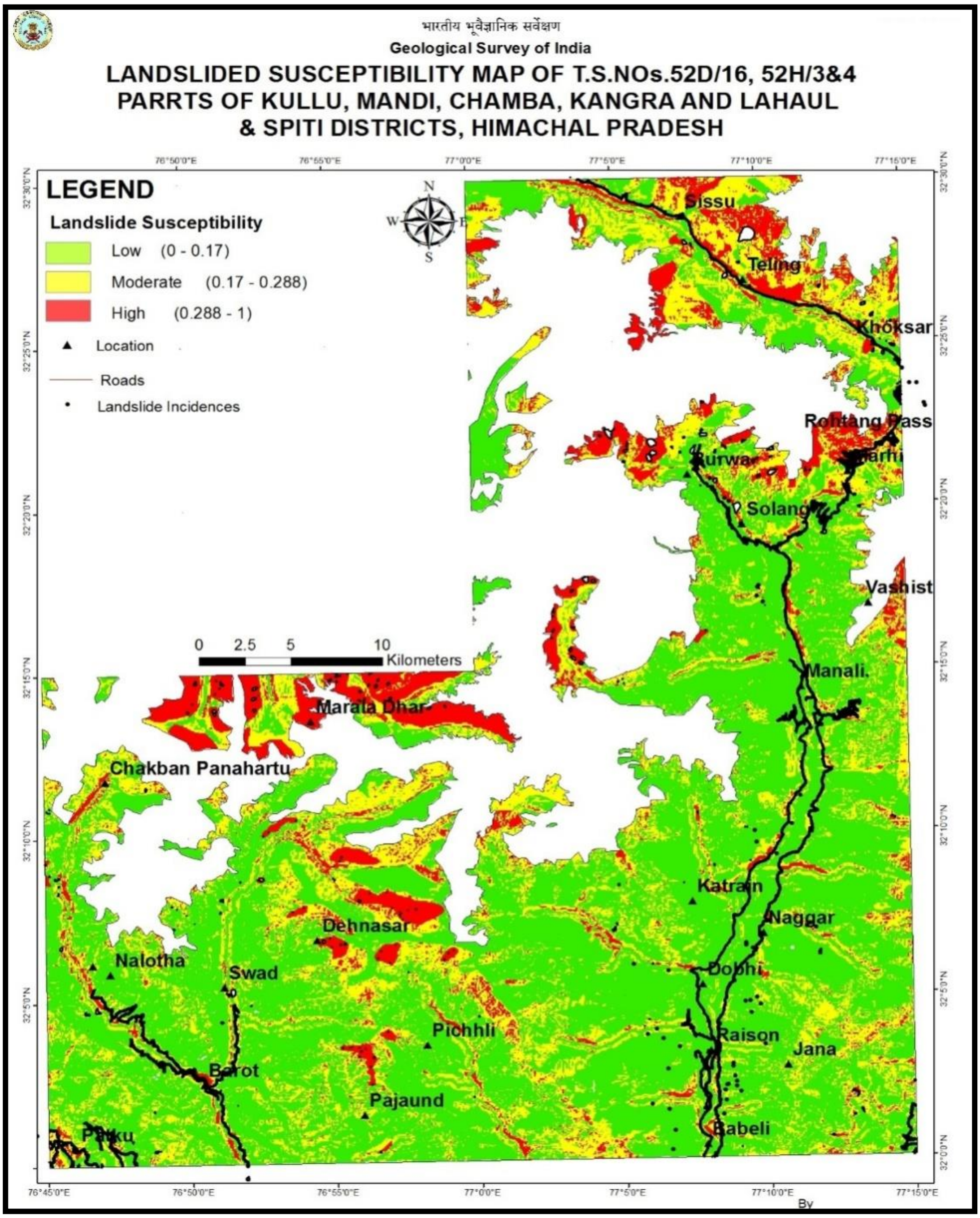

Figure 4 Landslide susceptibility map of study area showing high, moderate and low landslide susceptible zones landslide.

8. Conclusions:

Landslide susceptibility map revealed that 11% of the study area are grouped under high susceptibility class, mostly high susceptibility zones along and foot slope of the hills and along the steams and major streams such as Chandra and Beas River are due to the toe erosion of river banks represented by colluvium and alluvium cones/terraces. Moderate susceptibility zone encompasses 28% of the study area. It is manifested with moderately vegetated to agricultural land.This area showing rock fall in which rock outcrops are associated with highly to moderately dissected hills where rocksare mostly fractured, sheared and crumbled. Low susceptibility zone covers 61% of the study area, where flat to gently sloping lands and mild transported slopes mostly covered by moderate to thick vegetation. The obtained success rate curve is about 78% cumulative distribution of all landslide source areas is contained within 20% of the study area having higher susceptibility scores. The next 10% landslides or 90% of cumulative landslides are contained within 15% or 40% of the study area, respectively.

9. Recommendations:

The susceptibility map doesn't include temporal prediction of landslide event however the areas with high susceptibility should also be assessed for related possible hazards and their extent prior to execution of any civil constructions. Moderate zone are recommended for detailed/ landslide micro-zonation along with detailed assessment of extent of hazard and risk analysis. The 'low' susceptibility zones are suggested to be made available for urban and industrial planning keeping in view the sufficient buffer distance from river/stream course and thrust/fault zones, non-encroachment to flood active flood plains after applying proper control measures. It is recommended the development activities in the high susceptible zone may be avoided or be utilised for a purpose involving low risk only after execution of control measures. Landslide is a common hazard in the hilly regions which causes heavy losses to life and properties every year. The only economical way of reducing is by making people aware of the inherent risk. Therefore, it is recommended that more priority should be given in increasing awareness amongst people through Community Based Disaster Management Programme (CBDMP).The awareness should include information about identification of danger and its potential hazards and inherent uncertainties and ways to reduce landslide risk and the available local mitigation options.

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