EUROPEAN ACADEMIC RESEARCH
Vol. II, Issue 2/ May 2014

Impact Factor: 3.1 (UIF)
DRJI Value: 5.9 (B+)

ISSN 2286-4822
www.euacademic.org

Applying Geo-Spatial Technology to Identify Landslide Vulnerability: A Case Study of Hilly Landscape

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Abstract:

Landslides are the common sites in the hilly landscape of Himalayas. Landslide hazards are the one of the major natural calamities which has large influence and sturdy destroys leading to tremendous economic loss every year. Himalayan region faces landslide incidences every year of various scales, mainly in the post monsoon period. All the Himalayan divisions from outer to Higher Himalayas are vulnerable to landslide incidences and occur without any prior indication. However, the magnitude of the impact of the hazard can be minimized if its likelihood is recognized before land development activity. The present study aims at finding out landslide vulnerable zones and then ranking them in order of degree of hazard from landslides in the district Mandi of Himachal Pradesh. Present study seeks to delineate the study area into different categories with respect to its vulnerability and susceptibility to landslides with the help of GIS techniques. A GPS Survey was conducted for ground verification.

Key words: GIS, GPS, Impact, Landslide, Vulnerability, Zone, Survey.

Introduction

Natural hazard incidents are natural phenomenon with the combination of various natural physical processes (Feizizadeh, *et al.,* 2009). A disaster can be natural or man – made which results physical damage, loss of life or drastic changes to the environment or society. Earthquakes, floods, catastrophic accidents, fires or explosions are some of the awful events. The damage and destruction are related to the magnitude of the hazard and number of elements at risk at particular location (Hyndman, 2011).

Himachal Pradesh being a hilly state is exposed to various natural and man – made hazards in Himachal Pradesh. As per the Himachal Pradesh State Disaster Management Authority main hazards consist of earthquake, landslides, flash floods, snowstorms & avalanches, forest fires, droughts, dam failures, accidents (road, rail, air, stampedes, boat capsizing, biological, industrial and hazardous chemical etc.) which creates pressure on the state revenue and funds every year.

Landslides are recognized as the third type of natural disaster in terms of calamities and world importance (Zillman, 1999). The term "Landslide" is used to describe a wide variety of processes that results in the exterior downward and outward movement of the slope forming materials composed of instable rocks, debris masses, artificial fill or isssst can be the combination of all these factors under the action of gravity (Cruden, 1991; Avasar *et al.* 2003; Onagh *et al.,* 2012).

Zonation of landslide prone areas refers to the division of the landscape into homogenous area and their raking according to the degree of vulnerability (Varnes, 1984). Thus, identification of landslide hazard zonation is defined as the demarcation of areas with equal probability of incidence of landslides within the specific region (Guzzeti *et al.,* 1999).

Landslide vulnerability studies have been attempted by many researchers and scientist in the past all across the globe such as Skinner, Redfern and Farmer, 1999, Akgun, Dag and Bulut (2007), Anbalagan, Chakraborty and Kohli (2008), Bajracharya *et al.,* (2006), Chau *et al.,* (2003), Coe J.A. *et al.,* (2004) ,Danang Sri Hadmoko *et al.,* (2008), Dhakal *et al.,* (2000), Duran *et al.,* (2010), Esmali and Ahmadi (2003), Gorsevski *et al.,* (2000), Gorsevski, Gessler and Foltz (2000), Jian and Xiang-guo (2009), Jibson (1996) Jurko, Paudits and Vlcko (2006), Larsen (2008) Lulseged Ayalew and Hiromitsu Yamagishi (2005), Mark and Ellen (1995), Mathew *et al.,* (2007), Nagarajan *et al.,* , (1998), Nithya and Prasanna (2010), Pan *et al.,* (2008), Priyadharshini *et al.,* (2005), Ramakrishnan *et al.,* (2002),Sepulveda *et al.,* (2006), Sharma (1993), Sharma *et al.,* (2009) Sharma *et al.,* (2009), Sinha *et al.,* (2008), Wan and Khamarrul (2002) and Yixiang *et al.,* (2006), who have made significant contribution by focusing on different aspects of Landslides with different methodologies.

Aims and Objectives

The present study seeks to achieve the following objectives

- To identify the landslide prone areas using geo-spatial technology.
- To provide a decision support tool for hazard managers and planners.

Data and Methodology

Since this study is concerned with the use of geo-spatial technology to identify potential landslide zones, it involves the generation of thematic maps relating to the causative factors. These thematic maps have been based upon the data derived from Survey of India toposheets (SOI) at 1:50,000 scale; the Geological Survey of India maps and National Bureau of Soil Survey & Land use Planning (NBSS & LUP) maps. Similarly for information on hydrological aspects, the SOI toposheets has been used. Data on Slope, Aspect and Elevation have been derived from ASTER (Advanced Space borne Thermal Emission and Reflection Radiometer) Digital Elevation Model (DEM) using the 3D-Analyst module of ArcGIS software. To these thematic maps, ranks and weights have been assigned and then analysed in GIS domain. Final results have been verified by conducting a field survey. GPS data of existing landslide location have also been collected from field.

Study Area

There are twelve districts in Himachal Pradesh and Mandi is a centrally located district of Himachal Pradesh. Mandi is situated between 31°13'50" to 32°4' 30 North latitude, and 76°37'20" to 77°23'15" East longitude, lying along the left bank of the river Beas in the foothills of Shivalik range (Figure: 1.1). The total geographical area of the district is 3950 square kilometer which covers 7.10% area of the state and ranks 7th in the state Himachal Pradesh. The district is bounded by Kangra districts on the north-west, Hamirpur & Bilaspur districts in the west, Arki tehsil of Solan district in the south, Shimla district in the south-west and Kullu district in the east. The district was formed with the merging of two princely states - Mandi and Suket on 15th April 1948, when the State of Himachal Pradesh came into existence.

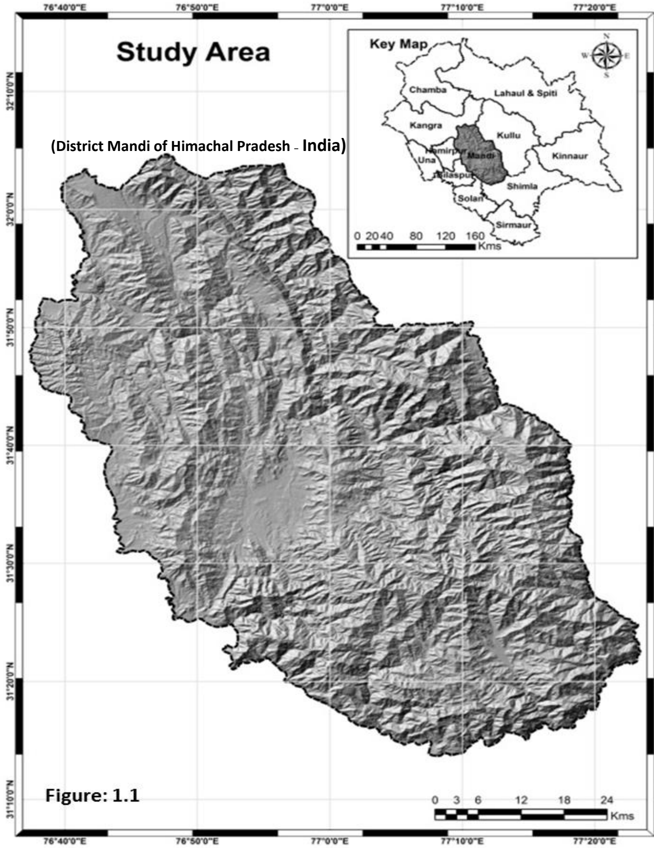
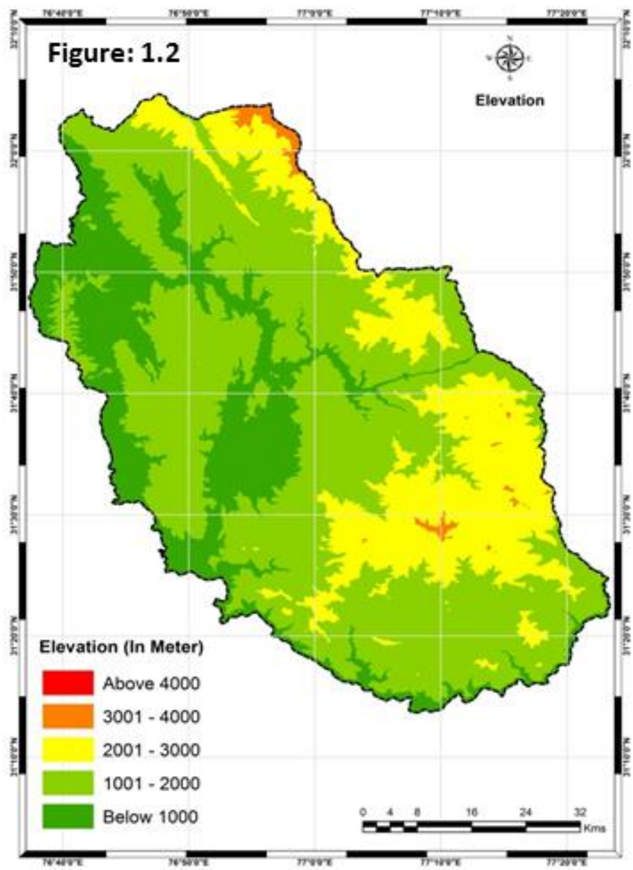


Figure: 1.1

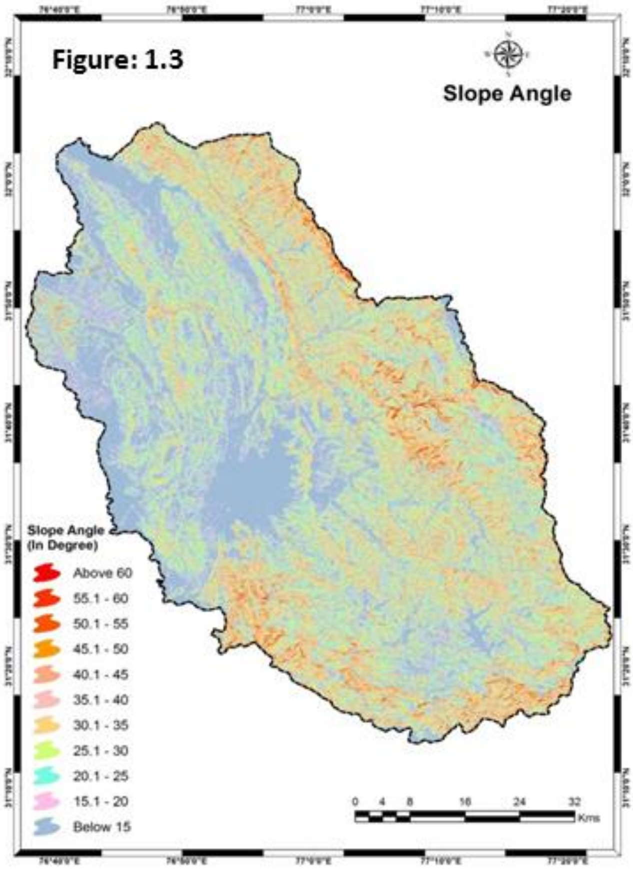
Data Presentation and analysis

The brief techniques and thematic maps of the input data produced, namely, Elevation (Digital Elevation Data -DEM, aspect, slope, landform topography), drainage pattern, geology (rock unit), soil properties (soil group unit, soil thickness), land use/land cover, infrastructure and human settlement and meteorology of rainfall intensity are consequently presented as below: -

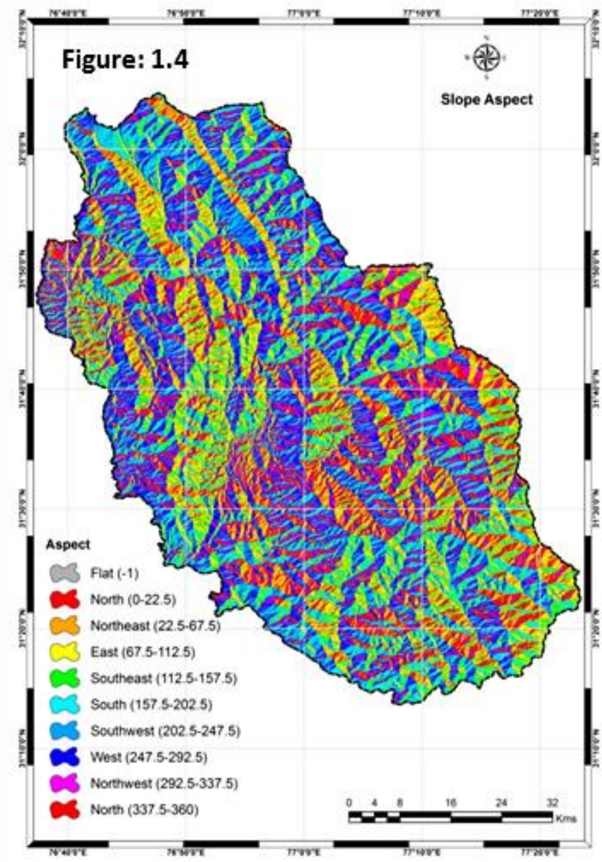
Elevation: Elevation of the study area is ranging between 500 and 4000 meter (Figure: 1.2). About 20.98 Per cent area is falling below 1000 meter elevation which is 828.76 square kilometres; 56.54 Per cent area is between 1001 to 2000 meter elevation which is covering 2233.81 square kilometres; 21.53 Per cent area is falling in the category of 2001 and 3000 meter; 0.97 Per cent area is lying between 3001 to 4000 meter and only 0.001 Per cent area is above 4000 meter elevation. The distribution of elevation for the study area has a mean value of 1626 meter with standard deviation of 787 meter which means that maximum area of district Mandi is lying in the category of 1001 to 2000 meter elevation which is occupying 56.54 Per cent (2233.81 sq. km.) area.



Slope: The minimum value of slope is 0 degree and the maximum 78.96 degrees (Figure: 1.3). About 27.33 Per cent area of district Mandi has slopes less than 15 degrees, 45.49 Per cent area lies between 15 to 30 degrees slope and 24.45 Per cent area having slope between 30 to 45 degrees. Around 2.72 Per cent area falls under the category of more than 45 degrees slope. The distribution of slope has a mean value of 22.70 degrees with standard deviation of 13.20. Thus maximum area is occupied by the 15 to 30 degrees followed by less than 15 degree, 30 to 45 degrees and more than 45 degrees.



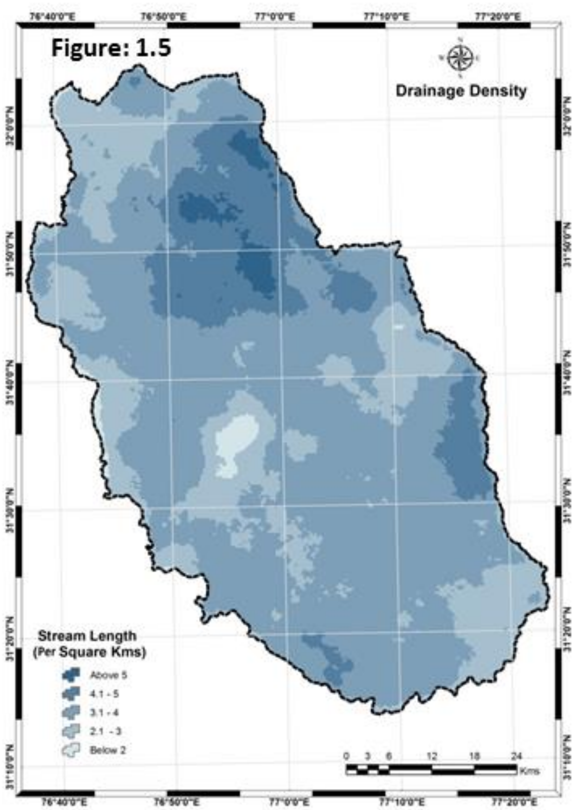
Aspect: In the produced aspect map, aspect area has been categorised into eight classes with the addition of flat area as: flat (-10), North (00 – 22.50), North – East (22.50 – 67.50), East (67.50 – 112.50), South – East (112.50 – 157.50), South (157.50 – 202.50), South – West (202.50 – 247.50), West (247.50 – 292.50), North – West (292.50 – 337.50) and North (337.50 – 3600) (Figure: 1.4). The distribution of aspect has a mean value of 175.95 with standard deviation of 103.69 which means that most of the study area (district Mandi) has the faces to South direction (aspect faces to 157.50 – 202.50).



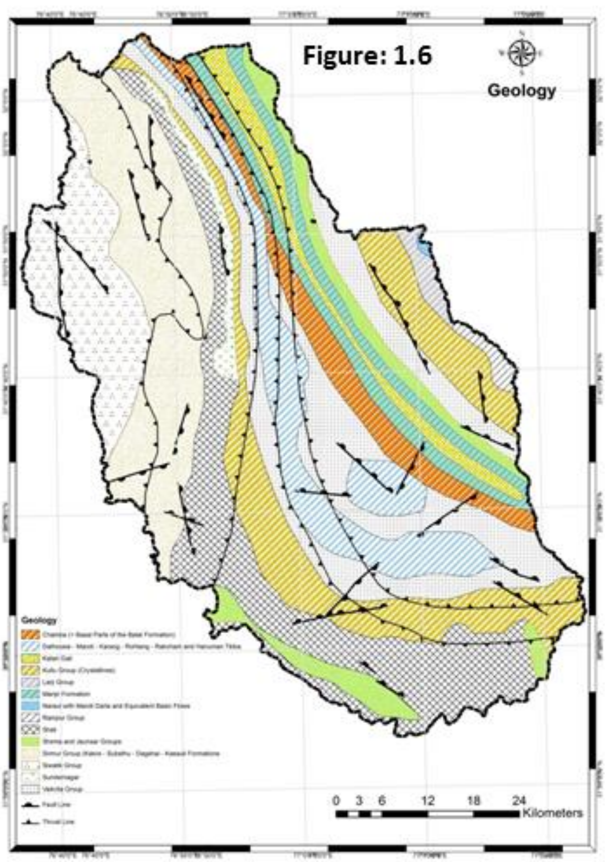
Drainage Density: The drainage density for the study area has been categorised in to five zones (figure: 1.5). About 1.49

Per cent area of the district Mandi has stream length less than 2 kilometer and 23.10 Per cent area has 2.1 – 3 kilometer stream length per square kilometer. Around 59.70 Per cent or 2358.33 square kilometer area has stream length 3.1 – 4 kilometer and 13.85 Per cent or 546.98 square kilometer area having stream length 4.1 – 5 kilometer per square kilometer. Highest stream length per square kilometer is found in around 1.89 Per cent or 74.46 square kilometer area.

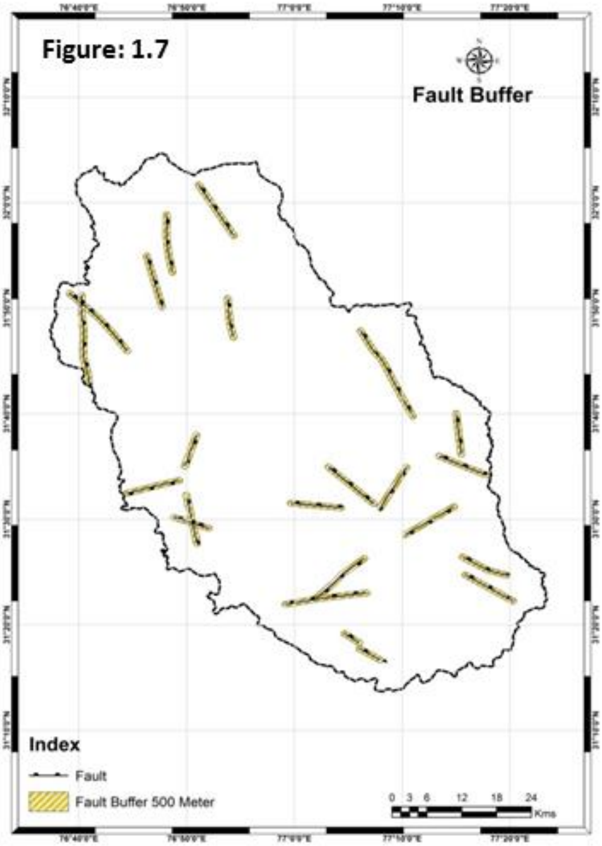
Drainage density of the study area has mean value of 3.39 with the standard deviation of 0.77 which means that most of the area of district Mandi has stream length between 3.1 – 4 kilometer per square kilometer. About 2358.33 square kilometer or 59.70 Per cent of the total study area is coming under the category of 3.1 – 4 kilometer stream length per square kilometre.



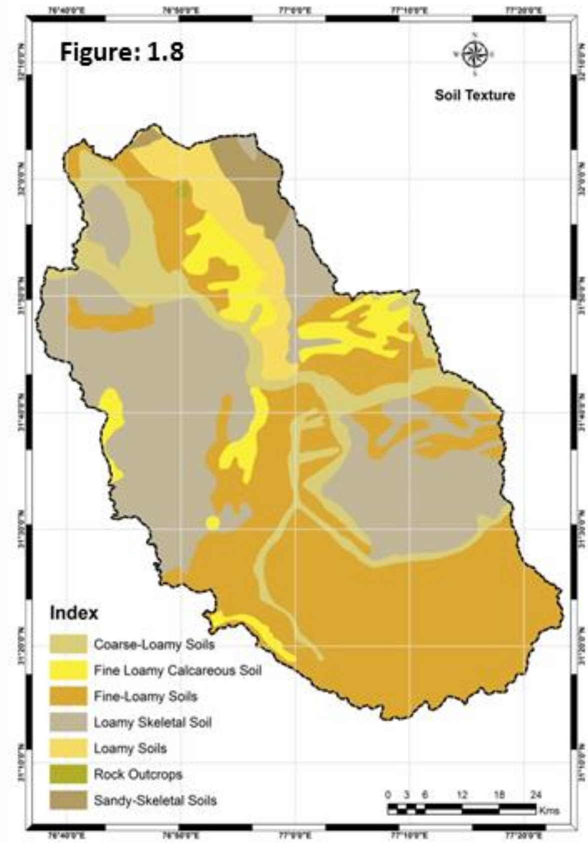
Lithology: Lithology (Figure: 1.6) is an important factor contributing to landslide occurrence (Bisht *et al., ,* 2006; Singh and Devi, 2006; Jian and Xiang-guo, 2009; Pandey *et al., ,* 2007; Naithani *et al., ,* 2007) because different lithological units have different sensitivities to active geomorphological processes such as landslides (Carrara *et al.,* 1991). Due to the importance of lithology, numerous researchers have used lithology as an input parameter to analyse the landslide susceptibility (Dai and Lee 2001; Cevik and Topal 2003; Sarkar and Kanungo, 2004; Suzen and Doyuran 2004a, b; Gokceoglu *et al., ,* 2005; Sahu at al., 2005; Yalcin 2008; Lee and Pradhan 2007; Akgunet *et al., ,* 2008; Asthana and Bist, 2009; Gemitzi *et al., ,* 2010; Nithya and Prasanna, 2010; Onagh *et al., ,* 2012).



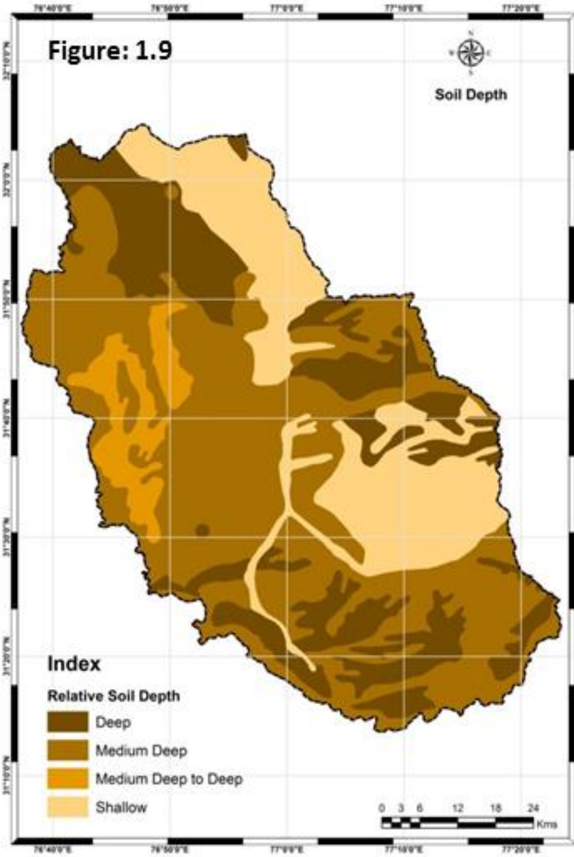
Distance from fault: A fault is a fracture in the crustal rocks wherein the rocks are displaced along a plane called fault (Singh, 2003). Faults represent weaker zones of the earth surface where crustal movements become operative for longer duration and along which landslide susceptibility is higher (Gemitzi, 2010). The probability of the landslide hazard increases along the faults, which affect the surface material structure as well as make a contribution to terrain permeability causing slope instability (Kanungo *et al., ,* 2006). Beside that "distance to faults" (Figure: 1.7) layer has been generated in order to take into account the probable seismic origin of the landslides *(Demoulin and Chung (2007).* Thus, structural feature like fault is very important in landslide studies (Saha *et al., , 2005).*



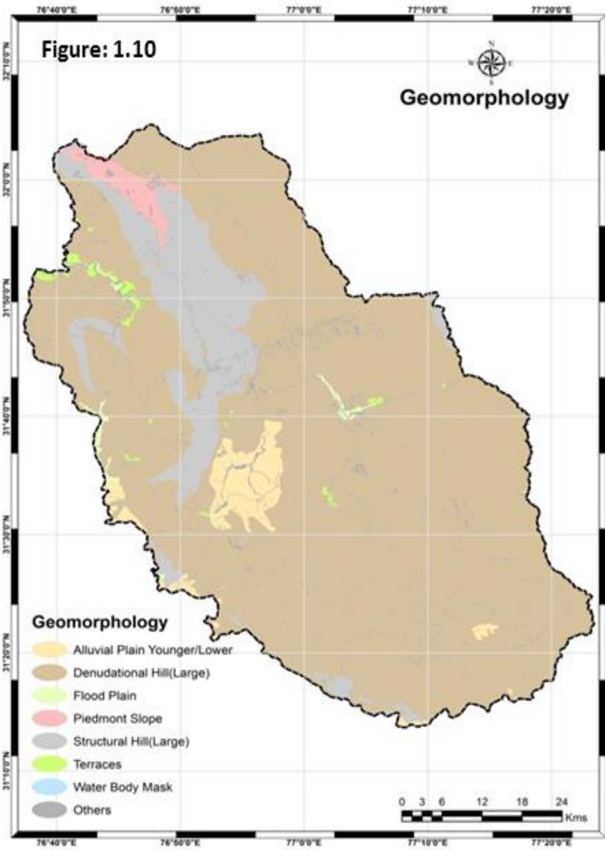
Soil Texture: Colour coded soil type map (Figure: 1.8) has been prepared for the study area. Maximum 41.86 Per cent area is covered by fine loamy soil, 32.68 Per cent area by loamy skeletal soil, 11.41 Per cent area by coarse loam soil, 6.54 Per cent area by fine loamy calcareous soil, 4.92 Per cent area by loamy soil, 2.52 Per cent area by sandy skeletal soil and lowest 0.09 Per cent area by rock outcrops. More than 73 Per cent area of the total geographical area is covered by fine loamy and loamy skeletal soils respectively 41.86 Per cent (1653.84 sq. km.) and 32.68 Per cent (1291.00 sq. km). Loamy soils generally contain more nutrients and humus and have better drainage and infiltration of water and air. Thus, study area is well drained and soil conditions are favourable to landslide occurrences.



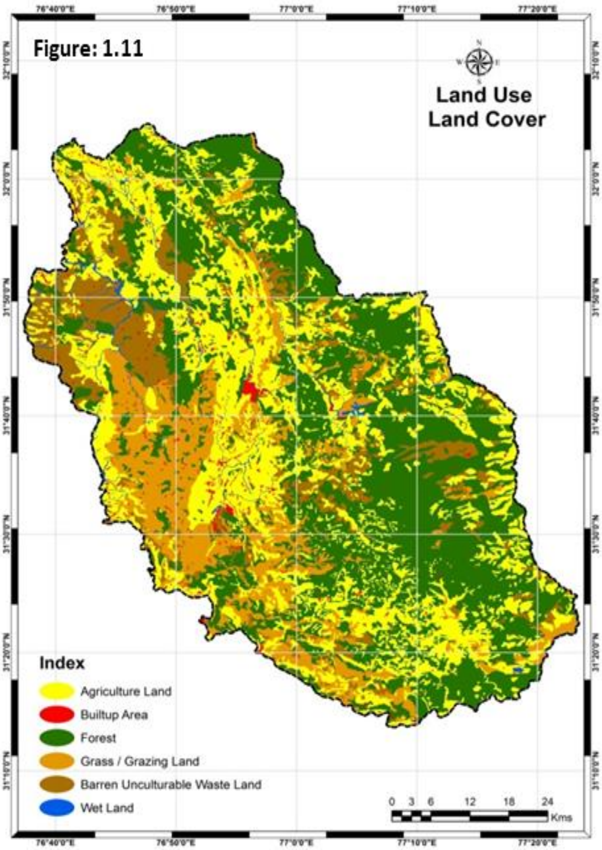
Relative Soil Depth: About 23.72 Per cent (937.21 sq. km.) area is having deep soil depth, 5.43 Per cent (214.53 sq. km.) area has medium deep to deep soil depth, 48.42 Per cent (1913.24 sq. km.) area has medium deep soil depth and 22.44 Per cent (886.64 sq. km.) area has shallow soil depth. Around half (48.42 Per cent) of the study area is lying under medium deep soil depth (Figure: 1.9).



Geomorphology: Study area is characterised by different landforms such as alluvial plains, denudation hills, flood plains, piedmont hills, structural hills, terraces and water masks (Figure: 1.10). About 128.55 square kilometer (3.25 per cent) area is alluvial plain; denudation hills occupy 3165.29 square kilometer (80.09 per cent) area; 18.50 square kilometer (0.47 per cent) area is flood plain; 53.58 square kilometer (1.36 per cent) is occupied by piedmont hills; 443.82 square kilometer (11.23 per cent) area is occupied by structural hills; 23.67 square kilometer (0.60 per cent) area is terraces and 118.99 square kilometer (3.01 per cent) area is water body & others. Maximum area is characterised denudational hills which is about 80.09 per cent of the total geographical area of study area.

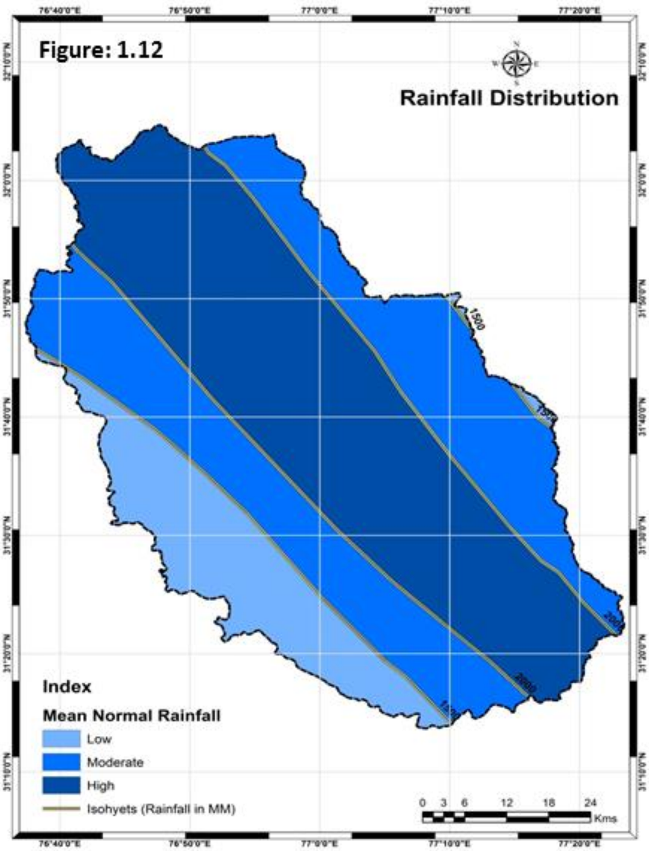


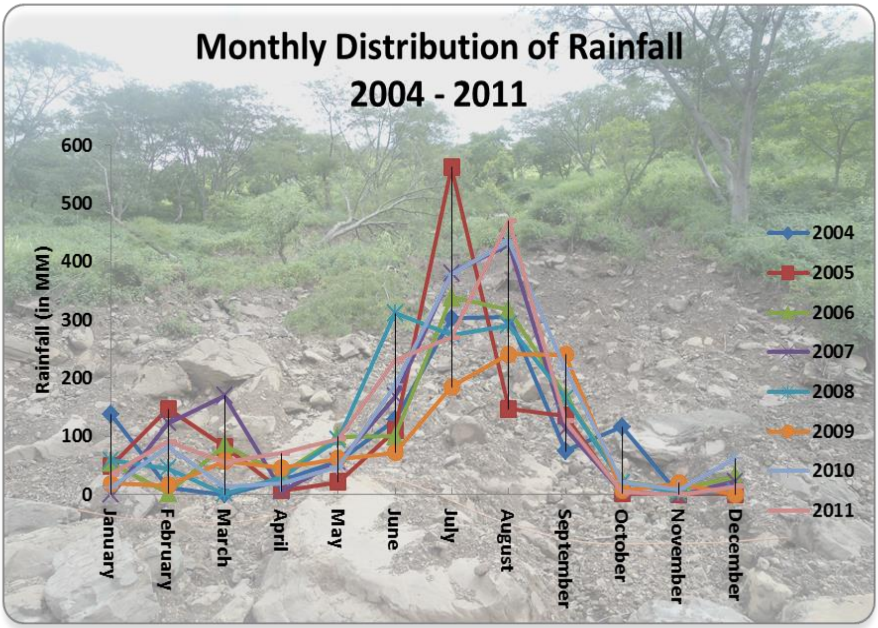
Land Use Land Cover: The land use / land cover map (Figure: 1.11) shows the different types of land cover pattern present in the study area. Vegetation cover is an important factor which influences the occurrence and movement of the rainfall which triggers the landslide. The study area is characterized by agriculture land, built-up area, forest, grass / grazing land, barren unculturable waste land and wet land.



About 1599.32 square kilometer (40.47 per cent) area is covered by forest; 1253.40 square kilometer area (31.72 per cent) is under agriculture; 553.87 square kilometer (14.02 per cent) area is covered by grass / grazing land; 438.01 square kilometer (11.09 per cent) is under barren unculturable waste land; 54.80 square kilometer (1.39 per cent) is wet land and 51.87 square kilometre (1.31 per cent) is built-up area. Maximum area is under forest and agriculture land followed by grass / grazing, barren unculturable waste land, wet land and built-up land.

Rainfall: Rainfall map of the study area (Figure: 1.12) shows that maximum precipitation is experienced in mid hill sub temperate area. Near about 627.43 square kilometer (15.88 per cent) area of the district Mandi receives more than 2000 millimetre annual rainfall; 1483.24 square kilometer (37.54 per cent) area receives between 1501 to 2000 millimetre annual rainfall and 1840.96 square kilometer (46.59 per cent) area receives between 1000 to 1500 millimetres.





Source: Hydromet Division, Indian Meteorological Department.

Results and Discussion:

As depicted, (figure 1.13) after overlaying various physical parameters study area has been categorised into three major zones as per landslide vulnerability. About 6 per cent of the total geographical area of district Mandi is under high vulnerability risk zone; 31 per cent area is having medium risk of landslide and rest of the area about 63 per cent of the total area have no vulnerability of landslide occurrence. Settlement locations which are coming under these zones has also been mapped (Figure 1.14). About 5 per cent population is habited in high vulnerable zone; 29 per cent is living in medium risk zone and rest of the population is habited in safer area. Thus we can conclude that geo-spatial technology is the powerful tool in any type of spatial analysis and helpful in decision making process.

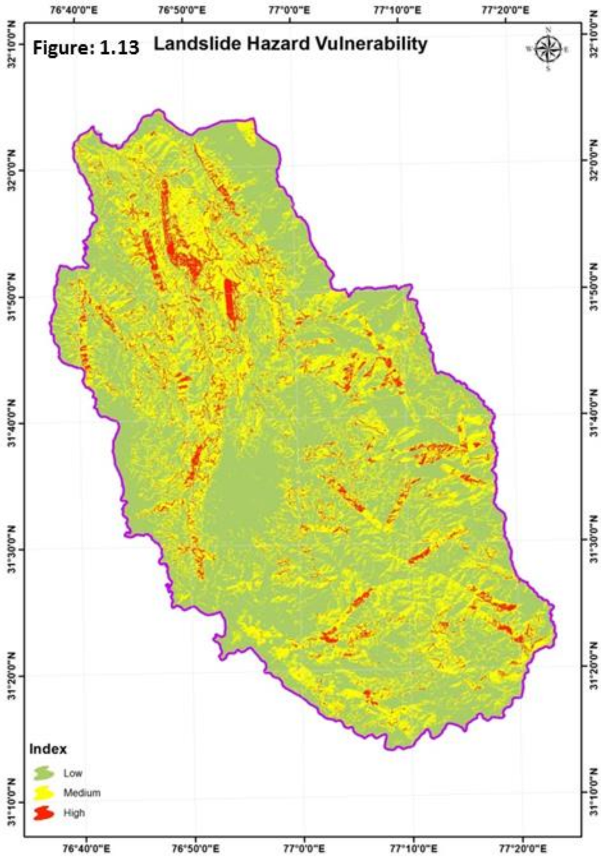
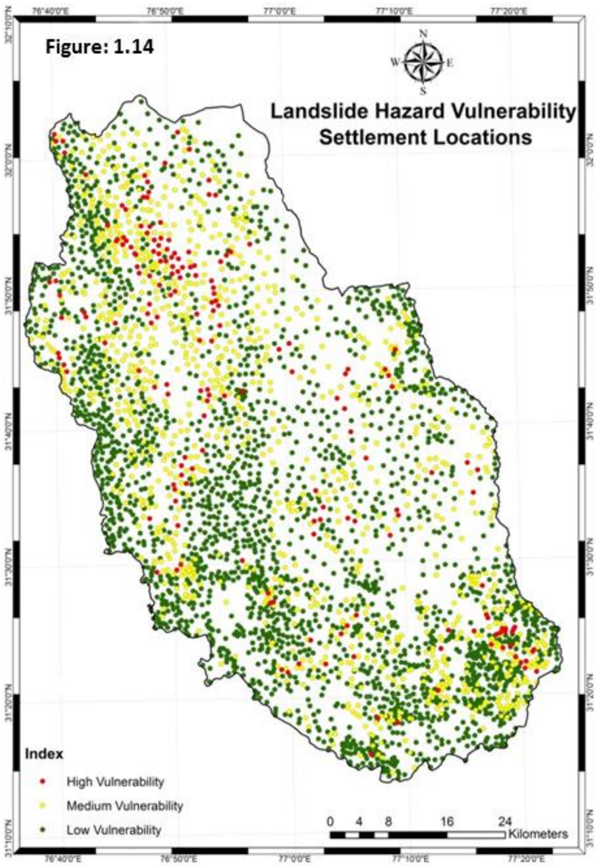


Figure: 1.13
Landslide Hazard Vulnerability
76°40'0"E
76°50'0"E
77°0'0"E
77°10'0"E
77°20'0"E
32°10'0"N
32°0'0"N
31°50'0"N
31°40'0"N
31°30'0"N
31°20'0"N
31°10'0"N
Index
Low
Medium
High



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