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Landslide Hazard Zonation Using Remote Sensing and GIS Technology: A Case Study of Landslide Prone Area near Mahabaleshwar, Maharashtra, India

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Abstract— Landslide is routine geological process on earth's crust, but recorded under disasters due to loss of lives and property. Prevention and mitigation of disaster can be planned if detected prior to the occurrence. The proposed paper is detection and mapping tool of probable mass movements and its destruction potential. The area surrounded by pre occurred landslide at Bhilar in Maharashtra is chosen for the present study. The effort has been made to study the Geo-informatics approach containing Remote sensing data and GIS as software integrated tool towards Landslide Hazard zonation. The various Spectral signatures and the image interpretation keys with respect to slope instability and various image data to identify Pre-occurred events and vulnerable sites are studied and used. The multivariate statistical analysis in the form of Information value method has been implemented along with the spatial analysis to obtain Landslide Susceptibility and Hazard Zonation. The methodology considers factors in the form of various thematic layers like lithology, slope, morphology, slope aspect, soil, relief, drainage, land use and pre-occurred landslides in the area generated using remote sensing data and GIS tools. From landslide hazard zonation map the hazardous locations are extracted from the study area and checked by the post analysis during field visit. The vulnerability zonation mapping and analysis of settlement and infrastructural facilities in high risk zone has been carried out. The present study demonstrates high degree of hazardousness at Bhilar and Godvali.

Keywords— Landslide hazard zonation, remote sensing, GIS, Landslide Susceptibility, Thematic layers, Information value method, Landslide Vulnerability.

INTRODUCTION

The landslides are hazards usually triggered by the neo-tectonic movements, earthquakes, heavy precipitation and those induced due to land-use changes such as felling of trees, agriculture, mining and road cutting in hilly terrain. Landslide is a general term used to describe the down-slope of soil, rock and organic material under the influence of gravity. The remote sensing and GIS based approach to map and study methodology involves generation of geomorphic map, NDVI map, soil map, slope map, DEM, drainage and lineament map, land use / land cover change map. LANDSAT TM and ASTER images have been used to generate a few of these thematic maps. Existing literature have also been referred to generate the thematic maps. To identify the vulnerable areas, the above-mentioned parameters were analyzed in a GIS by assigning appropriate ranks and weights. The result is a landslide hazard zonation map showing regions with varying degrees of vulnerability to landslides. It is opined that such a map (which is derived from the analysis of the causative factors) will enable to propose and implement suitable mitigating measures, thus preventing loss of life and property in the hilly area.

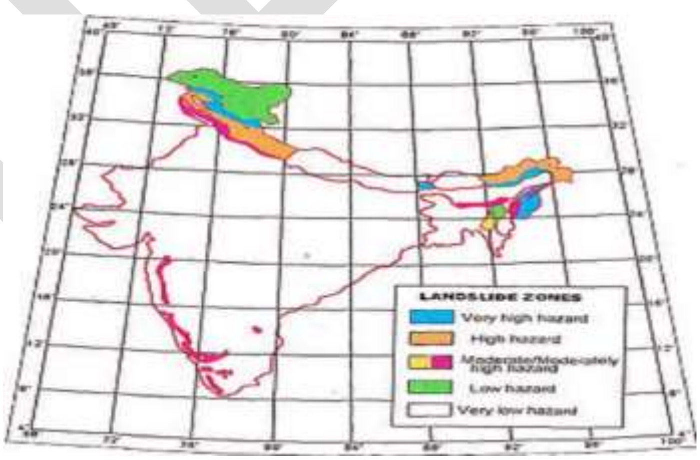

Figure 1 Landslide Hazard Zonation for India

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Landslide hazard is one of the most significant hazards that affect different parts of India every year during the rainy season. It has been observed that Himalaya ranges, North east India, Nilgiris, Western Ghats and Eastern Ghats, are affected by this hazard every year and suffer heavy losses in terms of life, infrastructure and property.

Landslides affect at least 15 per cent of the land area of India—an area which exceeds 0.49 million km^2 (ndma.gov.in). The landslide situation in the country is further compounded by increased vulnerabilities related to rapidly growing population, unplanned urbanization and fast-paced industrialization, rapid development in high risk areas, environmental degradation and climate change. It is observed that impact of landslide is felt more severely by people who are socioeconomically weak because their habitats are located in vulnerable areas and not designed to withstand the impact of natural disasters.

This study aims at proposing the strategy for Landslide hazard zonation mapping to formulate an efficient methodology to delineate the Landslide hazard areas. Integration of remote sensing and GIS allows most accurate and most updated data base on land information. It has been found to be very useful tool in combination with spatial data and very useful deriving the ideas for efficient management and mitigation during the landslide disaster(Raju, n.d.). Also in developing various layers like slope map, drainage map, flow direction map, flow accumulation map, land use map, soil map, settlement map and various point maps with different attributes(Raju, n.d.). Information in thematic mapping which in turn can be utilized in predicting and presenting the generated landslide hazard data. The remote sensing data provides synoptic view of a fairly large area in the narrow and discrete bands of the electromagnetic spectrum at regular intervals (Aggarwal, 2004). The multi spectral data enable generating timely, reliable and cost Effective information after applying various image interpretation keys to discover the parameters of landslide hazard.

2. Study Area

In Western Ghats (declared as World Heritage by UNESCO) many human habitats, tourist places & highways are vulnerable to landslide .Hence we have chosen "hilly areas near Panchgani" as our study area which connects two major tourist regions of Maharashtra. This Area is blocked many times in rainy season because of landslide & hence due attention must be given to Hazard Zonation Mapping & mitigate recommendations. Landslide hazard zonation helps in identifying strategic points and geographically critical areas prone to landslides along this highway. In this study, a methodology has been developed to identify landslide prone areas using Remote Sensing and tools of GIS environment like ILWIS software.

3. Methodology

3.1 Landslide hazard Zonation

Most popularly, "Natural hazard" is defined as possibility of hazardous occurrences within a given area and in a given period of time. (Hearn and Griffiths, land surface evaluation for engineering practice, 2001) It incorporates three components: magnitude, geographical location and time. Landslide hazard zonation (LHZ) refers to "the division of the land surface into homogenous domains and their ranking according to degrees of potential hazard due to mass movement".(Krishnan, 2015)Landslide hazard is presented with spatial distribution of hazard classes(landslide hazard zonation)."(D et al., 2007) Demarcation or mapping of these zones demands understanding of influencing processes in the study area and factors causing landslides.

3.2 Data Source

The analysis is based on maps from Survey of India and Geological Survey of India and satellite imageries. A landslide occurrence database was generated from GPS measurements were taken during field survey. Various thematic maps pertaining to slope, aspect, drainage, flow accumulation, lithology, and land cover are generated with the help of ILWIS software for Bhilar and Godvali area. The slope and slope aspect layers were derived from ASTER DEM in ILWIS, while flow accumulation is analyzed from drainage in ILWIS. The NDVI analysis was undertaken to enhance the spectral variation in LANDSAT ETM+ (2005) satellite imageries in order to derive meaningful land use/land cover classification(Journal and Geomatics, 2011).

Table 1 Illustration of Data type/source used for analysis.

SR. NO.	DATA TYPE	DATA DESCRIPTION	USE/PURPOSE
1	Topographical Map	Scale- 1: 50,000	Thematic Vector Data generation, Correlation with Remote Sensing Data
2	Satellite Data ASTER LANDSAT ETM+ 2005 Google Earth Images 2005 Google Earth Images 2010	Spatial Resolution 30 m Spatial Resolution 30m Spatial Resolution 1m	Digital elevation model: Slope, Aspect, Drainage network and Density Land use/Land cover Land use/Land cover, Pre-occurred landslides, Settlement
3	Geological Map	Scale- 1:2,50,000	Geology: Lithology and geo-coding and geo-

			referencing
4	GPS Data	Co-ordinates and altitudes	Landslide Location
5	Field Data	Lithology, Slopes, Vegetation, Settlement	Vulnerability Assessment and Accuracy verification

3.3 Input Parameters and Data Preparing:

The thematic layers were used for the landslide hazard analysis are listed below:

- Slope
- Drainage
- Lithology
- Land use
- Slope Aspect
- Roads
- Pre-occurred Landslides
- Settlement

The outcome of image processing is a set of thematic maps that are utilized as data inputs in different layers. The data is integrated using GIS technique to analyze the layers.

3.4 Information Value Method

Method adopted for the study area is a statistical method, namely the Information Value Method (Yin and Yan, 1988). The information value is calculated using the following formula (Van Westen, 1993)(Balasubramani and Kumaraswamy, 2013):

Prior Probability = nslide/ nmap

Information Value = log [(nsclass/ nclass)/ Prior Probability

Where: nmap = Total number of pixels in the map
nslide = Total number of landslide pixels
nclass = Number of pixels in each class
nsclass = Number of pixels containing slide

Negative values indicate negative correlation with landslides
Values around 0 indicate uncertainty or no evidence
Positive values indicates strong correlation with landslide.

For calculation of information value, each class of the thematic map is crossed with the landslide map (map x) with the active landslides. Cross tables were created which contain the pixel information value for the various classes of the individual layers. After crossing the landslide with all the individual layers, all the final maps were integrated together to derive a landslide hazard map. The equation for the final map is:

Landslide Hazard Map = Slide Slope + Slide Flow Accu + Slide Litho + Slide L Cover + Slide Asp + Slide Rd + Slide Settle

Where:
Slide Slope = Landslide and Slope Cross Weighted Map
Slide Flow Accu = Landslide and Flow Accumulation Cross Weighted Map
Slide Litho = Landslide and Lithology Cross Weighted Map
Slide L Cover = Landslide and Land Cover Cross Weighted Map
Slide Asp = Landslide and Aspect Cross Weighted Map
Slide Rd = Landslide and Road Density Cross Weighted Map
Slide Settle = Landslide and Settlement Cross Weighted Map

Following 7 parameters have been used. Before starting calculation the weights are assigned as per their importance. The weights are assigned by studying anaglyph, expert's opinion and actual site visits.

Table 2 Parameters with weights for statistical analysis

Parameter Maps	Weights
Slope	7
Drainage/ Flow Accumulation	6
Lithology	5
Land cover	4
Aspect	3
Roads	2
Settlement	1

4. ANALYSIS FOR LANDSLIDE HAZARD ZONATION:-

4.1 Digital Elevation Model (DEM): The DEM tile was imported in ILWIS environment and proper georeferenced was assigned to it along with WGS 84 coordinate system. Then the sub map was extracted to cover the study area. It has been observed that the minimum R.L. is about 840M in Kudali main stream and the top R.L. is about 1380M near west of Panchgani and east of Bhilar. To enhance the accuracy the digitized contour map was prepared from slicing the DEM by 20 M. the sliced DEM was vectored into polygon and then into segment map. This segment map was assigned the respective contour value in value domain. Again the same contour map was interpolated with 0.01 M precision to develop the new final DEM.

4.2 Digitized contour map: Digitized contour map of 20 M interval was prepared after slicing the DEM. It shows that, the contours are ranging between 800m to 1380m R.L. in the study area. It is observed that in certain elevation range the contours are much closed and nearly basic volcanic rock is present in the form of lava sheets. This area is being eroded since 53 million years. And has given rise to present contour pattern. Ridges, platu, valleys and the main stream, spurs of the hills are easily recognized from the contour patterns. The main function of the contour map was to prepare the enhanced DEM with 0.01 M precision.

4.3 Elevation sliced map: This is the layer prepared after slicing the DEM. It shows slicing of the study area into thirteen different zones of elevation range with 20 M precision. The layer was used to extract the contour data.

4.4 Slope map in degree: This is important layer in landslide hazard zonation mapping as slope is first causative factor of landslide. From slope stability point of view, the slope map was classified in three groups as Blue color indicates the slope from 0º to13º as gentle slopes; Yellow color indicates the slope from 13º to 50º as slide prone slopes and red color indicates the slope from 50º to 90º as steep stable slopes.

4.5 Slope aspect map: The slope aspect map was prepared from DEM. This map shows the ground slope direction with respect to North. It has been observed that in this particular area the slope aspect has a little control over landslide. After studying pre occurred landslides, the slope aspect map was also considered in Information Value Method. Slope aspect map has been sliced into 8 directions. (N1 and N2 both indicates Northward slopes).

4.6 Flow direction map: This map indicates the flow direction of the study area. Each pixel is assigned with direction out of eight in which the precipitated water may flow. It is used to prepare the flow accumulation map by calculating the number of pixels, from the upstream direction flowing towards each pixel. This layer is the pre-requisite raster for the flow accumulation map. It has not been used in Information Value Analysis.

4.7 Flow accumulation map: It indicates the number of pixels flowing towards any particular pixel. With the prior information of resolution and rainfall data, it is easy to calculate the volume of water that may accumulate at selected pixel, for known rainfall. Since water plays very important role in landslides the flow accumulation has been used as high weighted layer in the Information Value Technique. Pre occurred landslides have been associated with the maximum flow accumulation. Maximum flow accumulation in soft overburden on slide prone slopes enhances the susceptibility. In the final layer of Information Value Method the maximum landslide susceptible areas have been found in the flow accumulation zones.

4.8 Village Map: The village map has been added over each layer combination for getting the relative position of spatial features with respect to village settlement.

4.9 Road Map: Contoured topographic map and the satellite data are collectively used to prepare the road map. Road map is simply a vector segment layer digitized on map and satellite imagery. Road vector after converting to raster was used to analysis vulnerability in Information Value method. In present study area only three major stretches of the roads have found to be landslide prone. They are associated with vulnerable settlement. In the hilly areas excavation for the roads has found to be one of the important causes of landslide. Therefore the raster road map was used in Information Value Method with the weightage.

4.10 ETM+ DATA: Out of 8 bands of Landsat 7 ETM+ band 4, 3 and 2 i.e. 1NIR and 2 Visible bands where used for the remote sensing study of the area. The FCC was prepared from extracted portion of the study area. NDVI layers and various band combinations were prepared and same were utilized for supervised classification of the area. It has been observed that the area consists of the E-W ridges alongside the river Kudali. Various slopes, Lava flows, Mini water sheds, Lateritic Platu's, Forest and Vegetation Cover, Barren Land, Settlements were identified by using the image interpretation keys. The identified classes were co-related with topographic map and field observations. Then the imagery was classified for getting the output layer of land cover map. Some pre occurred landslides were identified from both ETM+ and high resolution Google Earth (IKONOS) imagery and the same information was used in calculating prior probability. By using the ASTER DEM as DTM the steriopair of the same imagery have been prepared. They were viewed as an anaglyph models, so as to realize the probabilistic accuracy of the outcome of the information value method used for hazard zonation.

4.11 Google Earth Data: The google earth data has been processed from high resolution IKNOS PAN to develop the PAN sharpened MSS merged data product giving the true color composites. Therefore the same was utilized to extract the information of settlement details, roads, lithology, vegetation and the pre occurred landslide events. After the image interpretation the various related thematic layers were on screen digitized and converted into the required raster data set to be used in information value method.

4.12 Land Cover Map: From supervised classification of multiband layer combination of ETM+ data the land cover map was prepared. This raster was directly used for information value method. Since it is having relatively low spatial resolution and also the lower thematic resolution it was given a less weightage in information value method.

4.13 Lithology Map: In the study area basaltic rocks are very common. Because of highly oxidizing and humid conditions prevailed in the past, the basalts were weathered to form thick layers of lithomarge clays later on converted to the capping of laterite. Therefore basalts caped by laterite is a common lithology of the area. During the field visit the basaltic outcrops were marked on map along with their RLs. It has been observed that above certain RL the lithomarge clay layers are outcropping and above that entire area is covered by laterites. Therefore elevation data was sliced to get the general lithology map of the area.

5.0 Calculations for Information Value by Statistical Relationship of various Classes with Active Landslides:

5.1 Landslide Hazard Zonation

By overlaying all these crossed layers new output in the form of Landslide hazard zonation has been obtained.

Table 3 Landslide Hazard Zonation

LANDSLIDE HAZARD ZONES	AREA (Sq.km)	% OF TOTAL AREA
Very Low	2.377215	7.03
Low	6.1312996	18.13
Moderate	13.9574223	41.28
High	9.7868371	28.94
Very High	1.5618777	4.62

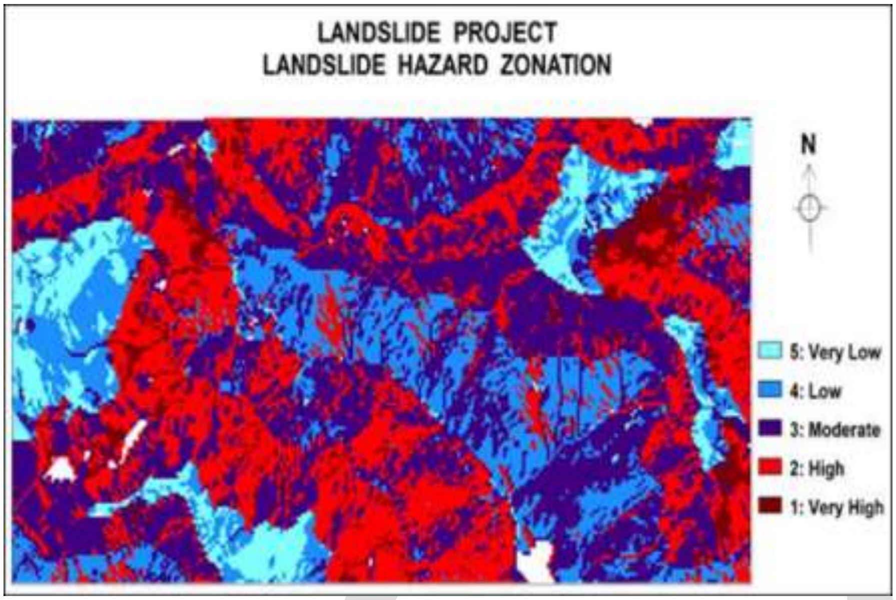

Figure 2 Landslide Hazard Zonation

5.2 Landslide Susceptibility Zonation

Form all zones only susceptible zone is delineated to focus on most hazard zone. By slicing operation the entire study area is divided in only two zones as susceptible zone and safe zone.

Table 4 Landslide Susceptibility Zonation

LANDSLIDE HAZARD ZONES	AREA (Sq.km)	% OF TOTAL AREA
Relatively Stable	29.752840.0	87.86%
Landslide Susceptible	4.110155.5	12.14%
Total	33.862995.5	100

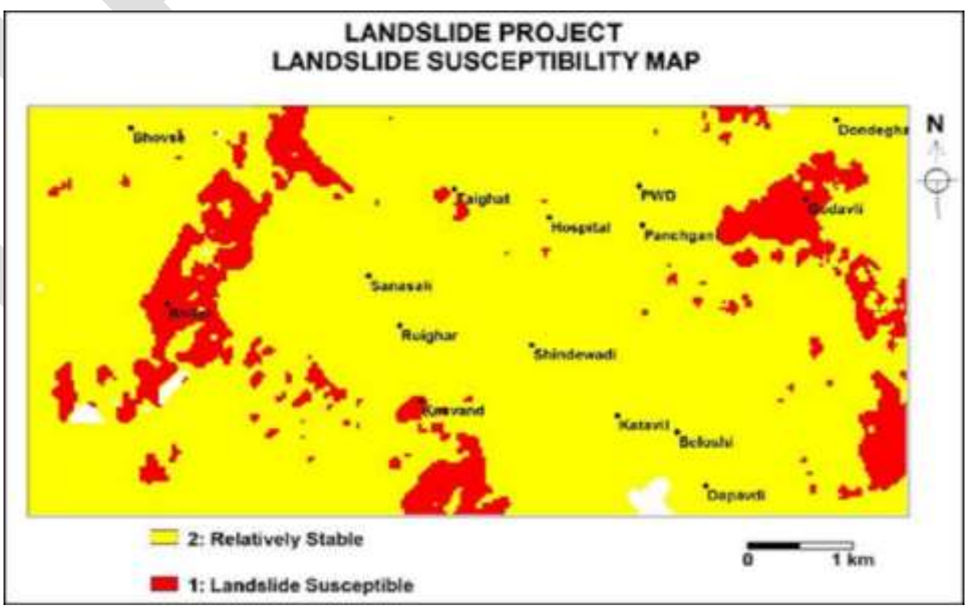

Figure 3 Landslide Susceptibility Map

5.9 Vulnerability Zonation Details:
By slicing operation the entire study area is divided in only two zones as susceptible zone and safe zone. For dividing the map in various zones slicing is done.

Table 5 Vulnerability Assessment Details:

LANDSLIDE HAZARD ZONES	AREA (Sq.km)	% OF TOTAL AREA
No Infrastructure	31.0200062	90.82
Safe Road	1.1602520	3.40
Non Vulnerable Settlement	1.2783225	3.74
Vulnerable Settlement	0.4797196	1.40
Vulnerable Road	0.2166176	0.63
Total:	34.1549179	100

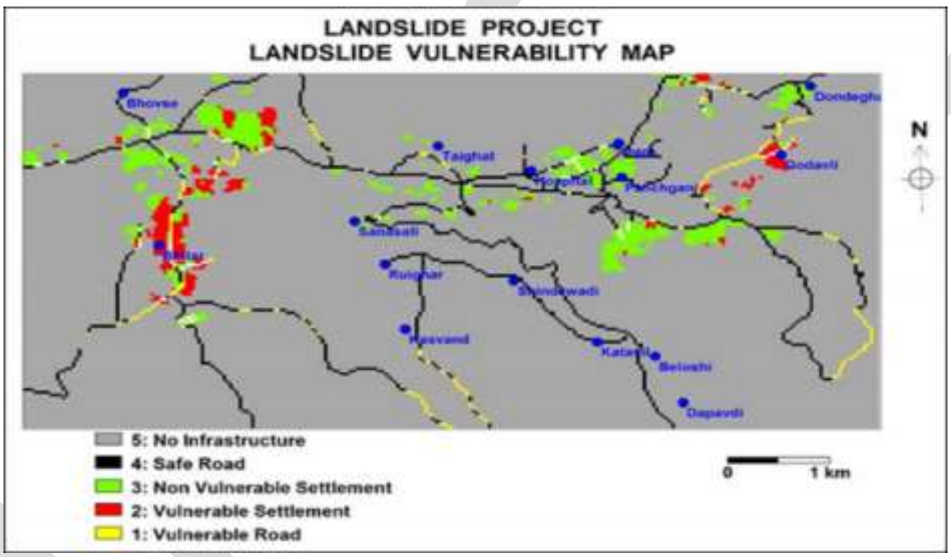

Figure 4 Landslide Vulnerability Map

From the information value method the Landslide Hazard Zonation, Landslide Susceptibility Zonation and Landslide Vulnerability Zonation has been obtained. From the statistical analysis the area of hazardous and vulnerable area has been calculated.

IMMEDIATE TROUBLE POINT LOCATIONS:

Following locations from the study area, demand immediate attention due to having high degree of landslide hazard. Efficient planning should be done to avoid the possibility of landslides and to reduce loss of economy.

Table 6 Immediate Trouble Point Location

SR. NO	LATTITUDE	LONGITUDE
1	17°55'25.9"	73°46'04.5"
2	17°55'12.8"	73°45'57.3"
3	17°55'01.8"	73°45'53.7"
4	17°54'57.1"	73°45'48.2"
5	17°54'50.8"	73°45'43.3"
6	17°54'40.8"	73°45'57.6"
7	17°54'33.6"	73°45'59.1"
8	17°54'30.7"	73°46'04.6"
9	17°54'26.4"	73°46'37.3"
10	17°54'25.9"	73°46'41.3"
11	17°53'50.1"	73°47'08.1"
12	17°55'59.4"	73°48'37.1"
13	17°55'19.7"	73°48'52.9"
14	17°55'57.5"	73°48'41.6""
15	17°54'53.9"	73°49'26.6"

7. Results and discussion:

Integration of Remote Sensing along with Geographical Information System (GIS) allows most reliable, accurate and updated database for land and water resource. Lack of land in hilly terrain has forced people to construct buildings on steep slopes with small or no retaining measure.

For the very first time in Maharashtra the information value method has been adopted and implemented by overlaying all the thematic layers to obtain Landslide hazard zonation map. This map is divided in five risk zones as Very Low, Low, Moderate, High, and Very High. In further part of the research from obtained hazard zonation map the only susceptible zone have been delineated to focus on most hazardous zone. This susceptibility map divides the entire study area in only two zones as susceptible zone and safe zone. This facilitates us to focus only on the most hazardous zone. This most hazardous zone map overlaid on landslide susceptibility map with settlement and road to obtain vulnerability zonation map.

The obtained vulnerability zonation map incorporated unnoticed area of Godvali which has shown equal risk for Godvali settlement as in Bhilar, therefore ground trothing visit immediately arranged to verify the accuracy of obtained output. It has been revealed that the settlement of Godvali is along deep and steep valley with flow accumulation passing from both sides. The entire settlement is on sloping ground which is having ground slope about 10^{o}. According to Young's slope classification it is steep for settlement. Some sliding movements has been noticed along with considerable creep towards the valley. This has proved the results obtained are satisfactory having utmost accuracy. According to vulnerability assessed results over 34 percent area is liable to high-severe landslide risk and within this about 5 per cent has very high to severe risk while about 29 per cent of the total area has high risk of landslide occurrence. Such areas include Bhilar and Godvali on eastern slopes of the hill. About 59 per cent area of the study area has low to moderate risk of landslides. The analysis shows that unmapped hilly terrain of Mahabaleshwar Tehsil may also lie under hazardous zone of landslide of varying magnitude.

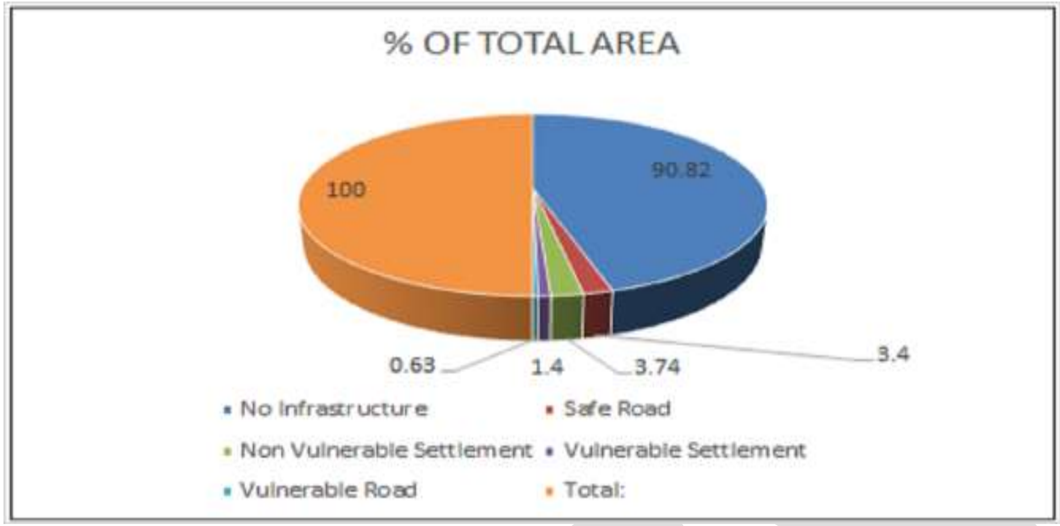

Figure 5 Graph showing Landslide Vulnerability Zonation classification

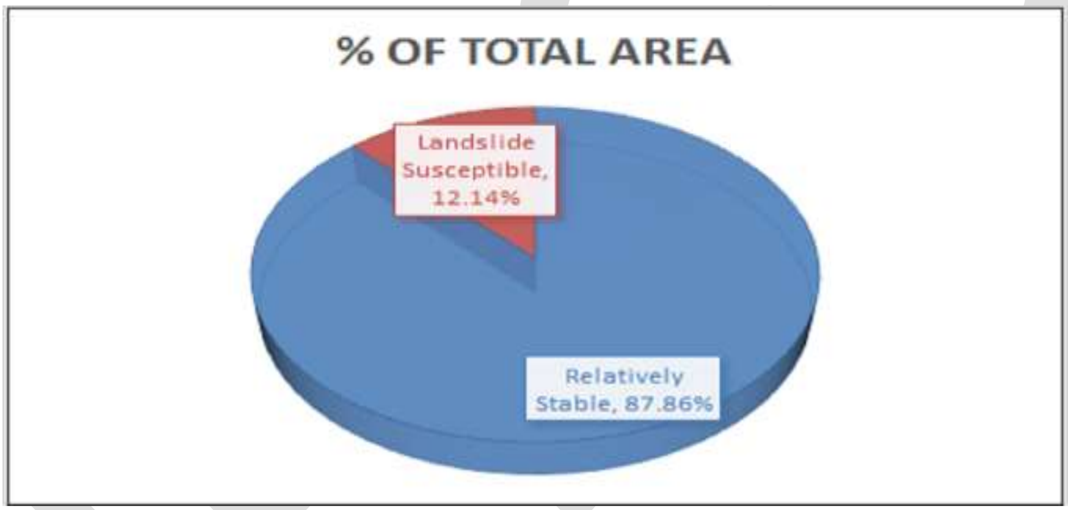

Figure 6 Graph showing Landslide Susceptibility Zonation Classification

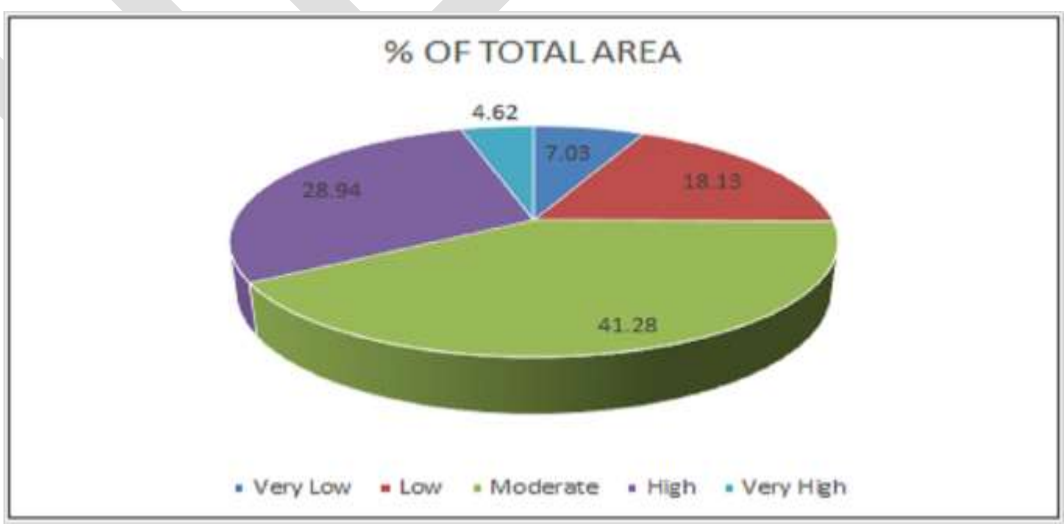

Figure 7 Graph showing Landslide Hazard Zonation Classification

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