Prediction and Mapping of Shallow Landslides in Kashmir Himalayas Using Remote Sensing and Geospatial Tools

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ABSTRACT-

The high susceptibility to landslides of the Himalayan terrain is mainly due to a complex geological setting combined with contemporary, varying slopes and relief, heavy rainfall, along with every increasing human interferences in the ecosystem. The Liddar valley in Jammu and Kashmir is undergoing very rapid development following completion of various tourists' spots. This development is adjacent to a range of steeply sloping hills that experiences levels of annual rainfall. Rainfall induced landslides on this steeply sloping natural terrain are therefore potential hazards to property developments downslope. To take a quick and safe mitigation measures and future strategic planning, identification of landslide prone areas and Landslide Hazard Zonation (LHZ) are carried out. The growing availability of digital topographic data and the increased reliability of precipitation forecasts invite modeling efforts to predict the location of shallow landslides in hilly and mountainous areas in order to reduce risk to an ever expanding human population. The various data layers generated and co-registered were: lithology, drainage map, slope angle and relative relief. The different landslide zones were identified namely, Fully stable, Stable, Partially stable, Unstable, Very unstable and Chronic instability. Field data on landslides were employed to evaluate and validate landslide hazard Zonation map. It is interpreted that the distribution of landslides is largely governed by a combination of geoenvironmental conditions like slope angle, distance from drainage line and barren or less- vegetated areas.

1. Introduction

Recently there has been an increasing occurrence of landslides in Liddar Valley Most of these landslides occurred on cut slopes or on embankments alongside roads and highways in mountainous areas. Some of these landslides occurred near high-rise apartments and in residential areas, causing great anxiety in many people. The area chosen in this study, Liddar in Kashmir Valley, Landslides triggered by heavy rainfall are the most common, but few attempts are made to predict them or prevent damage. To remedy this, it is necessary to assess scientifically the area susceptible to landslide. Subsequently, the landslide damage could be greatly decreased. Through scientific analysis of landslides, we can assess and predict Landslide-susceptible areas, and thus decrease landslide damage through proper preparation. The factors, which promote landslides, are water, slopes, nature of rock, and structure of rocks and disturbance of equilibrium. The majority of the earth or rock failure is confided to slopes. This indicates that slopes are directly responsible for landslides. An analysis of stability should determine under what conditions a slope will remain stable, the stability being an evaluation of slope stability by means of quantitative assessment of slope stability behavior and there by offers an input for the design and hazard assessment of slopes.

GIS have become increasingly valuable tools in the computer-based modelling of environmental processes. The current generation of environmental models requires large amounts of spatial data as input and produce predictions which can be displayed as maps. GIS are able to produce data required as input to models and excel at displaying spatial predictions. The simplest approach to using GIS in this way is to pass files between the GIS and the modelling software.

SHALSTAB model is based on an infinite slope form of the Mohr-Coulomb failure law in which the downslope component of the weight of the soil just at failure, t, is equal to the strength of resistance caused by cohesion (soil cohesion and/or root strength), C, and by frictional resistance due to the effective normal stress on the failure plane:

$$t = C + (\sigma - u) \tan \varphi \qquad (1)$$

In which σ is the normal stress, u is the pore pressure opposing the normal load and tan φ is the angle of internal friction of the soil mass at the failure plane. This model assumes, therefore, that the resistances to movement along the sides and ends of the landslide are not significant.

2. Description of the Study Area

Liddar valley situated in Anantnag district of Kashmir Valley has been selected as the study area for the present research "Slope Stability Analysis". Liddar or the 'yellow' river, a major right bank tributary of Jehlum River upper catchment of Sind Basin is formed

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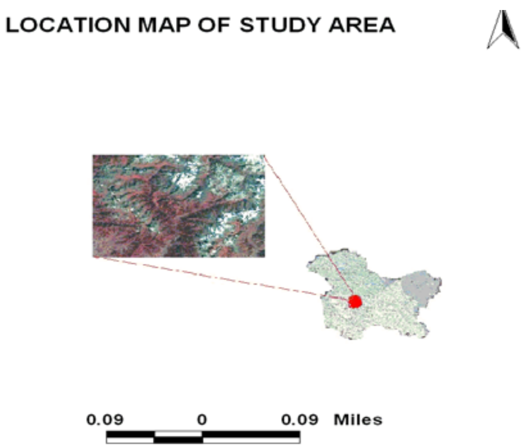
by two mountain torrents which, following from the north and north-east, unite near the village of Pahalgam, lat - 34°, long - 75° 22´. The people in the tourist town (Pahalgam) are engaged in tertiary activities, but agriculture is the main economic activity of the area which is highly vulnerable to landslide hazard and has a great impact on the socio-economic aspects.

Fig: 1



2.1 Geology of the area

The geological succession as observed in the area between Batkot to Logripur east of Liddar river and Dahwat to Chitrasbudur west of Liddar river is as fallows:-

Table 1.1

AGE	FORMATION
Recent to sub recent	Soil and Alluvium
Permian	Panjal Trap
Upper Carboniferous	Agglomeratic Slates
Middle Carboniferous	Fenestela Shale, Quartzite and Sandstone
Lower Carboniferous	Syringothyris Limestone
Devonian	Muth Quartzite
Silurian	Upper Silurian Shale

2.2 Structure:

On the eastern side of the Liddar River the uninterrupted sequence of sedimentaries broadly strikes NW-SE and dip at 35 to 45 to NE. At places the beds dip at steeper angles. In the SE part of the area under reference, the beds strike WNW-ESE with dips up to 60 towards NNE. On the western side of the Liddar River the beds show considerable swerving in the strike direction. While the regional strike is NW - SE the beds swerve at places to NE-SW and even ENE-WSW and really E - W. in the southwestern part of the area the beds dip southwesterly and in the western part around Sheikpur they dip towards WNW and further northwards the dip is towards NE. the variation in the strike direction of ‘S’ forming a broad ‘U’ shaped outcrop pattern indicative of an anticlinal structure with a gentle plunge towards NW. the beds exposed on the southwestern limb of the anticlinal have moderate to steep dips whereas the beds on the NE limb have moderate dips. At Sheikpura near the axis of the fold the beds dip at low angles.

Faults: the area is transversed by a major fault roughly trending NNE-SSW. The river Liddar has a remarkably straight course in NNE-SSW direction and appears to have been controlled by this major fault. It is significant to mention the deposition as a number of springs at Kotsu, and Goas in NNE-SSW direction parallel to the faulting in the area. Near Yenur on the eastern bank of the river a crushed clayey material (fault gouge) of about a meter width and over 20 meters in length also trends in NNE-SSW direction. However, to effect on the other side of the river near Salar and also SE near Logripura and Lotar is not clear in view of the large alluvial and soil cover present in the area. The only exposures of Syringothyris limestone on Salar side are seen at Kotsu and SW of Liddar. Keeping in view the general topography of the area and behavior of the overlying rocks of the Fenestella series the probable boundary of Syringothyris limestone has been marked. Thus in view of the reasons given above the effect of this fault on the axis of the fold. However, from the work of Middlemiss (1910 it seems that these lithological units continue further SE of Logripura near Veil and Maygam and the axis may be passing some where south of Logripura.

The fault appears to be pre-Panjal trap age as the trap sill noticed on either sides of the river near Yenur and Kullar has not been affected by the fault. Several cross faults have also been noticed in the region. One of them trending N80 E-S80W seen near Kanjdori on the Kotsu hill is evidenced by fault scrap. Sudden variation in strike and minor fault breccia whereas another trending N 80W-S80E noticed on the same hill is indicated by intense crushing of the surrounding rock, fault gouge and sudden abutting of a trap intrusive. This may be post- Panjal trap in age.

Joints: The joints noticed in the area are mostly observed in Fenestella quartzite and Syringothyris limestone. They are spaced at intervals of a few centimeters to several meters. Some joints continue for a length of over 25m.In elation to the disposition of lithological units these joints can be grouped as strike joints, dip joints and oblique joints. The average disposition of joints in Fenestella quartzite and Syringothyris limestone as determined from the contour diagrams is in NW-SE and NE-SW with steep to vertical dips.

2.3 Climate

Climate of a particular place is the net result of the combination of several factors like latitude, altitude, terrain, distance from the sea and the prevailing winds.
Latitudinally the state of Jammu and Kashmir lies in the sub- tropics but in reality the Kashmir and the Ladakh divisions experience quite different types of climate, the modification being introduced by altitude. The mean annual temperature and the climate type of Jammu, Srinagar and Leh are as under:

Table-1.2

City	Altitude	Mean annual temp.	Climate type
Jammu	366m	24.5˚C	Sub-Tropical
Srinagar	1585m	13.3˚C	Temperate
Leh	3505m	5.3˚C	Sub-Arctic

Precipitation around Liddar valley: the bulk of precipitation around Liddar valley is received in the form snowfall during winter –December to ending April. During these months the precipitation over the entire region of Kashmir and Ladakh as well as north India Plains is associated with "Western Disturbances" which are extra-tropical disturbances having their origin near about the Mediterranean. These disturbances travel from west to east and enter India through Iran, Afghanistan and Pakistan. These disturbances encounter first the Great Himalaya and the Trans-Himalaya in the north. As such, bulk of precipitation occurs.

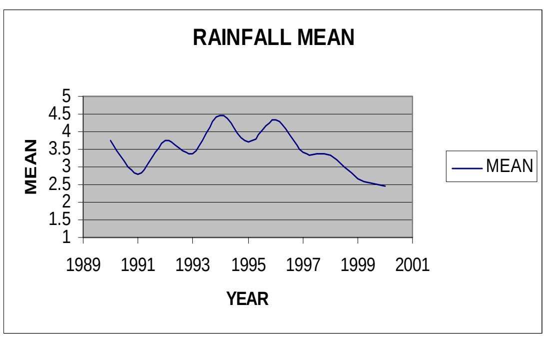


Fig: 2 the annual mean precipitation of the Liddar valley

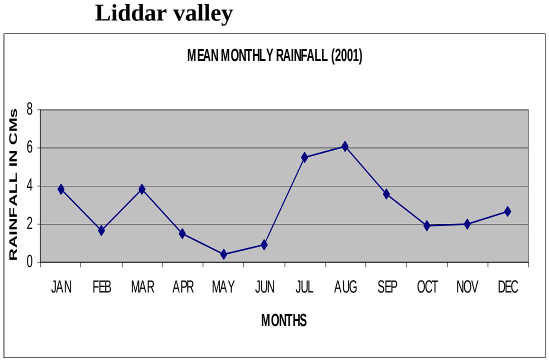


Fig: 3 the monthly mean precipitation of the Liddar valley

3. Data Sources

The study area was examined using the Arc View GIS software and other image processing software. The data available for this study include topography, land-use classification, a terrain morphological map, and the location and trails of landslides. a regularly spaced DEM was generated from the 1:40000 scale digitized topographical maps at a spatial resolution of 40 m. various topographical variables were then derived from the DEM including elevation, slope aspect, slope gradient, drainage contributing area. The landslide data base used was derived from the remote sensing images, three different images were used for this purpose i.e. ETM 2001, and ETM+ PAN with 15m resolution, MSS 1979 and both the images ETM 2001 and ETM+ PAN were fused for the better visualization of the landslides. The landslides were observed on the images as a distinctive light tone, which is generally bare of vegetation (King, 1999).

4. Methodology

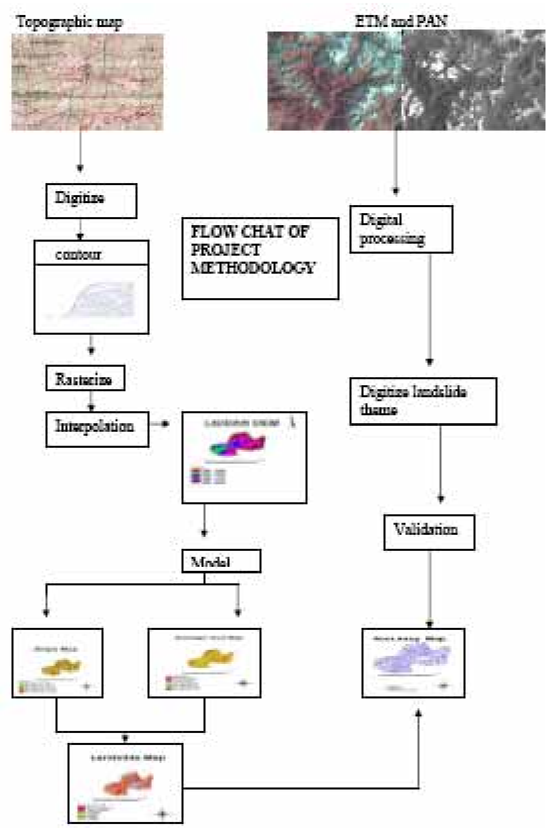


Fig: 4 showing project Methodology

4.1 Shalstab Tools to map shallow landslide potential:

Shalstab Tools is a suite of software routines that maps shallow landslide potential. The software has been implemented as an extension of the Arc View geographic information system (GIS) program. Using Shalstab Tools, I analyze digital elevation model (DEM) grid data generate statistics that compare mapped distribution of landslides with similar statistics of random locations.

- Shaltopo- Contributing area. This step uses elevation data with the sinks removed to calculate the drainage area to each grid cell.
- Shaltopo- slope. This step uses the elevation data with sinks removed to calculate the local average slope for each grid cell.
- Calculating the q/t ratio- This step calculate the ratio of steady- state effective precipitation (rain minus evapotranspiration) to transmissivity (the ground's subsurface ability to convey the water downslope), or the q/t ratio. Shalstab tools calculate this ratio from either the elevation grid, or from the slope and area grids. (Already generated in the first step).
- Shalstab now calculates the landslide stability (q/T) ratio for each cell and displays for this theme a range of log values (logarithmic values) from stable to chronic instability.

5. Results and discussion

5.1 land use\ land cover

A land-use types for the whole study area based on the interpretation of ETM images with verification of field check. Although 28 land-use types were classified, these were simplified into 10 categories for the purposes of this study: Forest, Shrubs & grass land,

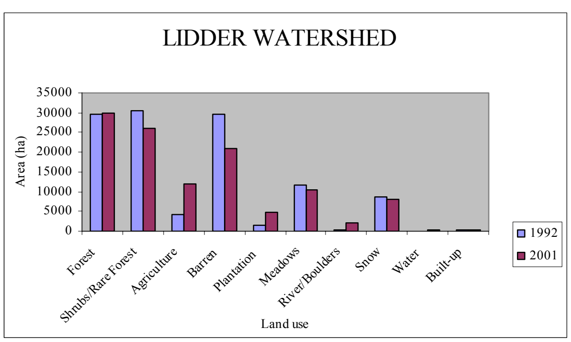
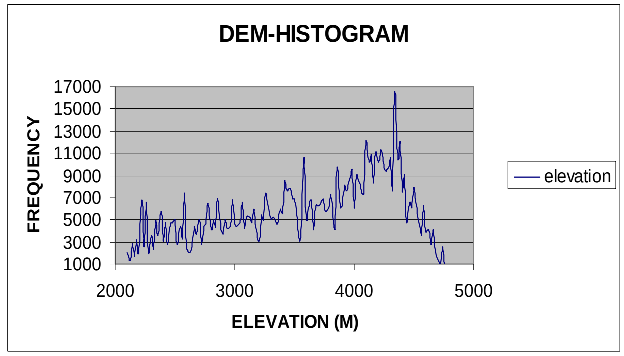


Fig 5 showing land cover graph

Agriculture, Barren, Plantation, Meadows, River/Boulders, Snow, Water, and Built-up.

Fig: 6 Histogram of the DEM



5.2 DEM

The Liddar Valley stretch from Pahalgam to Shesh nag has been divided into six classes on the basis of elevation. The elevation values are derived from the generated DEM. The first elevation class ranges from 1693-2265 meters. And the other five elevation ranges are 2267-2821, 2822-3385, 3386-3949, 3950-4513 and 4514-5078 meter respectively. The Histogram of the generated DEM shows the highest frequency 16000 having elevation value from 4000-4500 meters, the second high frequency area is from 3500-4000 having 13000 pixels. And the frequency 1000-5000 is low frequency areas. The intermediate frequencies are 5000-7000; elevation values are 2500-3500.

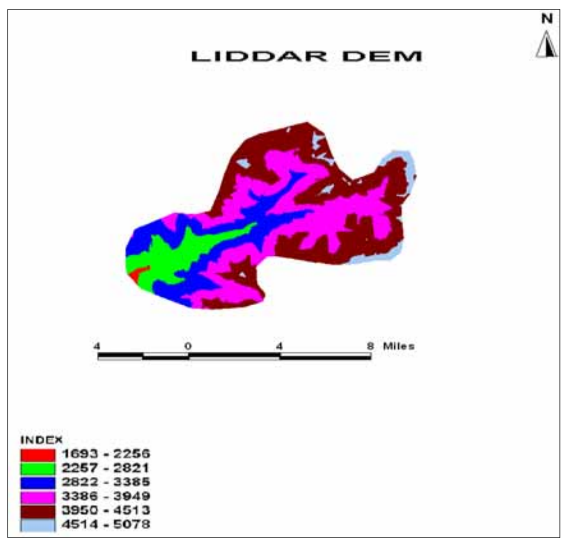


Fig: 7 Liddar DEM

5.3 Model results:

Slope: The slope map generated through the model using elevation data, the Shalstab divides the area into 8 slope classes and also give the slope in terms of percentage as well as radians (1 radian =57˚).

Class one of slope map of study area having 0-10 % or 0-0.1 radian value. This range is the lowest degree of slope in the study area. The other slope ranges are 10-20%, radian value 0.1-0.2, 20-41% 0.2-0.39 radian, 41-60% 0.39- 0.54 radian, 60-70% 0.54-0.61 radian, 70-80% 0.61-0.67 radian, 80-100% 0.67-0.78 radian and over 100% almost vertical slopes having radian values of 0.78-1.48.

Class	**Slope %**	**Radian value**	**Slope (˚)**
1	0-10	0 - 0.1	5.7
2	10-20	0.1 – 0.2	5.7-11.4
3	20-41	0.2 – 0.39	11.4-22.23
4	41-60	0.39 – 0.54	22.23-30.78
5	60-70	0.54 – 0.61	30.78-34.77
6	70-80	0.61 – 0.67	34.77-38.19
7	80-100	0.67 – 0.78	38.19-44.46
8	Over 100	0.78 – 1.48	44.46-84.36

Table 1.3 Showing Slop Classes.

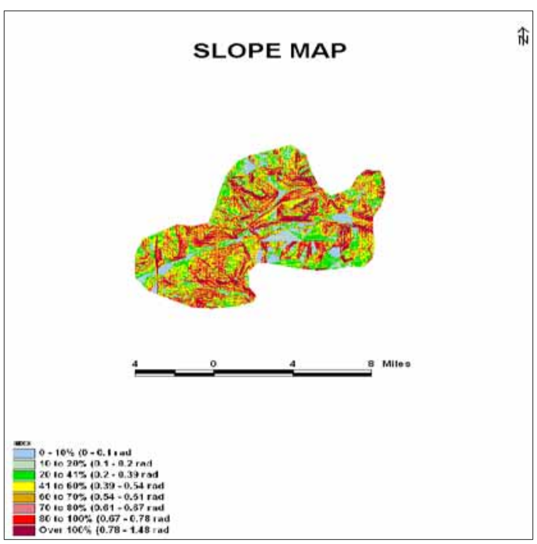


Fig: 8 showing different slop classes

Contributing area: The Shalstab calculates the drainage area to each grid cell. And gives the log values for this theme and classify the area into 9 classes on the basis of these log values.

In the first class having the value of log 10 is upto 25 (0-1.397) means a cell is having less drainage area so the percolation of water is also less, these area are mostly steep slopes. As the contributing area increases the ability of water to percolate down words also increase, the other classes of contributing area ranges from 25-50, 50-100, 100-200, 200-500, 500-1000, 1000-2000, 2000-4000 and over 4000.

Class	**Log 10**	**Log value**
1	**Under 25**	**0 - 1.397**
2	**25-50**	**1.397 – 1.699**
3	**50-100**	**1.699 – 2**
4	**100-200**	**2 – 2.30**
5	**200-500**	**2.30 – 2.699**
6	**500-1000**	**2.699 – 3**
7	**1000-2000**	**3 – 3.30**
8	**2000-4000**	**3.30 - 3.60**
9	**Over 4000**	**Over 3.60**

Table 1.4 Showing different drainage area Classes.

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From 1000 – over 4000 the contributing area is very large due to flat topography and in these areas the precipitation have enough time to percolate downward, which act as the lubrication of material

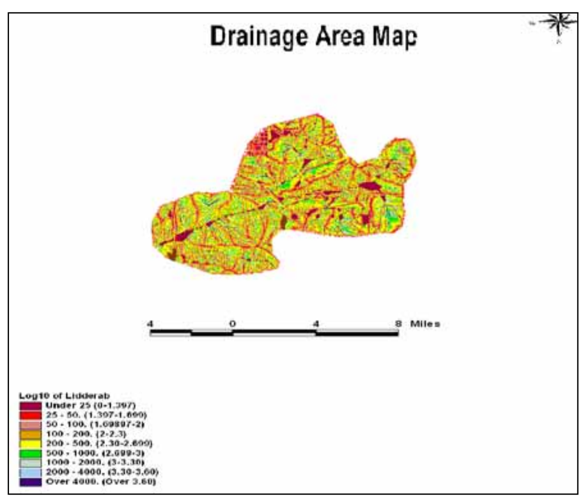

Fig: 9 Showing different drainage area Classes

and ultimately decreases the slope stability.

Landslide Stability (q/t) ratio: The Shalstab calculates the landslide stability ratio and displays for this theme a range of log values (logarithmic values) from stable to chronic instability. Shalstab calculates this ratio from slope and area grid. As we know the Shalstab is parameter free model, and for shallow stability it use constant soil bulk density 1700 kg/m^3 and friction angle 45^0 (W.E Dietrich) to calculate the shallow stability.

The Shalstab give 7 stability classes from stable – chronic instability. Shalstab uses two themes to calculate the landslide stability ratio; one is slope and second drainage contributing area. The seven stability classes with the area covered by it are given in the table 1.5

Class	**Area (%)**
Chronic Instability	**3.64**
Very unstable	**5.14**
Unstable	**3.40**
Partially stable	**3.19**
Stable	**2.56**
Fully stable	**82.07**

Table 1.5 showing different stability classes

The landslide map suggests that if q/t ratio steady – state effective precipitation (rain minus evapotranspiration) to Transmissivity. The surface runoff is more and the downward percolation of the water is less. The soil saturation also decreases, which ultimately reduces the mobility of the soil hence reduces shallow landslides.

At very steep slopes (90°) the q/t ratio is very high, but due to the absence of soil material at such places, the Shalstab classify these areas as chronic instability.

As q/t ratio decreases, the transmissivity increases, which increases the shallow instability. These conditions are mainly present at the middle stability classes from class 3 to class 6.

Further q/t ratio becomes less the precipitation have enough time to percolate and increases the mobility of the material but at the same time the topography will be flat (slope 0-10) that will stabilize the ground. This shows the inverse relationship of the q/t ratio with slope.

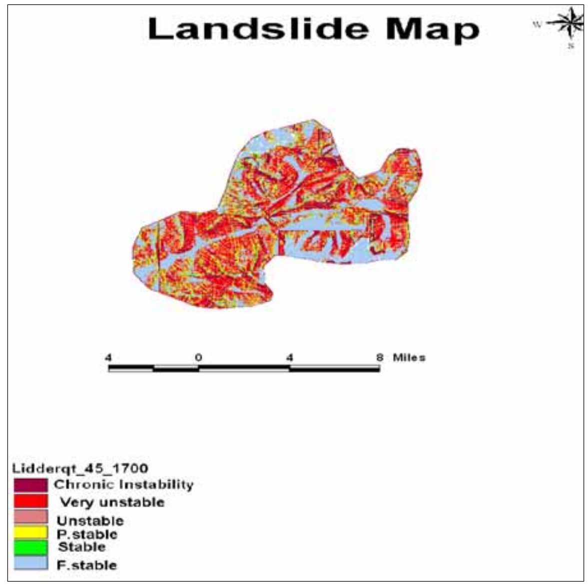

Fig:-10 showing area under different stability classes

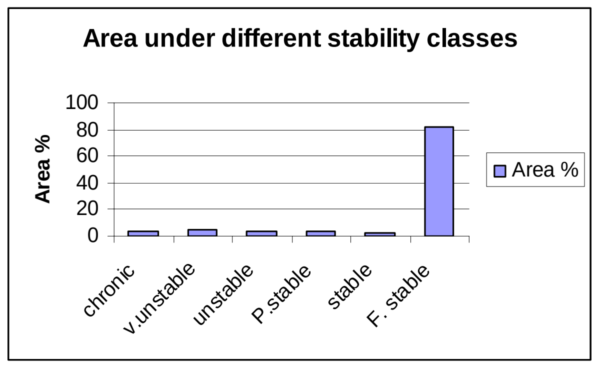

Fig:-11 Histogram showing area under different stability classes

- q/t high--- topography vertical---- absence of soil---no shallow landslide.
- q/t moderate--- slope moderate--- presence of soil--- instability increases.
- q/t less--- topography flat--- even presence of soil--- ground becomes stable.

5.4 Model validation

I validate the Shalstab results with the landslides digitized from the remote sensing images the results will be the model results matched almost 85% with the existing landslides, so this indicates that the Shalstab gives accurate stability classes for the Liddar valley.

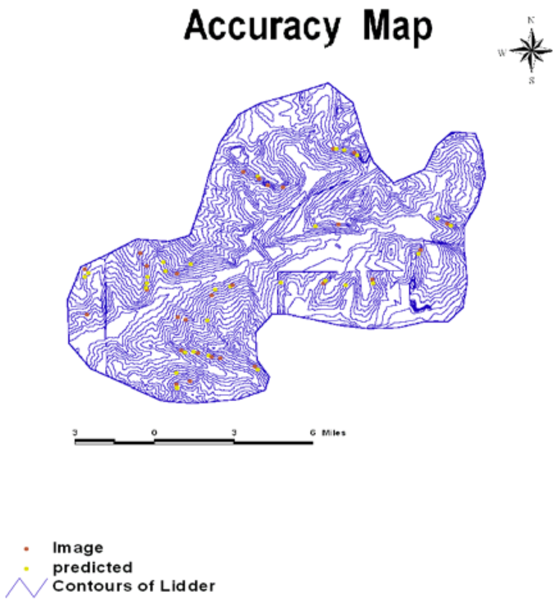

Fig:-12 showing Accuracy map.

6. Conclusion

The slope stability analysis for Liddar valley Pahalgam were carried out in order to determine the slope angle and to characterize the soil slope surfaces for protective measures. Gravity increasing pressure due to overloading structural weakness in the soil cover and percolating rainwater are the main causes of instability in the soil cover on a slope which ultimately slides down as a shallow landslide. Examination of landslide propensity and the geologic and geomorphologic parameters indicates that slopes which are most susceptible to landslide are those with slope angles in the range of 30˚ – 40˚ with q/t ratio range of log 200 – log 4000. On the basis of slope map, and landslide Hazard Zonation map, developed by the Shalstab, shallow landslides can be protected by using drainage holes and retaining walls, and by aforestration depending upon the nature of requirement. The out come of the above studies is to determine the stability of the slopes with a purpose to constitute to the safe and economic design of soil slopes.

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