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Landslide Forecasting in Kedarnath - Gaurikund Route

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Abstract: Landslide forecasting has been one of the major subject of interest in most of North India since 2013 flash flood event of Kedarnath, this model tries to draw a more realistic attempt to forecast landslides in Kedarnath and Gaurikund route, the article goes through a limited data related to landslide events of the study area and used a statistical approach towards the question. The attempt is to draw a linear regression model of relevant factors and derive a probabilistic function in its respect , the use of SPSS software is done to compile various available data and forecast a few missing data with highest possible accuracy.
Keywords: Landslide forecasting, discharge, precipitation, regression, OLS

I. INTRODUCTION

Kedarnath is one of the most holy locations in India where at least 1 lakh people travel up the Himalayas to worship Hindu gods and it is pretty spectacular to see them payingtheir tribute. But this location is not as innocent as we just described above, this place is in fact one of the most vulnerable places to landslide and flood disasters due to many natural and manmade causes. In 2013 due torrential rainfall and cloudburst like conditions this beautiful place turned into a spot for massacre where up to 700 people lost their lives and more went missing.

Location

1. Location— Kedarnath is located in the Himalayan region at the height of approx. 3,500 meter above sea level in the Mandakini valley of Rudraprayag- Uttarakhand state ofIndia.The study area covers of about 2000 sq. Km and lies between latitude 30deg.012’58.132 to 30deg. 048’27.642 and longitude 79deg. 02’58.649 to 79deg. 02’0.952. (Fig 1.)
2. The frequency of landslide in this region varies from region to region and it can be expected to take place in areas where they have taken place historically, the route between Gaurikund and Kedarnath bordered by river Mandakini which flows in continuation with Chorabari lake, there are steep valley following the course of the river which make it more vulnerable to landslides.
3. Uttarakhand suffered several major disasters in the past including:

Fig. 1 location

Factors Responsible

Due to unavailability of historical data our study will be restricted, though we tried our best to get important statistics, use of ISRO's BHUVAN satellite image has been done which presents an idea about the terrain, the highlighted area suggests the terrain of the region surrounding NH 109 which follows our study area.

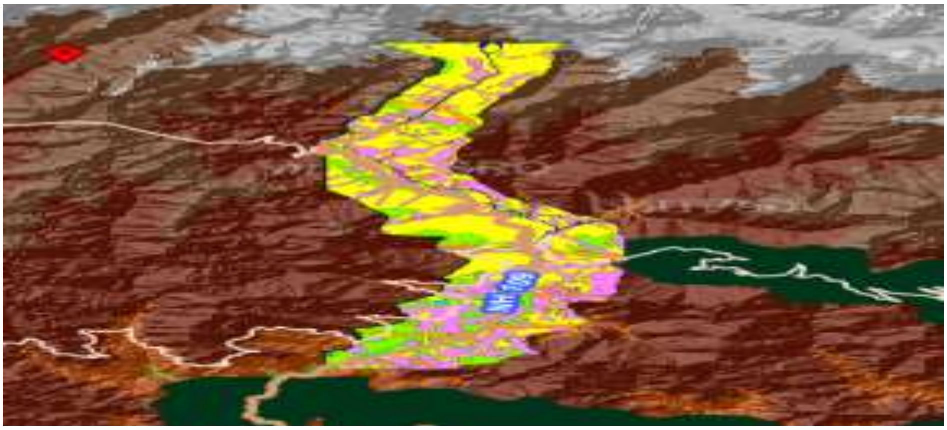


Fig. 2

- **Changing Forest Cover—**

Mandakini valley of Rudraprayag district has a thick forest cover, there are very few places of degraded forest and degraded pastures but according to our estimates the forest cover has been depleting in the recent past i.e. since 2007 and there are notable relation between the landslide events and depleting forest cover, theoretically as the forest cover reduces the ability of the land to hold the soil decreases with which the region becomes more vulnerable to landslide. Data as suggested by published articles suggest the declining trend in forest cover of the region under our study later we will provide a correlation matrix as generated by statistical software SPSS which suggests a negative correlation between deforestation and landslide vulnerability. Deforestation aggravated floods in Uttarakhand, the forest eco-system have been severely damaged due to large number of developmental projects.Besides, there has been a troublesome damage in the forest sector also where a loss of forest area of about 80 hectares along river courses is estimated. Almost 1,000 km length of forest roads and about2,500 km of bridle paths are reported to be damaged, One kilometer length of road constructed on hilly terrain requires removal of approximately 60,000 cubic m of debris from the site.

Table 1

Year	Vegetation Cover (%)	Change In Vegetation Cover (%) Calculated (ΔV)
2007	63.1	-1.1
2008	62.68	-0.42
2009	61.92	-0.76
2010	61.26	-0.66
2011	60.91	-0.35
2012	60.03	-0.88
2013	58.71	-1.32

The above data source has been acquired from MOEF India annual publications since year 2007 to 2013 and along with other NGO studying related activities also form https://data.gov.in/catalog/district-wise-forest-coverRudraprayg district of Uttarakhand, it should be noted that this data has been modified to minimize the differences of data from the these sources. The data suggests a rapid declining trend of vegetation cover with major causes as developmental projects, tourism pressure etc.

- **Precipitation—**

Climate has been the most influential factor in our study also in recently published articles, our data presents a very strong correlation between landslide events and precipitation caused due to monsoonal rains in the region. In fact most of the reports suggest that due to convergence of westerly winds and monsoon winds resulted heavy downpour in 2013 also it is a statistically significant factor. Due to presence of extra tropical depression which arrived from Black sea-Caspian Sea region over the Uttarakhand and adjoining areas, right before the arrival of South Western Monsoon, In 2013, Monsoon arrived before the usual time. This extra tropical depression pulled the Monsoon towards western Himalaya. Due to collusion between two air-masses, the formation of cumulonimbus cloud was rapidly generated. More over the faster rate of evaporation of glacial lakes in Uttarakhand especially the Chorabarital (Gandhi Lake) increased the amount of moisture content of the cloud. The concentration of water in the clouds was pretty high that there were multiday cloud burst type rain in Kedar Dome and surrounding areas.

Table 2

Year	(June - August) Total Precipitation (Mm)
2007	1685
2008	1513
2009 (El Nino Year)	734
2010	1662
2011	1348
2012	1115
2013	2305

SOURCE: https://data.gov.in (please note some of this data is available in IMD, 2013- A preliminary report on heavy rainfall over Uttarakhand, during 16-18 June 013. Govt. of India, Ministry of Earth Science, Indian Meteorological Department, Lodi Road, New Delhi, July 2013.)

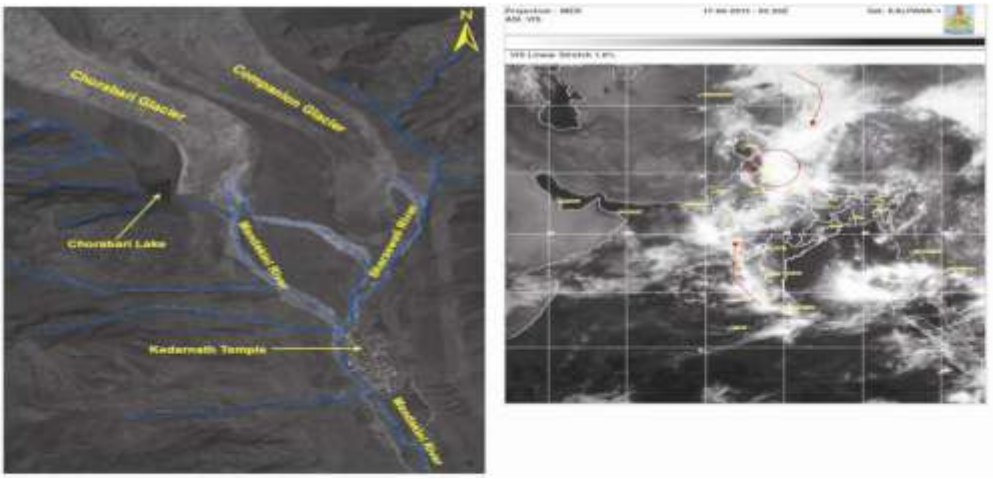


Fig. 3

Satellite view of Kedarnath area, showing drainage basin of the riverMandakini, glaciers.The India Meteorological Department image (17 June 2013) suggested that the heavy rainfall on the higher Uttarakhand, Himachal and Nepal Himalaya caused the collision of the monsoon and westerly disturbance. Arrows (yellow color) on the map indicate the moisture sources of the area.
(Source:http://www.imd.gov.in/section/satmet/dynamic/insat.htm)

As we can see from the given data that the surplus amount of precipitation received in the year 2013 by the region could not have gone into runoff all at once into the Mandakiniriver and surrounding water bodies. Though a strong correlation exists between the two phenomena i.e. the change in discharge is found to be proportional to the precipitation in the Rudraprayag district as we will introduce in the later sections.

- **River Mandakini discharge—**

Discharge per square Km of basin area is used to estimate the discharge of the concerned river, we have obtained data from mean annual flow which is the average flow for multi-year period for the months of june to august from 2007-2013, before introducing the data it is preferable to introduce the various factors that influence the volume of flow in the river Mandakini.

We can see from the fig. 3 that the river receives a large volume of fresh water from Chorabari glacier, during the summer months the melting glacier pours river Mandakini with water though the winters leave the river almost dry, the major cause of concern is the rate at which the Chorabari glacier is likely to melt at which will increase the discharge in the concerned river by a huge volume, besides this the other major source for Mandakini is the monsoonal precipitation which enhances its discharge to a very large extent, moreover there are other non-traceable sources of water in the region which contributes to the river, most of the error in our estimates can be explained by above.

Table 3

Year	Avg. Discharge (M^3/Sec)
2007	6.2
2008	3.4
2009	2.5
2010	5.1
2011	6.4
2012	3.5
2013	8.7

Simple Linear Regression

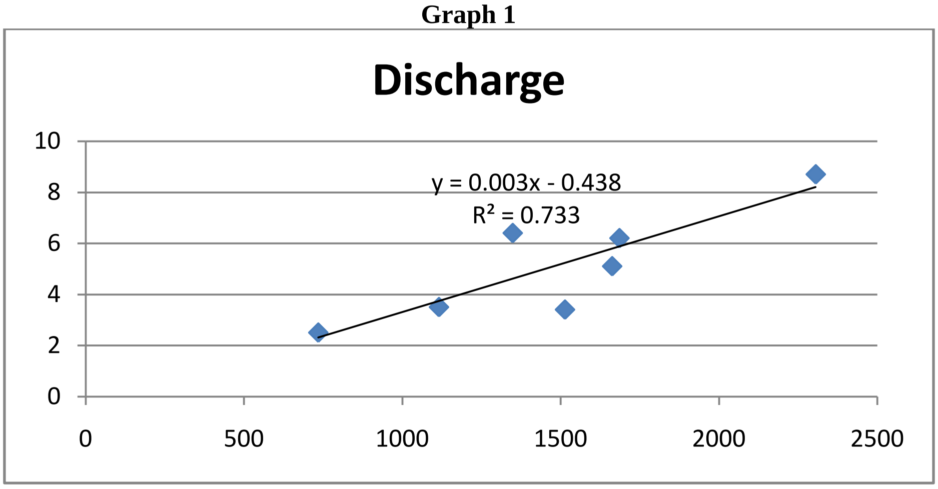
Table 4 (Correlations)

		Discharge	Precipitation
Discharge	Pearson Correlation	1	.857*
	Sig. (2-Tailed)		.014
	N	7	7
Precipitation	Pearson Correlation	.857*	1
	Sig. (2-Tailed)	.014	
	N	7	7
*. Correlation Is Significant At The 0.05 Level (2-Tailed).			

Table 5 model summary

Model	R	R square	Adjusted R Square	Std. Error of the Estimate
1	.857[a]	.734	.681	1.22239
a. Predictors: (Constant), Precipitation				

Graph 1



Other important statistical tests are provided with their result in the appendix I, the key contribution of precipitation to the river Mandakini is not only the change in its volume but the increase in its violent surges that later results in faster erosion of river valley. It is not a difficult task for one to draw a strong correlation between the river discharge and landslide events that occur in the region, as we have done.

- **Slope of terrain—**

The occurrence of landslide is a repeated phenomenon i.e. an area that has been a victim of land slide in the past is most likely to be its victim in the future as well, many studies have already suggested this. The slope of the terrain is a very important factor that determines this repeated occurrence of landslide, In the Rudraprayag district slope of deforested hills is pretty sharp and varies from 8-26 degrees from the horizontal, the important reasons for presence of such steep slope is the seasonal erosional activity of locally present small streams and occasional tectonic activities.

II. METHODOLOGY

Landslide forecasting has been a scrutinized subject since 2013 hazard of Kedarnath and Badrinath, often very skeptical stance has been taken over the issue. Our study are consist of Gaurikund and Mandakni river, our model suggest that landslide forecasting can be regarded as a function of interaction between many natural factors, in our area of concern i.e. Kedarnath and Gaurikund the most important players have been vegetation cover, Mandakni river discharge, slope of river valley and rainfall in the catchment area that feed the Mandakni river, it is important to note that discharge in Mandakni river is largely dependent on glacial melting and monsoon rainfall as we have already shown. Also the whole area of study is surrounded by calc-silicate, biotite, gneisses, schist and granite mineral deposits which do not resist flow of mud over them.

Land slide events are estimated using death toll data as published (https://data.gov.in/catalog/stateut-wise-distribution-accidental-deaths-natural-causes)

Notations

Discharge= (Q)

Rainfall = (P)

Change_Vegetation = (ΔV)

Events are number of landslide event; they are only representative in nature and are estimated from death-toll data of kedarnath and chorabari lake.

Events (E) = Number of deaths in a given year/average death per landslide event.

Table 6

Year	Events	Avg. Discharge	Total Precipitation	Change In Vegetation Cover
2007	525	6.2	1685	-1.1
2008	305	3.4	1513	-0.42
2009	64	2.5	734	-0.76
2010	351	5.1	1662	-0.66
2011	205	6.4	1348	-0.35
2012	456	3.5	1115	-0.88
2013	1102	8.7	2305	-1.32

We have used multiple linearregression to draw a relationship between landslide and the mentioned factors with the following results:

Table 7

Correlations

		Events	Discharge	Rainfall	Change_Vegetation
Events	Pearson Correlation	1	.775*	.858*	-.792*
	Sig. (2-Tailed)		.041	.013	.034
	N	7	7	7	7
Discharge	Pearson Correlation	.775*	1	.857*	-.494
	Sig. (2-Tailed)	.041		.014	.260
	N	7	7	7	7
Rainfall	Pearson Correlation	.858*	.857*	1	-.495
	Sig. (2-Tailed)	.013	.014		.259
	N	7	7	7	7
Change_Vegetation	Pearson Correlation	-.792*	-.494	-.495	1
	Sig. (2-Tailed)	.034	.260	.259	
	N	7	7	7	7

*. Correlation Is Significant At The 0.05 Level (2-Tailed).

Table 8 (model summary)

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.957[a]	.916	.832	136.82682

a. Predictors: (Constant), CHANGE_VEGETATION, DISCHARGE, RAINFALL

If events (landslide events) in the study area denoted by E then model estimate

$E = \beta_1 Q + \beta_2 P + \beta_3 \Delta V + C$

The above model is a multiple linearregression with describing the below given values of landslide probability –

$\beta_1 = 3.136$

$\beta_2 = .406$

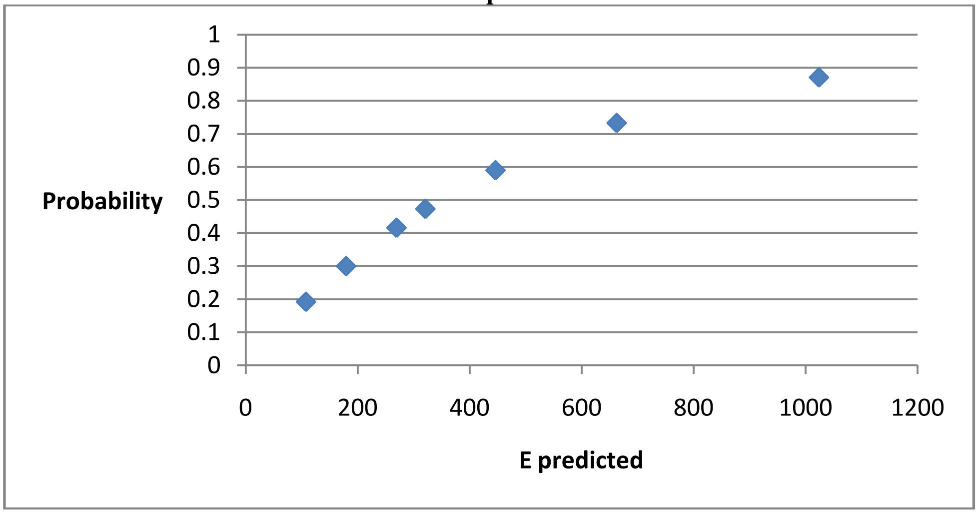
β_3 = -462.938
C = -550.116
Rest of the details will be provided in the appendix II.
The probability of landslide increases as event E increases,

$$\mathbf{p = 1 - e\hat{}(-\frac{E}{500})}$$

Table 9

YEAR	E predicted	Probability predicted
2007	662.66	.733
2008	269.25	0.416
2009	107.55	0.192
2010	446.18	0.59
2011	179.26	0.3
2012	320.93	0.473
2013	1024.06	0.871

Graph 2



III. CONCLUSION

The statistical model is based on very limited availability of data and we have used a very simple methodology with very few variables, though the correlation and t- test provide a very significant relation that is surprisingly good. The studies carried out in relation to landslides in Rudraprayag district are indicating a very strong and positive relation between landslide and annual precipitation. It is also important to understand that the variability in precipitation data can be a major determiner of many related events that has been occurring in the Kedarnath district, flooding in Mandakini river valley is a case in example. Once more data is available to researchers there can further improvement in the quality of models that try to predict landslide hazards and various other hazards.

The study suggests that the major causes of such hazards are both natural as well as manmade, the increasing demand for natural resources has led to a decrease in vegetation cover in the study area also there is a increase in the area under agriculture in the recent past, the local authorities are not as active as they are expected to be but the real problem is that the local public is unable to understand the seriousness of their decisions. Though after the disastrous flash flood of 2013 the awareness has increased and we can expect a better future.

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