Remote Sensing Based Regional Landslide Risk Assessment

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ABSTRACT: Landslides are common in Himalaya due to high relief, weak, tectonised& highly weathered rocks, glacial debris and man-made activities like road construction and step cultivation. The triggering of landslides are caused mainly due to prolonged or high-intensity rainfall. Losses caused due to landslide are over 200 deaths and Rs. 550 crore annually in Himalaya. It is therefore a necessity to assess Landslide Risk. Remote sensing and GIS is an effective tool for the assessment of landslide susceptibility at regional scale. The area for current research study is Chamoli-Joshimath region. Satellite data, toposheets, digital elevation model data, field observations and satellite based rainfall data are used as input data in this study. Various thematic layers, i.e., lithology, fault, lineament, geomorphology, drainage, slope angle, slope aspect, landuse /land cover, soil texture, and soil depth are generated by manual remote sensing based interpretations. Subsequently these thematic layers are integrated based on predefined rankings and weightages calculated using map algebra in GIS environment for generation of Landslide Susceptibility maps.The results show that this approach for the susceptibility evaluation is fairly accurate and precise after field validation.Landslide susceptibility map that gives spatial probability of landslides in conjunction with empirical rainfall thresholds can be used to warn the residents and local authorities about the hazard early on. In future, we plan to use the generated landslide susceptibility maps for risk perceptions studies in the area of interest.

Keywords: Rainfall thresholds, landslide, regional scales, slope stability.

I. INTRODUCTION

There can be little argument that rainfall primarily accounts for some of the world's most destructive landslides. Mitigation of landslides can be achieved by appropriate measures of slope stabilization. The mitigation requires detailed site specific geo-technical appreciation and appropriate Engineering infrastructure. In Uttarakhand, large stretches of land are venerable to landslides and every year new stretches are becoming venerable to landslides due to geomorphic process and due to human intervention. The mitigation through conventional engineering effort is difficult and not feasible, as unstable slopes are too many or too expensive to stabilize. In these cases remote sensing based assessment of regional scale landslide risk and early warning is only feasible and economic solution to curtail loss to human life and property[1].

For realization of landslide risk model a detailed understanding on landslide dynamics including the triggering factors is required. Landslide risk may be quantified as the probability of hazard multiplied by the vulnerability. Thus hazard probability is an important constituent to compute the risk. In this research paper, landslide hazard in terms of spatial and temporal probability is computed. Based on this model potential landslide events may be predicted leading to timely evacuation of exposed population. Such prediction model based systems are referred to as Landslide early warning system[2].

The Landslide Hazard Assessment Model can be grouped in to two broad categories as Empirical & Physical Models. The Empirical model tries to establish relationship between rainfall and landslide, or tries to relate the geo-environmental parameters with probability of landslide occurrences. The physical models also known as process models are based on modeling of landslide dynamics in according to varying geo-environmental parameters.[3] In these model variations in hydrological parameters based on rainfall infiltration raters are modeled. These parameters are used for estimation of slope stability and temporal prediction of slope failure.

Physical model take into account the relationship between rainfall, pore pressure, and slope stability by coupling hydrologic and slope-stability (Geomechanical) models. But, Process/Physical models are not widely developed as generally, they require detailed knowledge of the boundary conditions, which are seldom available outside specially equipped test fields (rain gauges, piezometers, inclinometers etc.).These models are generally applied in *site specific studies*.[4]The Empirical thresholds, based on historic analysis of relationship of rainfall/geo-environmental parameters with landslides occurrences are widely used for *regional landslide prediction* and as early warning systems.

II. STUDY AREA

Many large, episodically active landslides disrupt highways in Uttrakhand state along Chardham route. Incidentally it is the major transportation corridor that serve link with Indo-Tibet border. Landslides in Chamoli district, Uttrakhand have a history of movements during rainy seasons. The area selected for **regional scale model** is *Chamoli to Joshimath road axis.* The geology along Chamoli – Joshimath area is complex, consisting of Precambrian lithological units of Garhwal region of the NW Lesser Himalaya. The study area lies in the vicinity of Main Central Thrust (MCT). Besides MCT there are other faults also. Because of the tectonic setup, this area is tectonically active and experiences moderate to high magnitude earthquake. The area is drained by the river Alaknanda and its tributaries. Geologically the rocks in the landslide area belong to the Tejam and Damtha Group. The rocks mainly comprises of phyllites / slates and dolomites. The main causes of the landslides are highly jointed & fractured rocks, unfavorable discontinuity, surface water flow and tectonically active zone.

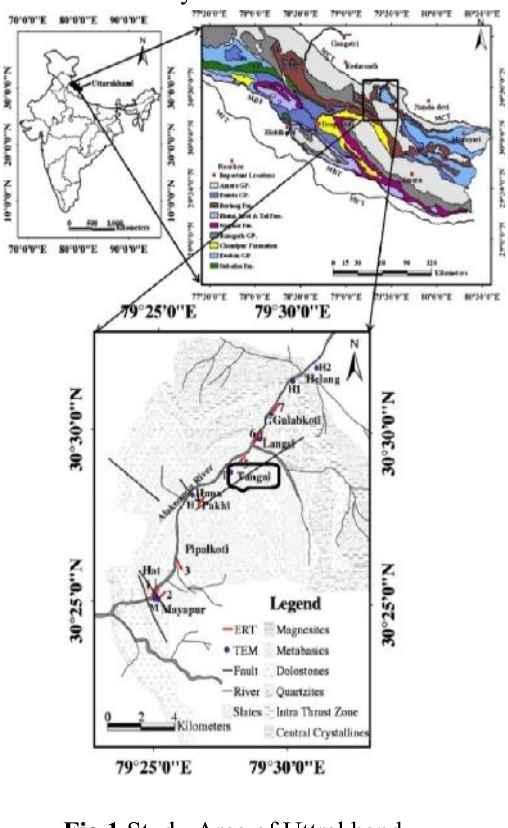


Fig.1 Study Area of Uttrakhand

III. METHODOLOGY

A. Regional Landslide Risk Assessment Model

Landslide occurrences at regional scale can be modeled by assessing the local geo-environmental set-up. The methodology adapted for spatial landslide susceptibility modeling is in vogue since last twenty years. Rainfall is a primary triggering factor for landslide. The prediction accuracy of the temporal model can be established by a probabilistic empirical relationship between landslides with rainfall. Regional landslide risk can be assessed by jointly using empirical rainfall thresholds and information related to landslide susceptibility. These Empirical models do not provide a link between the rainfall and the water pressure increases which actually trigger slide movement. Neither have they taken into account local variations in geology and geomorphology. Nevertheless they have proved to be a useful guide to planners and engineers. These relationships once established, enable automatic rain gauge networks to be used as landslide warning system.[5]

B. Spatial landslide Susceptibility Modeling (Landslide Hazard Zonation Mapping)

LHZ mapping is a tool to identify those areas which are, or could be, affected by a landslide. It involves assessing the probability of such landslide occurring within a specified period of time. The preparation of LHZ map includes study of regional geology and geomorphic setting, slope conditions including existing and potential instability and land use information. Scale is an important factor of LHZ mapping. Maps of 1:10K or 1:50K scales are appropriate for regional studies, larger scale maps on 1:10K or 1:5K scale are taken up for detailed studies at local level.

During the course of present study various thematic maps have been prepared for generation of Landslide Hazard Zonation maps. Thematic maps/layers generated are lithology, fault, lineament, geomorphology, drainage, slope angle, slope aspect, slope morphology, landuse /land cover, soil texture, soil depth and landslide occurrence, slope–dip and rock weathering. These thematic layers are then further integrated based on predefined ranking and weightages for generation of LHS maps as shown in fig. 2.

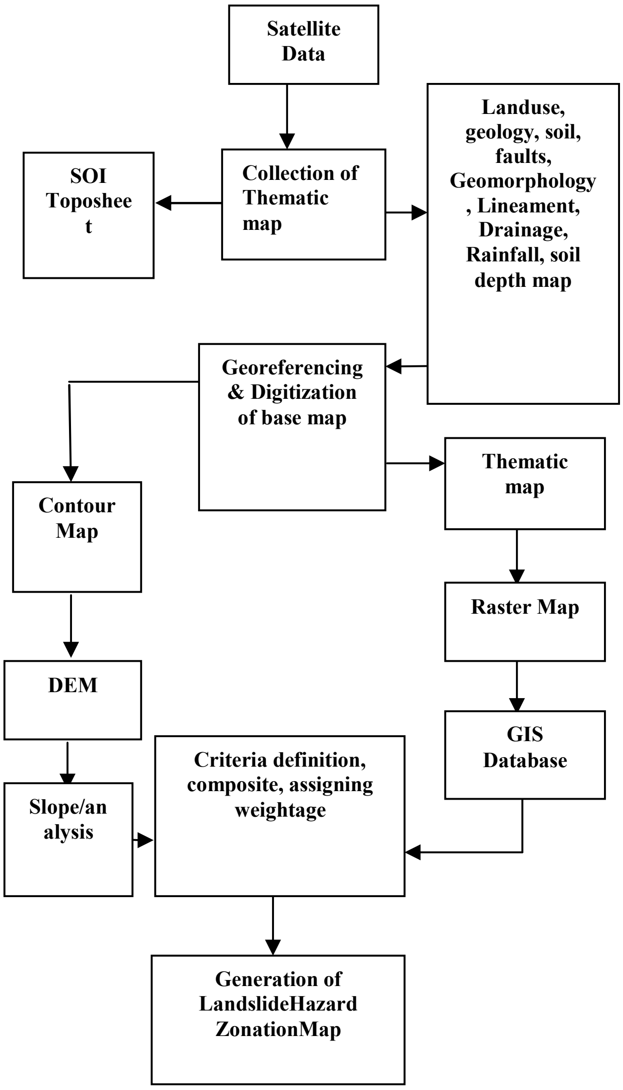


Fig.2. Flow chart for LHZ Map

C. Temporal Probability of Landslides based on Rainfall Thresholds:

Empirical rainfall thresholds are determined by studying rainfall events that have resulted in landslides. The thresholds are usually obtained by drawing lower-bound lines to the rainfall conditions that resulted in landslides plotted in Cartesian, semi-logarithmic, or logarithmic coordinates. Based on the rainfall measurements, empirical rainfall thresholds can be further grouped in two broad categories: (i) thresholds that combine precipitation measurements obtained for a specific rainfall event (Rainfall Intensity-duration (I-D) threshold, (ii) thresholds that consider the antecedent conditions (Cumulative Rainfall threshold).[6]In order to derive a regional rainfall threshold model for the landslide occurrences along the national highway corridor of about 80 km stretch around Chamoli-Joshimath region, the rainfall and landslide information were collected from the Border Road Organization office stationed at Pipalkoti. Landslide information in terms of location of slide with reference km milestone, name of road, name of nearest place/camp/village, name of landslide, dimension of disruption due to landslide, type of slide, date of occurrence/reoccurrence, etc. were extracted to make the landslide database.[7]

IV. RESULTS & DISCUSSION

A. Regional landslide Susceptibility Mapping

As per the methodology described in III, a landslide hazard map is generated for the study area which can provide information about "where" landslides are likely to occur. Thematic inputs that have been prepared for generation of Landslide Hazard Zonation maps are integrated using GIS. Six hazard categories viz. Severe, very high, high, moderate, low and very low have been identified in the study area. The high hazard classes are assigned the higher wavelength colours while lower wavelength colours are assigned to the lower hazard classes in output map. The criteria adopted for classification of categories of landslide hazard zonation is based on ranking and weightage assigned to each categories in different thematic layers prepared for generation of landslide hazard zonation map.All thematic map layers were integrated and clubbed together and values of each 25m grid cell arrived after integration have been clubbed together and sheetwise histogram was generated to classify six classes of hazard zones indicating relative instability for each hazard zones. The tail ends of values obtained are classified into low and very low categories.

Severe hazard zone is very unstable zone where landslides are likely to occur in view of the prominent causative factors present. The area is almost highly fragile, weathered, dissected, denuded and degraded to a state that the area has to be entirely avoided for settlement and other developmental activities and has to be left out for regeneration of natural vegetation and attainment of natural stability in course of time through the physical processes active in the area.After generating all the maps, these maps have been validated in the field and they show good correlation between the map and ground conditions.

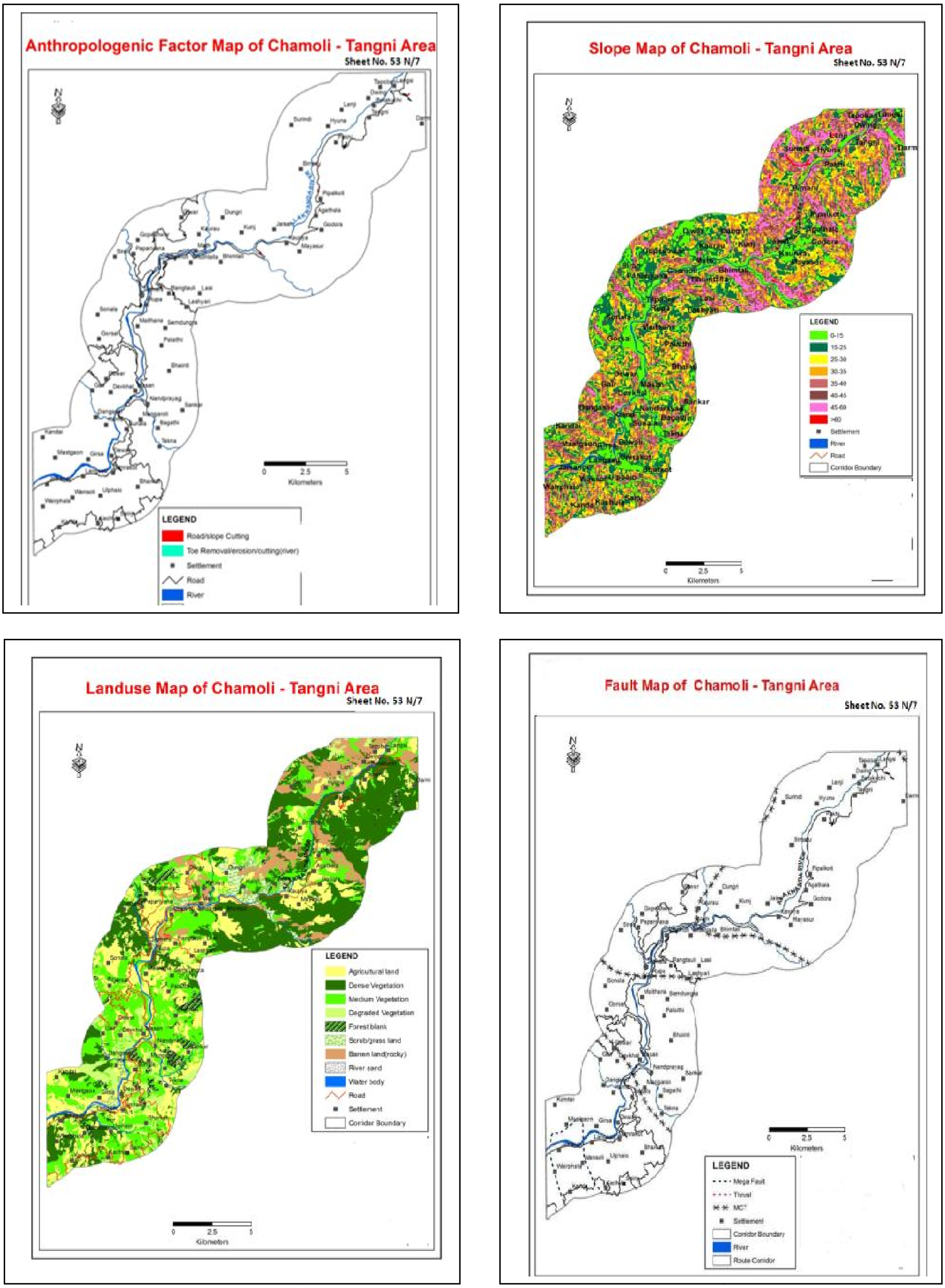
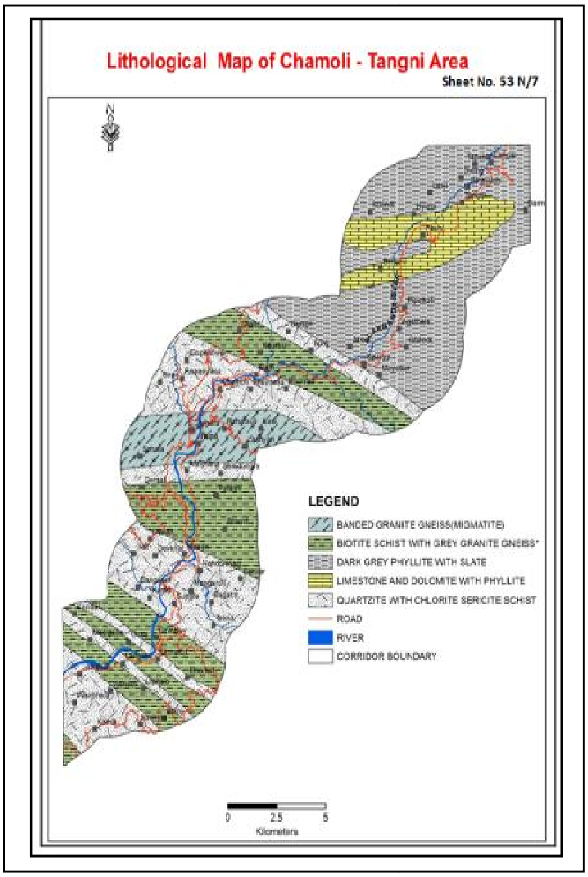
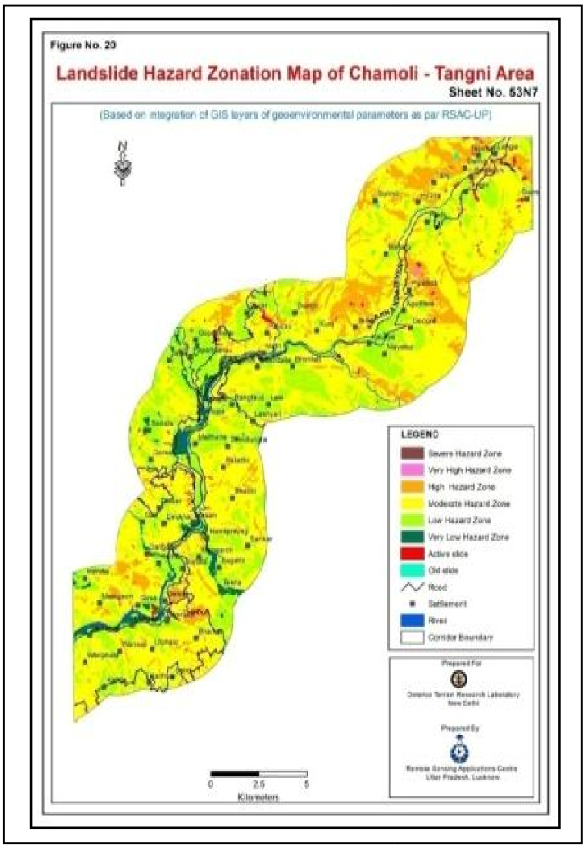


Fig.3. Different Thematic maps and final LHZ Map





B.Empirical Rainfall Thresholds for Landslides:

(i) Intensity- Duration(I-D) Threshold:

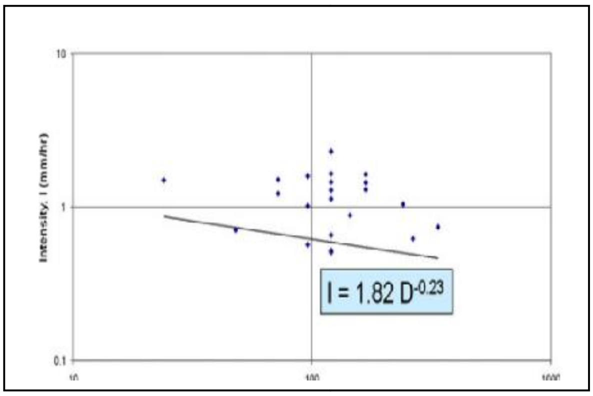


Fig.4. Rainfall intensity-duration (ID) threshold based on estimation of daily rainfall data for the initiations of landslide in Chamoli- Joshimath [7]

The I-D threshold, as defined by the lower boundary the points representing landslide triggering rainfall events, is expressed as:

$I = 1.82 * D^{(-0.23)}$------------------------ (1)

Where I is the hourly rainfall intensity in millimeters (millimeters per hour) and D is the duration of rainfall in hours. Equation has a coefficient of determination of 0.997. [7]

(ii) Cumulative Rainfall Threshold:

It is also important to study the effect of antecedent rainfall in triggering of landslides. Results of the study indicate that 15-day cumulative precipitation influences the amount of 3-day precipitation required to initiate landslides at the specified level of landslide occurrence as shown in fig. 5.

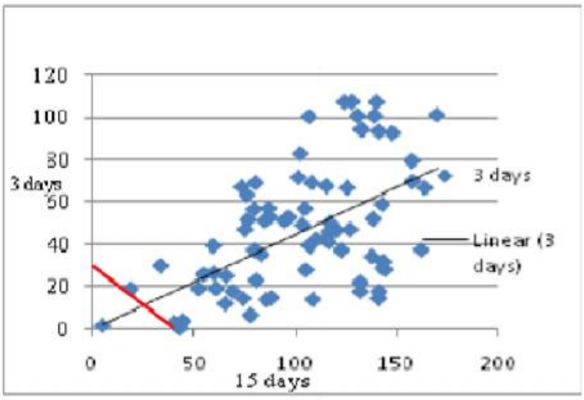


Fig.5. cumulative rainfall plot of 3 vs. 15 days rainfall prior to landslide event

Threshold line equation is:

P3 = -0.73*P15+29.3---------------------------- (2)

Where P3 and P15 are the amount of rainfall that have occurred 3- and 15- days prior to the landslide events occurred. Therefore, by combining I-D threshold, Cumulative threshold and landslide hazard maps, a regional landslide risk assessment model for landslide is realized.

V. CONCLUSION

In this way, state of the art for the regional approach for risk assessment of landslides is attempted.In the last three decades, the use of rainfall ID threshold and Antecedent rainfall thresholds to derive the triggering of shallow landslides has been applied worldwide on regional scale. Results show that the approach used for landslide risk evaluation is accurate and precise after a field validation of the study area. Temporal probability of landslide risk, calculated using empirical rainfall thresholds is also validated. Future work will be to investigate the vulnerability computation of the study so as to assess the risk of landslides and also how landslide risk perception is influenced by people's social-economic status (education, income), psychological vulnerability (sense of powerless and helpless), risk perception (perceived impact and control) and social trust. The project output will be helpful for strategic planning, road construction, and maintenance activities carried out in Uttarakhand.

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REFERENCES

[1]. RAINFALL AND LANDSLIDES. T. P. GOSTELOW. Engineering Geology Research Group. British Geological Survey. Keyworth. Nottingham. N612 EGG. UK

[2]. Landslide Analysis and Early Warning SystemsLocal and Regional Case Study in the Swabian Alb, Germany, BenniThiebes,ISBN:978-3-642-27525-8

[3]**.** Critical rainfall thresholds for triggering shallow landslides in the Serchio River Valley (Tuscany, Italy), R. Giannecchini, Y. Galanti, and G. D'Amato Avanzi, Nat. Hazards Earth Syst. Sci., 12, 829–842, 2012.

[4].A warning system for rainfall-induced shallow failures, Pietro Aleotti*

[5]. Dahal, R.K., Hasegawa, S., 2008, Representative rainfall thresholds for landslides in the Nepal Himalaya, Geomorphology, 100 (3-4), 429-443.

[6]. Rex L. Baum . Jonathan W. Godt Early warning of rainfall-induced shallow landslides and debris flows in the USA,Landslides (2010) 7:259–272.

[7]. D.P.Kanungo, Shaifaly Sharma Rainfall thresholds for prediction of shallow landslides around Chamoli-Joshimath region, Garhwal Himalayas, Journal of the International Consortium on Landslides **2013**,ISSN 1612-510X.

[8].Agarwal, N.C. and Kumar, G., (1973), "Geology of the upper Bhagirithi and Yamuna valleys, Uttarkashi district, Garhwal Himalaya," Himalayan Geology, Vol. 3,pp. 2–23.

[9]. Anbalagan, R., (1996), An overview of landslide hazards in Himalaya–Available knowledge base, gaps and recommendation for future research. Him. Goel., Vol. 17, 195–197.

[10]. Varnes, D.J., (1984), Landslide hazard zonation : A review of principles and practice. Commission on Landslide of the IAEG, UNESCO, Natural Hazards, 6pp