LANDSLIDE HAZARD EVALUATION OF HILL SLOPES IN AND AROUND MUSSOORIE TOWNSHIP, INDIA

A SYNOPSIS REPORT

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Chapter 1

INTRODUCTION

Landslides are a widespread and frequently occurring natural hazard, which cause serious damages to lives and property, especially on mountainous terrains (Anbalagan et al., 2008). Particularly, landslide occurrences are more important in highly urbanized hill stations where they may cause severe damages to properties and affect human life (Anbalagan et al., 2008). India's long Himalayan Mountain in the north is geologically a young range of mountain chain. Every year this region faces several hundreds of landslides, from Jammu & Kashmir to North Eastern states including Himachal Pradesh, Uttarakhand, and Sikkim Himalaya, leading to enormous loss of life and property (Anbalagan et al., 2007; Kumar et al., 2017). The Uttarakhand Himalaya has been a hotspot for landslide related researches, particularly in the last two decades due to the frequent occurrence of landslides and increased pressure of urbanisation in the region (Gupta et al., 2013, 2000, 1993; Gupta and Anbalagan, 1997; Kumar et al., 2008 Ray et al., 2009) In this context, stability of hill slopes in and around heavily urbanized township of Mussoorie have been evaluated systematically in order to identify suitable remedial measures and to identify suitable sites for future urbanization in and around the township.

1.1 Study area

The Mussoorie Township, generally dubbed as the queen of hills is one of the most famous excursion destinations in the Indian State of Uttarakhand. The city was initially established as a sanatorium for British militants in 1826, has grown to become a popular holiday destination in the country. Ever since its establishment, the city has been expanding at a rapid pace to exploit its tourism opportunities. The township falls in Zone IV of the Seismic Zonation Map of India (IS1893, 2002) and it receives annual precipitation of 150 mm/year on an average. A heavy winter with snowfall and a modest summer being the characteristic seasons of the township. Considering its importance and rate of expanding and need of future urbanization in the area, a 43km^2 area in and around Mussoorie Township has been taken up as the study area. Location of the study area is shown in Fig. 1.

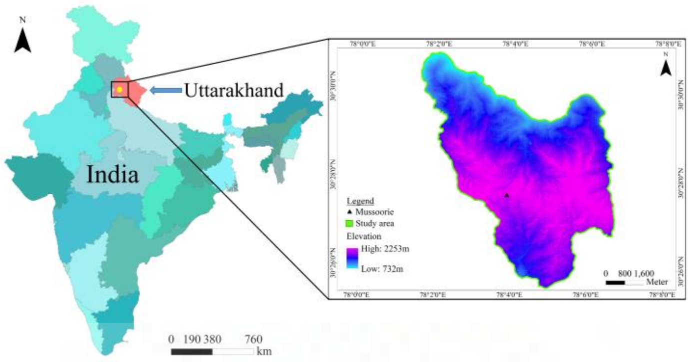

Fig. 1 Location of study area

1.2 Landslide inventory

Landslide inventory is a detailed account of distribution and characteristics of past landslides in an area(Flentje et al., 2011; Kannan et al., 2011, 2015, 2013). In total, 49 landslides were identified by fieldwork, and classification scheme proposed by Varnes (1978) has been followed to prepare the landslide inventory of the study area. Translational failure of slopes constituted by scree of slate, shale, or phyllite and complex failure of shallow debris and underlying competent rock is the common slope instability problem in the area, besides rotational and creep failure of debris slopes and minor rockfall incident.

1.3 Definition of problem

In a mountainous environment like the Himalaya, anthropogenic activity in the form of urbanization and hill cutting always aggravates the problem of slope stability as it disturbs existing geo-environmental balance (Chakraborty and Anbalagan, 2008; Saranathan and Kannan, 2017). This problem is more acute where hill slopes are made up of soft sedimentary rocks, low grade meta-sedimentary rocks or loose overburden material. The hill station of Mussoorie has been expanding at a rapid pace ever since its inception in 1826 and consistently been ravaged by slope instability problems (Panikkar and Subramanyan, 1996; Sanwal et al., 2004; Rautela et al., 2013). Thus, a systematic study on stability of hill slopes is necessary for the sustainable developmental practices and geo-environmental conservations of this township.

1.4 Objectives

1) Landslide susceptibility zonation of Mussoorie area on meso-scale (1:15,000)
2) Detailed stability evaluation of hazard prone slopes or landslide slopes of high risk and design of control measures
3) Identification of suitable slopes for future urbanization

Chapter 2

GEOLOGICAL SETTING

2.1 Regional Geology

The rocks exposed in the Mussoorie area belong to the Mussoorie Group, which forms part of Krol nappe. The Krol nappe exposed in the Mussoorie and adjoining area is delimited to the south by main boundary thrust, which separates the Siwaliks and Lesser Himalayan rocks.

2.2 Local Geology

The study area comprised of two Formations - Krol and Tal Formations of Mussoorie Group. In the context of landslide study, the slope forming materials have been considered broadly as two categories, rock exposure and soil materials. The rock exposure in the study area is dominated by the massive and hard limestone of Krol Formation. On the south part of the study area, limestone with thin beds of shale (Ls-K) is exposed. In central, west and northwest region, massive limestone and dolomite with minor intercalation of slate, calcareous phyllite, quartz arenite and chert (LDspqc-K) is observed. In the eastern part of the study area, slightly weathered massive quartzite of Tal Formation (Q-T) makes a presence. In case of soil, lithological mapping has been carried out by considering the soil thickness and prevalence of debris constituting rock fragments. The lithology map of the study area is shown in Fig. 2

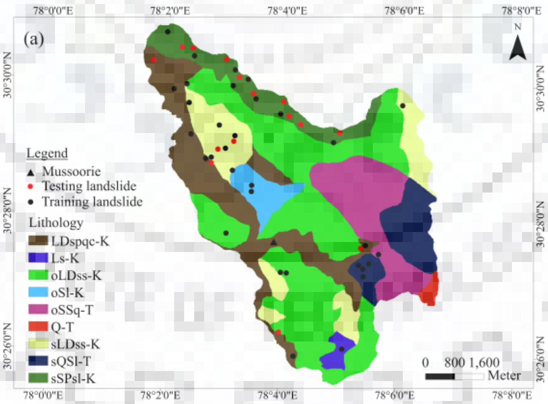

Fig. 2 Lithology map of the study area

Chapter 3

METHODOLOGY

3.1 landslide susceptibility zonation

The landslide susceptibility mapping techniques can be broadly classified into two categories, qualitative and quantitative approaches (Dahal et al., 2008). Due to objectivity, and capability to model non-linear interrelation of causative factors and landslide, bivariate and multivariate statistical techniques such as fuzzy logic, logistic regression and neural networks are been widely preferred over other quantitative and qualitative approaches to carry out LSZ in fusion with geographic information system (Chimidi et al., 2017; Ermias et al., 2017; Mengistu et al., 2019; Bhandary et al., 2013) However, the fuzzy logic or neural network approaches, two broad domains of artificial intelligence (AI) have been applied regional scale attempts to this date (Nedumpallile Vasu et al., 2016; Nedumpallile Vasu and Lee, 2016), and a sound recommendation of suitable AI technique for the present objective of meso-scale LSZ is not available in the literature. Thus, a wide range of AI techniques was chosen based on its genre are, fuzzy logic, neural network (NN) and neuro-fuzzy system. The fuzzy logic techniques are fuzzy set procedure (FSP), fuzzy expert system (FES), the NN models are artificial neural network (ANN), extreme learning machine (ELM) and support vector machine (SVM), and one neuro-fuzzy system, extreme learning adaptive neuro-fuzzy system (ELANFIS).

3.2 Detailed slope stability study

Finite element method (FEM) is one of the numerical methods which has been widely used for stability analysis of slopes and underground structures (Gupta et al., 2016; Bhasin and Pabst, 2015;). The advantages of FEM over conventional limit equilibrium (LE) approaches that it does not need of presumption about the failure and complex geometry of the slope can be considered for the analysis, and its output also depends upon global response. The Three failure criterions, namely, Generalized Hoek & Brown (GHB) Criteria (Hoek et al., 2002), Barton-Bandis Criteria (Barton and Barton, 1990) and Mohr-Coulomb Criteria were used for the rock, joint and debris respectively for the FEM model shear strength reduction technique (Gupta et al., 2019; Bhasin et al., 1996; Bhasin et al., 2002; Chowdhury et al., 2010).

3.3 Identification of suitable slopes for future urbanization

FES which allows incorporation of expert knowledge in the basic fuzzy logic has been chosen the method to propose a novel methodology for remote sensing based generation of site favourability map (SFM) for selection of slopes for future urbanization.

Chapter 4

MESO-SCALE LANDSLIDE SUSCEPTIBILITY ZONATION OF MUSSOORIE TOWNSHIP

4.1 Characterization of causative factors for Mussoorie Township

The degree of slope instability is controlled by the net effect of inherent causative factors (Mani and Saranathan, 2017). A total of eight causative factors, two categorical, and six numerical causative factors which are generally featured in GIS based LSZ were considered in the current study. They are: lithology, land use & land cover (LULC), lineament, slope gradient, slope aspect, altitude, curvature and topographic wetness index (TWI). Thematic layers of causative factors were prepared for the study area through fieldwork and processing digital elevation model (DEM) (Alos Pulsar DEM of 15m resolution) and satellite images (LISS-III and Radarsat) on ArcGIS 10.2.1.

4.2 Execution of AI techniques

The FSP has been executed with the help of cosine amplitude method with fuzzy operators, AND, OR, SUM, PRODUCT and GAMMA operator with five different values, 0.1,0.3,0.5,0.7,0.9. And the LSMs are marked as LSM-I to IX. For, FES, a mean and neighbour strategy has been developed to construct the structure of FES and a novel rule fabricating system based on frequency ratio method has also been developed to put forth an improved FES. Two FES structure has been developed under the strategy, and two LSMs are developed and designated as LSM-X and IX.

The execution of NN models and ELANFIS starts with training and testing phases to obtain the ideal neural network structure and weights. In order to train and test, a training and testing datasets were prepared from the whole dataset. The training and testing datasets comprised of landslide and non-landslide data samples (pixels). For the that, the landslide inventory was randomly split into 70% and 30% landslides (Zhou et al. 2018; Tien Bui et al. 2016; Pham et al. 2017), contributing landslide pixels for the training and testing datasets respectively. The training dataset comprised of 1,013 landslide pixels and very same count of non-landslide pixels. Whereas, the testing dataset has 254 pixels of landslide and non-landslide pixels each. The ANN, ELM, and SVM generated maps are designated as LSM-XII, XIII and XIV respectively. The ELANFIS was executed with 10 different number of membership functions from 4 to 14, and the maps are designated as LSM-XV to XXIV.

4.3 Validation of models and LSMs

Spatial and statistical analysis is mandatory for any probability based landslide susceptibility mapping to validate the reliability of the outcome. The spatial analysis aims at close inspection of the distribution pattern of susceptibility zones in correlation with input thematic layers, whereas statistical assessment validates accuracy with regard to an event (i.e. landslides). In this study, a statistical model validation technique (pre-production of LSM) and map validation technique (post-production of LSM) have been chosen; they are receiver operating characteristic (ROC) (Zweig and Campbell, 1993) plot and FR analysis respectively. The LSMs produced through FSP shows an unacceptable distribution of susceptibility classes with a definite pattern of input parameters, and the statistical validation has also indicated inaccuracy. Whereas the maps produced through FES shows significantly better display of susceptibility classes with no traces of input parameters, and performed satisfactory on statistical validation. On the other hand, only LSM produced through ANN showed satisfactory display of susceptibility classes while the maps of ELM and SVM showed cragged distribution pattern, and FR assessment points inaccuracy, though the ROC model indicates accuracy and. The ELANIFIS generated maps have performed significantly better than any other maps in terms of spatial distribution of susceptibility classes and statistical validation measure. Based upon validation the LSM produced through ELANFIS with membership function 11 has been taken up as LSM of Mussoorie Township.

Chapter 5

DETAILED STABILITY EVALUATION OF HAZARD PRONE SLOPES OR LANDSLIDE SLOPES OF HIGH RISK AND DESIGN OF CONTROL MEASURES

Based the LSM of the study area 6 slopes/landslides are taken up for the detailed stability evaluation, they are; Surabhi landslide Santura, Devi landslide LBSA slope, Civil landslide Landour landslide and Woodstock landslide slope.

5.1 Slope stability study at Surabhi landslide

5.1.1 History of Surabhi landslide

The landslide occurred in August 1988 and affected 38 families and affected 5 hectares of land.

5.1.2 Geomorphology and Geology

The landslide occurred on the north-easterly slope of NW-SE trending major ride which extends from Mussoorie and runs by the side of Kempty fall. The rocks exposed in the landslide site is dolomitic limestone of Krol Fm. In general, two types of slope forming materials are present at the site, in-site rock and debris material.

5.1.3 Slope stability analysis of Surabhi landslide

The kinematic analysis showed no possibility of rock failure. The FEM analysis showed that the overburden above the landslide crown is stable and the in-situ rock is stable with no formation of shear strain and no displacement. The FOS of the slide debris was found to be 0.93 with shear strain formation and total displacement of 16m.

5.1.4 Remedial measure for Surabhi landslide

In order to stabilize the slope, soil nails of plane strand cable are suggested for the shear strain formation zone of the landslide, which analysed with FEM model and found that the FOS is increasing to 1.1 with no displacement. Further, a series of peripheral reinforced gabion wall is recommended for the tail reaches of the landslide to mitigate the influence of narrow stream course.

5.2 Slope stability study at Santura Devi landslide

5.2.1 History of Santura Devi landslide

The Santura Devi landslide occurred during the rainy season of 2003

5.2.2 Geomorphology and Geology

The landslide occurred on the north-easterly slope of NW-SE trending major ride which extends from Mussoorie and runs by the side of Kempty fall. The slope is comprised of thick overburden of sandy gravel size

5.2.3 Slope stability analysis of Santura Devi landslide

The stability analysis of this slope indicates that the slope is stable with FOS >2, and no shear strain formation along the front face of the landslide.

5.2.4 Remedial measure for Santura Devi landslide

Upon the analysis result, and the gentle gradient of the slope with no presence of streams around, the slope should leave as such it is and stabilize further with the course of time.

5.3 Slope stability study at LBSA slope

5.3.1 History of LBSA slope

The LBSA slope experience a complex type of failure of creep on the thick overburden and rock failure on the cliff of approximately 60m height.

5.3.2 Geomorphology and Geology

The slope instability problems occur on the NNE slopes of NW-SE trending major ridge. The slope is composed of dolomitic limestone at the main ridge area and dominated by thick overburden till the cliff.

5.3.3 Slope stability analysis of LBSA slope

The LBSA slope was modelled two models, roc model and debris model. Both models showed unstable condition as FOS is > 1 along with failure possibilities derived from kinematic analysis.

5.3.4 Remedial measure for LBSA slope

The creep failure was found to be a deep seated failure from the analysis as the shear strain formation takes place at a depth of >40m. Thus it is impossible to implement any conventional control measures like soil nails. Enforcing the drainage system and biotechnical treatment would be the ideal treatment for the debris slope. For the cliff face, rock bolting was tested with the FEM model at different lengths and found out that the measure is inadequate to achieve desired FOS of >1. Thus, a curtain of chain link fabric is recommended for the slope to mitigate the disaster.

5.4 Slope stability study at Civil hospital landslide

5.4.1 History of Civil hospital landslide

The Civil hospital landslide occurred on July 2016. The landslide causes tremendous economic loss as has washed out the Mussoorie-Chamba bypass road and damaged several buildings around the slide.

5.4.2 Geomorphology and Geology

The landslide occurred on a north-easterly slope of east trending spur which joins the NNW trending major ridge to the west. The rock exposed in the site is quartzite of Tal Formation with shallow overburden of sandy gravel size. The rock is traversed by a single set of foliation and three sets of joints.

5.4.3 Slope stability analysis of Civil hospital landslide

The FEM analysis revealed that the slope has a critical FOS of 2.38 with no shear strain accumulation on the rock slope. However, the shallow debris cover shows shear strain formation and displacement of 0.14m. upon the analysis and field investigation, the slide type can be talus failure, where the shallow debris slide over the rock below. Since the slide surrounded by number of huge buildings, it was observed during the field investigation that waste water from these buildings had been disposing on to this slope from the crown portion to the right flank. Hence the cause of the slide could be anthropogenic activity and rainfall.

5.4.4 Remedial measure for Civil hospital landslide

The slide has been supported by RCC wall by the national highway authority to restore the damaged road. Since the rock is very stable and shallow debris lies at a gradient <40°, there is no acute necessary of rock bolting or soil nails. However, the crown portion shows moderate surficial weathering, hence shotcrete of 50mm on chain link fabric is recommended for the crown portion.

5.5 Slope stability study at Landour landslide

5.5.1 History of Landour landslide

The Landour landslide occurred just below the Landour market of Mussoorie Township three decades ago. The slide has damaged numerous buildings of this area and continued to be an active slide which consistently causes troubles to the traffic on Mussoorie-Chamba bypass road.

5.5.2 Geomorphology and Geology

The slide occurred on the south-westerly slope of SSW trending spur. The slope is composed of overburden material of shallow depth and in-site slate which is highly weathered.

5.5.3 Slope stability analysis of Landour landslide

The slope was modelled as soil slope on FEM analysis. The analysis showed that the FOS is 0.95 with shear strain formation close to the cut slope of Mussoorie-Chamba bypass road. Thus it can be inferred that the failure was talus failure of shallow overburden during rain and ignited by the road cut slope.

5.5.4 Remedial measure for Landour landslide

The slide surface shows relatively stable condition with vegetation growth. However, the zone close to cut slope shows indications of instability. Thus, gabion wall protection of five rows has been recommended to stabilise the cut slope and to provide toe support for the slope. The slope with gabion wall was modelled on FEM analysis, and the FOS was found to be >1.

5.6 Slope stability study at Woodstock landslide

5.6.1 History of Woodstock landslide

There is no clear record of Woodstock landslide occurrence or its social and economic impact

5.6.2 Geomorphology and Geology

The slide occurred on a north-westerly slope of a SW trending ridge. The slope is composed of overburden material of shallow depth and in-site slate which is highly weathered.

5.6.3 Slope stability analysis of Woodstock landslide

The slope was modelled as soil slope on FEM analysis. The analysis showed that the slope has is stable as the FOS is >1. Further, the analysis showed that there is no shear strain formation along the front face of the slide. The slide can be a minor talus failure of shallow debris over weathered slate. Since the cause of the slide can be natural cause either rain triggered or earthquake induced.

5.6.4 Remedial measure for Woodstock landslide

As the slope is stable even with SSR technique, and showed no signs of headward migration so far. Hence it is ideal to leave the slope as such it is and get stabilize further with the course of time.

Chapter 6

IDENTIFICATION OF SUITABLE SLOPES FOR FUTURE URBANIZATION

Site selection of future urbanization is an important step for sustainable developmental practices in landslide prone terrains (Flentje and Chowdhury, 2006). A novel concept of slope favourability map (SFM) has been introduced for the site selection for future urbanization. The novel concept of SFM generation is based on AI and remote sensing. The LSM of the township and various thematic layers relevant to various factors that determine the suitability of the slopes for future urbanization has been considered to generate an SFM of Mussoorie Township.

Chapter 7

SUMMARY AND CONCLUSION

Slope instabilities, commonly known as landslides are the commonest form of mass wasting process in hilly terrain. Planning civil constructions have always been considered arduous due to occurrence of such geo-environmental hazards. The slope stability studies in and around Mussoorie Township has been carried out in two-fold assessment of preliminary LSZ and detailed investigation of hazard prone slopes of high risk and a SFM has been generated for the study area. Shallow overburden is particularly vulnerable to failure along with ill planned hill cutting and improper drainage management aggravates the slope instability problems in the area. Hence the future urbanizations in this area should consider the existing instability of the area and adequate treatment for slope stabilization and drainage facilities should consider in the planning and implementation stages.

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