ORIGINAL PAPER

Hazard risk assessment of landslide-prone sub-Himalayan region by employing geospatial modeling approach

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Abstract

Ecological processes such as landslide disaster are primarily impacted by both geological and land use activities happening at different spatiotemporal scale. They specifically impact the socioeconomic development in the sub-Himalayan region of Pakistan. Ecological risk assessment and restrictive zonation mapping are therefore prerequisites for mitigation and compensation of landslide losses and risks. The current study has mapped landslide vulnerable Guoien Nullah road located in sub-Himalaya ranges of Pakistan via Landslide Hazard Zonation (LHZ) technique. Landslide active points were identified through field surveys, verified through the readings taken from Global Positioning System and mapped through geographic information system-based software. Seven landslide activating factors, i.e., slope angle, lithology, precipitation, tilt direction, land use/land cover, Normalized Differentiation Vegetation Index and elevation, were evaluated. Analytical hierarchical process (AHP) was used to assign weights to each activating factor. Precipitation, followed by lithology, and slope angle were found most influential in instigating landslide as indicated by AHP. Furthermore, three susceptibility zones were obtained using the weighted overlay method, i.e., high hazard susceptibility zone, moderate hazard susceptibility zone and low hazard susceptibility zone. The study concluded that 69% of the total landslide occurred in the high susceptibility zone which comprised of 36% of the total study area. Ground control points on active landslide sites authenticated the LHZ generated map. These maps help in restrictive zoning in the high hazard zone area that is considered important for engineers, geologists, and land use planners for future area-specific developmental projects. Besides, the current study will aid disaster management authorities, developers, policy makers and researchers in identifying the hazard disposal of the selected area.

Keywords Ecological risk assessment · LHZ · AHP · WOM · Susceptibility zones

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1 Introduction

Landslide is among the most damaging ecological disturbances throughout the world that subsequently result in biodiversity loss (Fig. 1) incorporating loss of human life, property, and infrastructure damage (Vorpahl et al. 2012; Girma et al. 2015; Basharat et al. 2016). Therefore, in the last decade, studies on landslide assessment and management have gained worldwide importance. Researchers found the factors most important for landslides to be geological and geomorphological conditions, precipitation and human activities (Hamza and Raghuvanshi 2016).

Various qualitative and quantitative methods have been devised throughout the world for hazard risk assessment and mapping. Among the qualitative methods most common and successful tools are analytical hierarchical process (AHP) and landslide hazard evaluation factor (LHEF) (Yalcin et al. 2011; Kayastha et al. 2013; Kanwal et al. 2016). Multivariate and bivariate analyses, on the other hand, are commonly accounted for quantitative methods (Ayalew and Yamagishi 2005; Wang et al. 2016; Youssef et al. 2016). Recently some researches have also been dedicated to artificial neural networking and fuzzy logic for landslide hazard zonation (LHZ) mapping (Bui et al. 2012; Park et al. 2013; Dehnavi et al. 2015; Can et al. 2019).

Himalayan mountain ranges face landslide hazards every year which poses harmful risks to the environment and the society. Iran is geographically situated in the seismicity belt of Alps-Himalaya ranges which are highly susceptible to mass wasting and slope
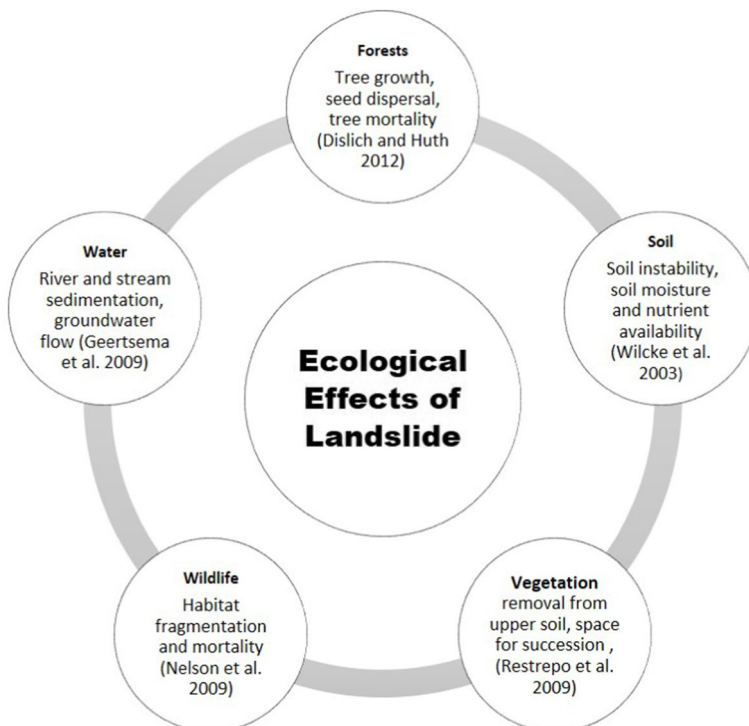

Fig. 1 The figure illustrates possible landslide effects on ecosystem services

angle instability. These mass movements led to many types of research on landslide assessment in the Himalaya region of Iran. At the Alborz Mountains, a study on the Weight of Evidence (WOE) model was applied for LHZ mapping (Farrokhnia et al. 2011). Later on, step-wise weight assessment ratio analysis (SWARA) and adaptive neuro-fuzzy interference system (ANFIS) model were utilized for LHZ mapping in high hills of Alborz and Zagros (Dehnavi et al. 2015). Moreover, random forest (RF) and evidential belief function (EBF) hybrid methods were tested in the Mazandaran Province of Iran (Pourghasemi and Kerle 2016). In Himalaya region of Nepal, AHP (Kayastha et al. 2013), Certainty Factor (CF), Index of Entropy (IOE), Logistic Regression (LR) (Devkota et al. 2013), WOE (Dahal et al. 2008; Kayastha et al. 2012) models were tested for LHZ mapping.

Pakistan is among those countries where Himalayan ranges are prone to abundant landsliding every year especially during monsoon season. These mass movements of rock and soil pose threats to transportation, residences, agriculture, and tourism (Rahman et al. 2014). So far, only a few studies have highlighted the most landslide vulnerable regions in Pakistan. In past extensive field surveys, questionnaires and interviews were conducted (Khan et al. 2011; Rahman et al. 2014) in Murree hills and Muzaffarabad region. Later on, remote sensing and GIS were integrated with statistical methods for creating LHZ maps (Basharat et al. 2016; Kanwal et al. 2016; Shafique et al. 2016) in the main cities of Kashmir and Gilgit Baltistan provinces. Therefore, the aim of current study was the development of LHZ map of the Guoien Nullah area in lower Himalaya using the AHP method, where landslide is a major problem due to rainfall, steeper slope angles, varied vegetation cover and complex lithology. The objectives of the study were determination and characterization of predisposing factors for landslide occurrence, evaluation of the relationship between landslide predisposing factors using AHP and creation of LHZ map using Weighted Overlay Method (WOM).

2 Materials and methods

2.1 Study area

Guoien Nullah Road joins Azad Pattan to Rawalakot and passes through Sudhanoti and Poonch districts of Azad Kashmir, Pakistan (Fig. 2), an area that lies in the Himalayas mountainous region where landslide is a yearly environmental concern. This landslide is also a cause of soil erosion and water sedimentation of river Jhelum. There is a possibility that the water carrying capacity of Mangla Dam may fall because of this sedimentation. The area under study is underdeveloped with farming and poultry as the main source of income for its inhabitants. People have to travel long distances across the Guoien Nullah road not only for export of their dairy products but also for assessing medical and education facilities. As landslide results in road inaccessibility, it brings damages to the properties, lives, and livelihoods. Therefore, landslide hazard assessment and zonation mapping were carried out in the current study to minimize the worsening impacts of the landslide.

2.2 Data acquisition

In the present study, both primary and secondary data were used. Primary data encompassed the Global Positioning System (GPS) control points obtained through field surveys, whereas secondary data comprised Landsat sensor data, geological map of 1: 50,000 scale
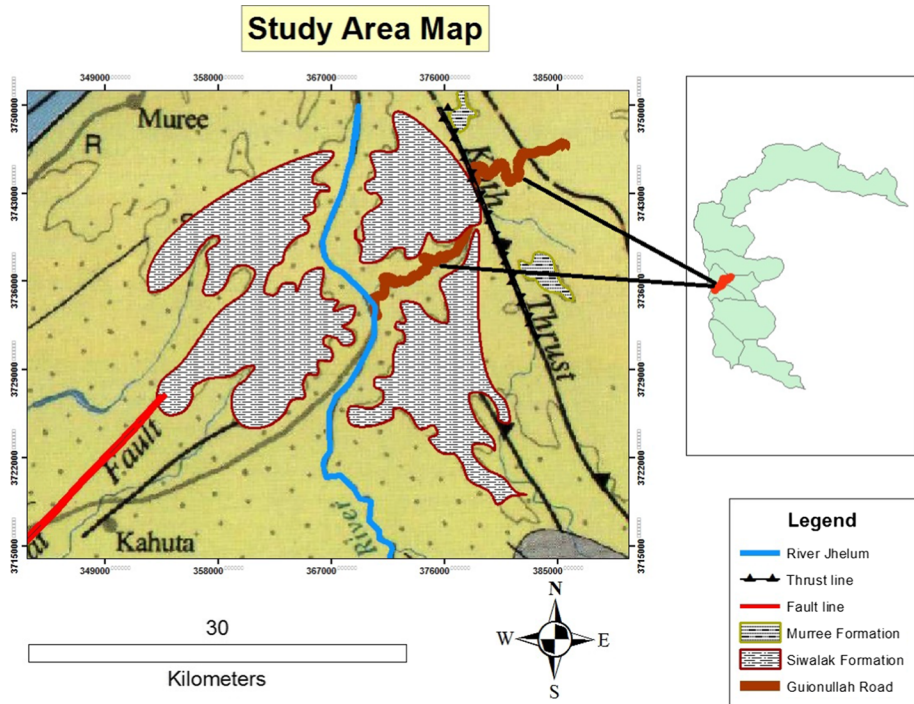
Fig. 2 Administrative and geological position of Guoien Nullah road

and precipitation data assembled from USGS glovis, Geological Survey of Pakistan (GSP) and Pakistan Meteorological Department (PMD), respectively.

2.3 Generation of landslide inventory map

The systematic and comprehensive landslide map of active landslide areas of Guoien Nullah road was generated using GPS points. These points were collected in the month of September 2016 and April 2017. Field survey revealed 40 active sites of landsliding in the study area as shown in Fig. 3.

2.4 Creation of buffered thematic layers of landslide activating factors

Landslide activating factors were classified into three sets, i.e., topographic factors, physical factors and anthropogenic factors. Topographic factors included tilt direction, slope angle, and elevation. These factors were derived from the Shuttle Radar Topography Mission (STRM) Digital Elevation Model (DEM) of 30 m resolution. Area under study fell in the elevation range of 437 to 2053 m as shown in Fig. 4. Ten classes of Tilt direction were created, i.e., flat (-1), north (0–22.5), northeast (22.5–67.5), east (67.5–112.5), southeast (112.5–157.5), south (157.5–202.5), southwest (202.5–247.5), west (247.5–292.5), northwest (292.5–337.5), north (337.5–360) (Fig. 5), whereas slope angle was divided into five intervals, i.e., 0°–45°, 45°–65°, 65°–77°, 77°–84°, 84°–89°, respectively, as shown in Fig. 6.
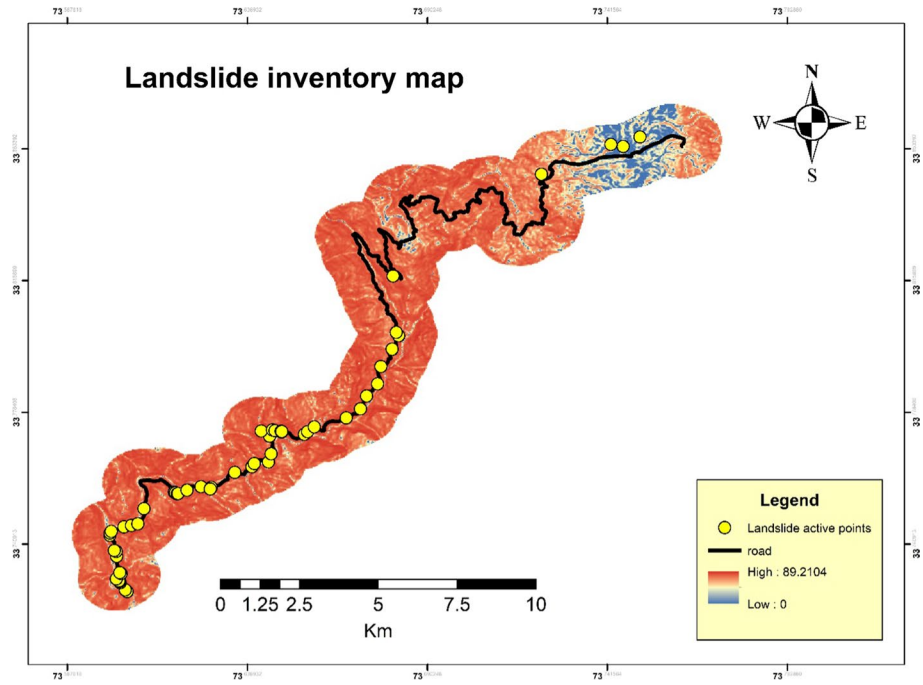
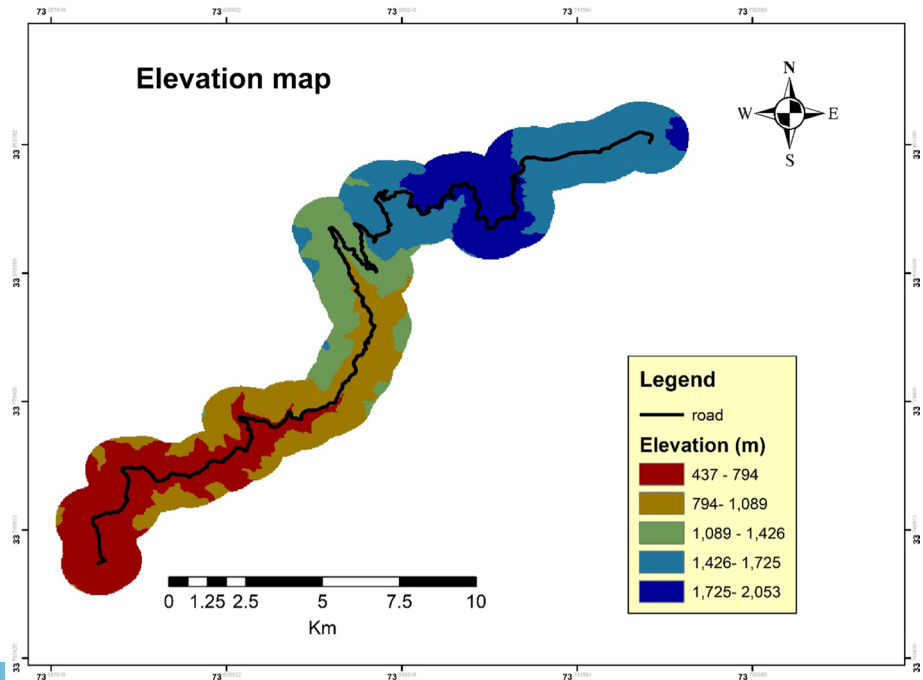**Fig. 3** Active landslide points along Guoien Nullah road
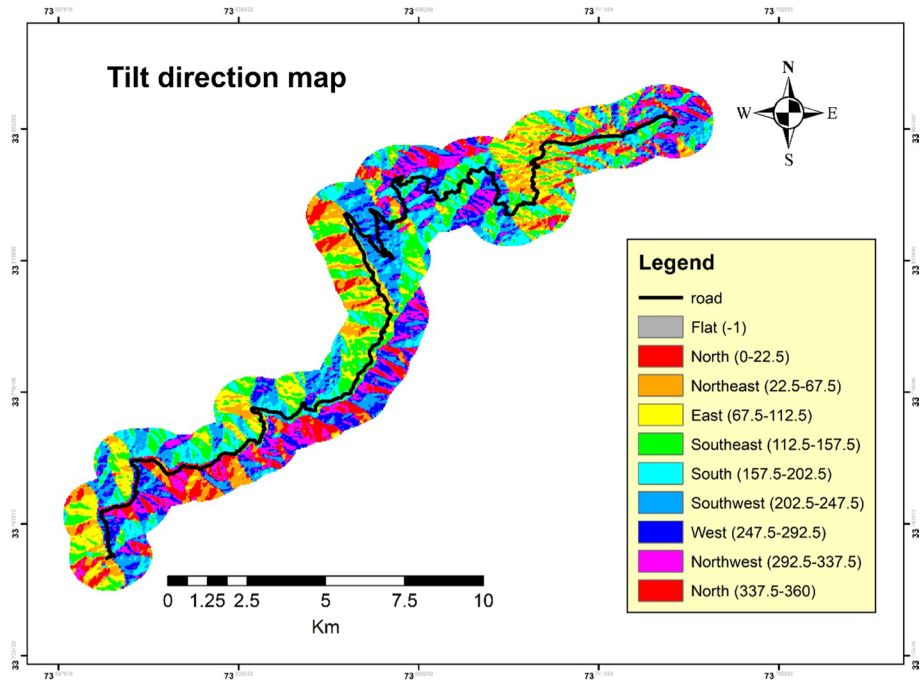

Fig. 4 Elevation map of the study area

Fig. 5 Tilt direction map of the study area (Numerical values in legend shows the compass direction)
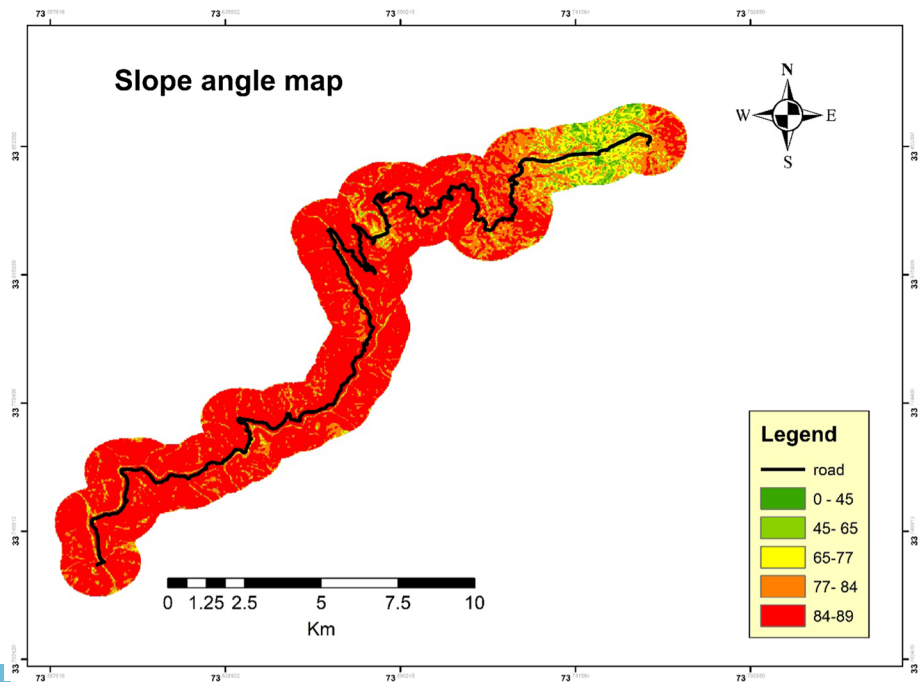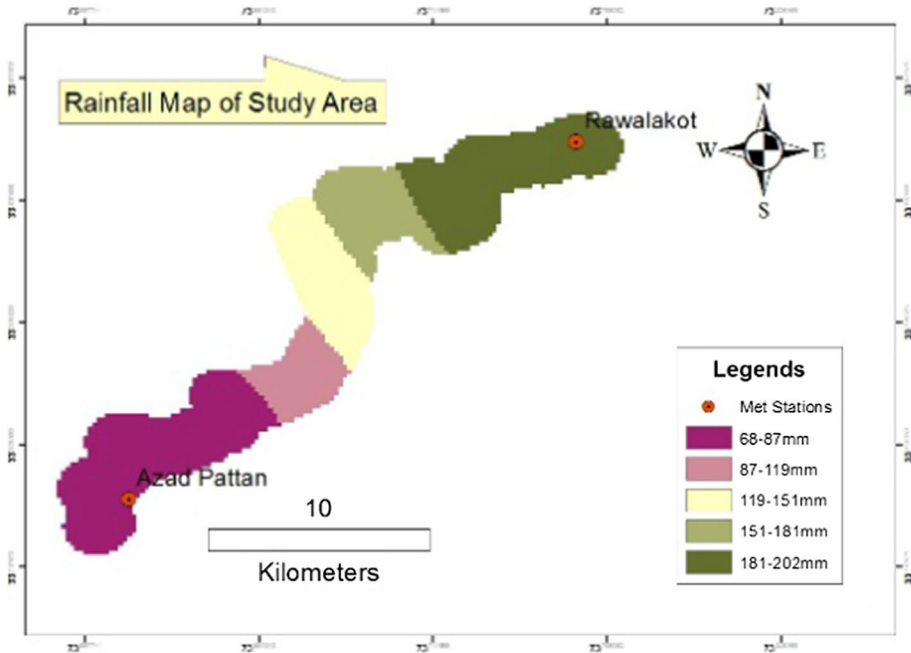

Fig. 6 Slope angle map of the study area

Fig. 7 Rainfall map of the study area

Table 1 Area and percentage distribution of LULC classes of the studied region

LULC classes	Higher vegetation	Lower vegetation	Water bodies	Buildup area	Road
Area of class in hectares (ha)	3824	1048	370	123	802
Percentage of area covered by class (%)	62	17	6	2	13

Physical factors consisted of lithology and rainfall. Lithological study of the area revealed that Guoien Nullah road falls under Siwalik and Murree formation consisting of conglomerates, mudstone, siltstone and calcareous shales. The study area is surrounded by Riwat Fault from southwest direction and Koth Thrust in northeast direction (Fig. 2). Rainfall data for years 2005–2015 acquired from PMD were interpolated using Inverse Distance Weighted (IDW) to find the intensity of rainfall in the area which is shown in Fig. 7. Land use/land cover (LULC) and Normalized Differential Vegetation Index (NDVI) were considered as anthropogenic factors in the present study. These factors were analyzed through Landsat product of 30 m resolution for the year 2015. LULC map was created using the maximum likelihood supervised classification technique. As a result of classification, five LULC classes were delineated as mentioned in Table 1 and shown in Fig. 8. LULC classes accounted for a total area of 6168 hectares (ha). NDVI was calculated through Band 5 and 4 of Landsat 8 and was divided into five categories, i.e., area with no vegetation, meager vegetation, sparse, moderate and densely vegetative area as shown in Fig. 9.
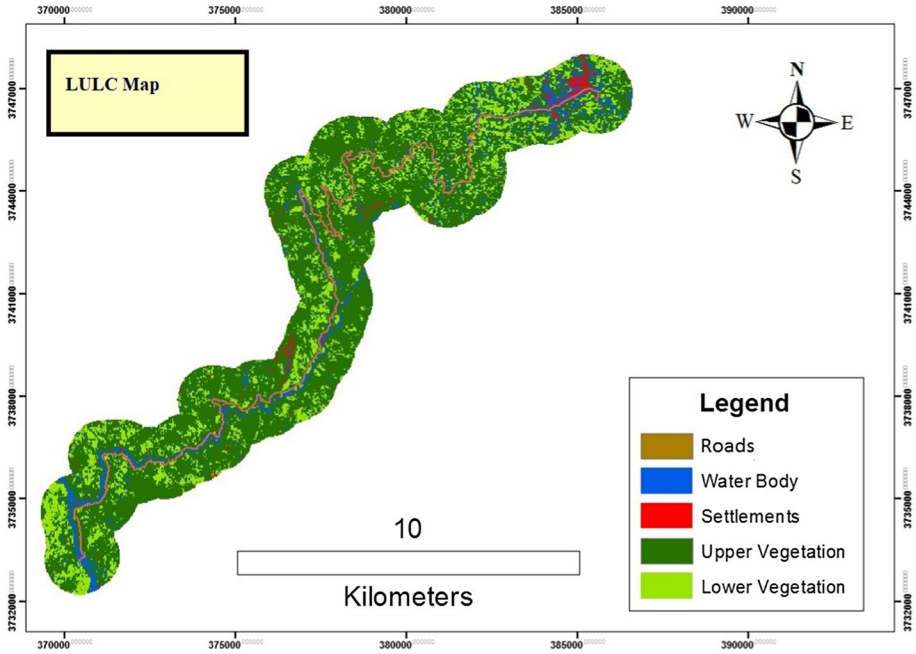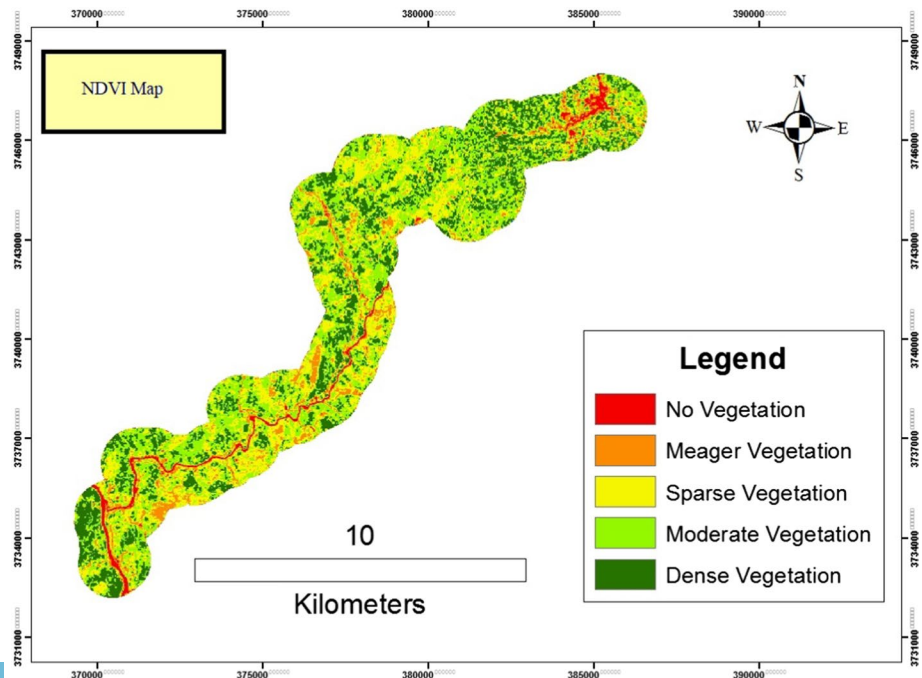
Fig. 8 LULC map of the study area

Fig. 9 NDVI map of the study area

2.5 LHZ mapping technique

Multi-criteria evaluation (MCE) technique was used for landslide hazard assessment and mapping. This technique is a decision-making approach that combines various features together to obtain a single output. A single output is attained by allocating weight to each feature. This method contains the field study, geological settings, LULC pattern and analyst opinion. Both qualitative and numerical tools are used in MCE Technique (Basharat et al. 2016). In the present study, AHP and WOM were used as MCE techniques for obtaining LHZ Map.

2.5.1 AHP

AHP is a semi-quantitative method that assigns a weight to the landslide activating factor through pairwise comparison matrix (Saaty 2004, 2008). In the present study, each activating factor was rated between scale ranges from 1 to 9 against the transecting factor. In the case of direct proportion between factors, 1–9 values were assigned, while inverse scale, i.e., 1/2 to 1/9 was used for indirect proportion between transecting factors (Bhushan and Rai 2007). Expert knowledge and field studies were taken into account for allocating weight and rating among activating factors. Later on, the pairwise comparison method was applied for calculating weight values. The preference scale of the pairwise comparison method is shown in Table 2. In order to maintain the consistency of judgment, calculation of the consistency ratio was also done.

2.5.2 Weighted overlay technique

The weighted overlay technique was used in a present methodology to develop a zonation map. This technique generally utilizes thematic raster layers of each parameter that are overlaid on the basis of their weights to generate a cumulative map. The weights are assigned on the basis of the relative importance of each parameter (Saaty 2000). In the current study, all thematic layers of activating factors were added in ArcGIS software through a weighted overlay tool for LHZ mapping.

3 Results and discussion

3.1 Landslide spatial distribution

In the present study, landslide spatial distribution was evaluated through the landslide inventory map. Thematic layers of each landslide activating factors, i.e., slope angle, tilt direction, elevation, LULC, NDVI, precipitation, and lithology, were overlaid with landslide inventory map to determine the correlation between landslide activating factors and landslide occurrence.
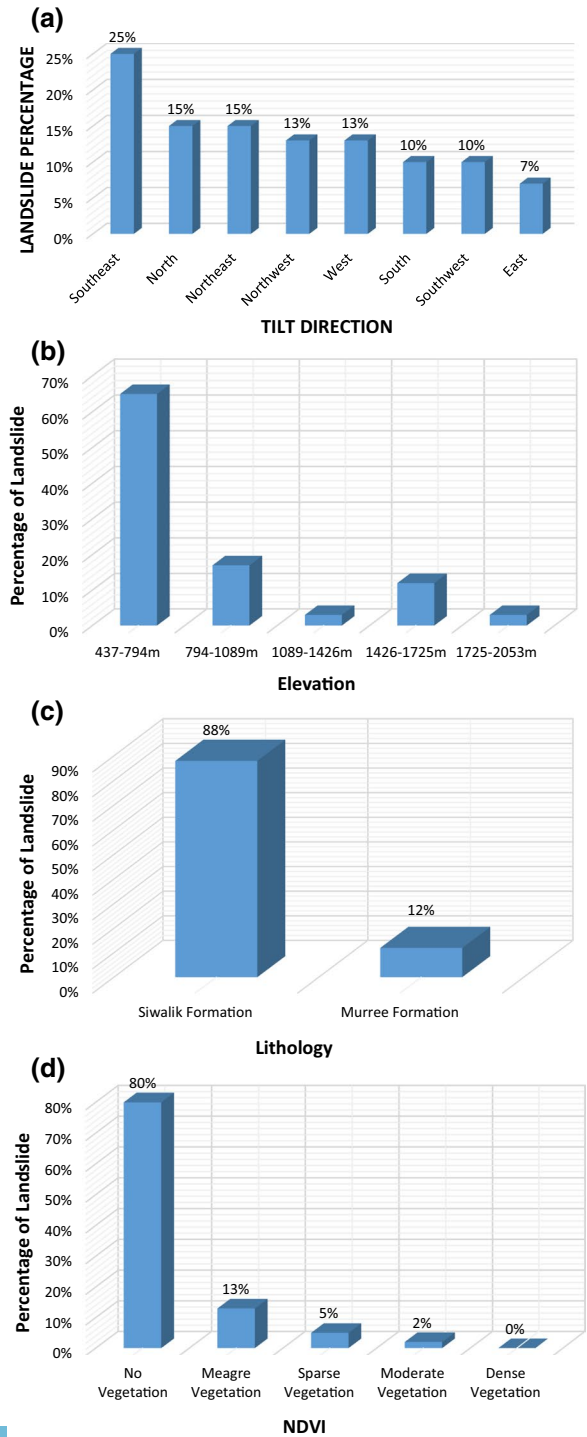
3.1.1 Landslide relation with tilt direction

Landslide distribution with reference to tilt direction revealed that the majority of landslide events happened along southeast direction (25%), while 15% occurred along with north and northeast directions as shown in Fig. 10. In accordance with the monsoon pattern of

Table 2 Preference scale for pairwise comparison matrix (Saaty 2003)

Rating	1	2	3	4	5	6	7	8	9
Definition	Equal	Equal to moderate	Moderate	Moderate to strong	Strong	Strong to very strong	Very strong	Very Strong to Extremely Strong	Extreme

Fig. 10 a Relationship of tilt direction with landslide occurrence, b Relationship of Elevation with landslide occurrence, c Relationship of physical factor with landslide occurrence, d Relationship of anthropogenic factors with landslide occurrence

Pakistan, rainfall is predominant across the southwest to northeast direction. This predominance along southwest to northeast directions exerts more pressure on slope angles facing southeast to northwest direction and causes more events of landsliding along with these particular directions (Ahmed et al. 2014).

3.1.2 Landslide relation with slope angle

The maximum slope angle observed in the study area was 89° and 70% of the total landslides at slope angle ranging from 84° to 89° (Fig. 10). Commonly steep slope angle reduces the shear strength of earth holding materials which in turn results in land subsidence (Saba et al. 2010; Shafique et al. 2016).

3.1.3 Landslide relation with elevation

By overlapping the inventory map on the elevation map, it was found that at height of 437–794 m, the maximum percent of landslide incidences occurred. 17% of total landslide events were observed at height ranges from 794 to 1089 m and 12% at range from 1426 to 1725 m, whereas lower incidence of landslides was found at the height range of 1089 to 1426 m and 1725 to 2053 m, respectively (Fig. 10). The composition of earth material was found to be mainly responsible for this unique distribution of landslide incidence along with the height. Areas with lower elevation were found with abundant deposition of alluvium material in their earth crust which has high susceptibility toward the Slope angle instability (Dunning et al. 2007; Rahman et al. 2014).

3.1.4 Landslide relation with lithology

Lithology is another most important activating factor of the landslide. Distribution of landslide points on lithology map showed that 35 out of 40 landslide incidences occurred along with Siwalik formation while remaining events were observed in the area with Murree Formation (Fig. 10). The geological map of the area highlighted the presence of fault lines in the area with Siwalik formation. It has been shown that landslide is more prominent in the area close to the faults lines because of the following reasons. One reason is the restriction of groundwater flow by fault lines which results in slope angle failure (Hewitt et al. 2011). The second reason is the crack formations in the underlying bedrock. The earthquake of 2005 has created cracks in the bedrock of the Kashmir region. During rainfall, these cracks become more active and activate the landslide (Basharat et al. 2012, 2014). The study area is a river valley as river Jhelum flows through it. Specifically, in study region, river valleys are surrounded by thick colluvium earth material, having weak cohesion with underlying rocks. This weak contact enhances the chance of land subsidence in an area (Ray et al. 2009; Rahman et al. 2014).

3.1.5 Landslide relationship with anthropogenic factors

Principle human-induced factors responsible for escalation of landslide in an area are: population expansion, overgrazing and construction of roads and houses. Plain and levelled land are rare in study area; therefore, inhabitants are forced to construct houses over fragile slope.

Distribution of landslide in the study area revealed that maximum landslides were observed along road sides. The Communication and Works Department stated that road density has leaped up to almost twenty times since 1950. From literature review it has been reflected that increase in road density on steeper slope has direct relation with the occurrence of landslide events. Hence, it clearly supports the findings of the current study that construction activities over fragile slopes intensify the landslide incidence. After rainfall, blockage of roads by landsliding was also found during field visit. This blockage has resulted from the construction of roads along susceptible steep slopes, which dislocates the thick beds of underlying conglomerates rocks, consequently resulting in slope failures (Akbar and Ha 2011).

Vegetation cover plays an important role in preventing landslide hazard. Vegetation cover binds to the loose material and restrained it from slope failure. NDVI Map of Study Area was overlapped with the Landslide Inventory Map to determine the relationship of Vegetation with the Landslide occurrence. The distribution of Landslide with reference to Vegetation shows that maximum landslide (80%) occurred in the area with no Vegetation.

3.1.6 Landslide relation with rainfall

In the study area, monsoon season with western disturbances causes high-intensity rainfall that makes rainfall as a prominent factor for landslide activation. Monsoonal rainfall speeds up the soil infiltration and surface runoff rate that leads toward slope angle instability. Moreover, winter disturbances also play an equal role in monsoonal rainfall in instigating landslide events. In winters, hilly areas receive rainfall in the form of snow. This snow seeps and infiltrates into the rocks and creates weak contact among surface rocks and underlying bedrock, consequently leading to Slope angle failure (Ahmed et al. 2014).

3.2 LHZ map

Prior to LHZ map generation, ranking and weightage of all factors through AHP are a necessary step. In the present study, each factor was assigned weight against another factor through the pairwise comparison method and results are shown in Table 3. Consistency ratios were then calculated for obtained weights using the methodology presented by Saaty (2000). In this study, the value of the consistency ratio (CR) was 0.048 which is less than 0.1. This shows that the generated matrix was consistent and assessments were acceptable.

It has been observed that the highest weight was assigned to rainfall followed by lithology and slope angle. Elevation was also observed as somehow effective whereas LULC, NDVI, and tilt direction were found to be less influential. After the application of the AHP method on thematic layers of landslide activating factors, the resultant map was generated using weighted overlay method. The resultant map is classified into three zones that defined the susceptibility of landslide hazard in the study area. The LHZ map of the present study area specified that 36% of the total study area falls under the high hazard zone area. In contrast to it, 34% of the area comes under the low hazard zone while 30% of the area falls in the category of moderate hazard zone as mentioned in Table 4 and shown in Fig. 11.

The high hazard zone was located in the southwestern region of the study area, while the low hazard zone was concentrated along a northeasterly direction. Correspondingly, a moderate hazard zone occupied the region between the high hazard zone and the low hazard zone of the study area. The reason behind the presence of high hazard zone in the southwestern direction is the type of slope material present in the area. Alluvium and Colluvium

Table 3 Pairwise comparison matrix, weight and normalized principal eigenvalue of all thematic layers

Criteria	Rainfall	Lithology	Slope angle	Elevation	LULC	NDVI	Tilt direction	Weight	Normalized principal eigenvalue
Rainfall	1	3	2	4	5	5	7	0.36	7.45
Lithology	1/3	1	2	3	5	5	7	0.23	7.4
Slope angle	1/3	½	1	2	4	4	7	0.17	7.1
Elevation	1/4	1/3	1/2	1	3	3	5	0.11	7.2
LULC	1/5	1/5	1/4	1/3	1	1	3	0.05	7.45
NDVI	1/5	1/5	1/4	1/3	1	1	3	0.05	7.45
Tilt direction	1/7	1/7	1/7	1/5	1/3	1/3	1	0.026	6.96

Table 4 LHZ classes, areas and percentage distribution of classes in the study area

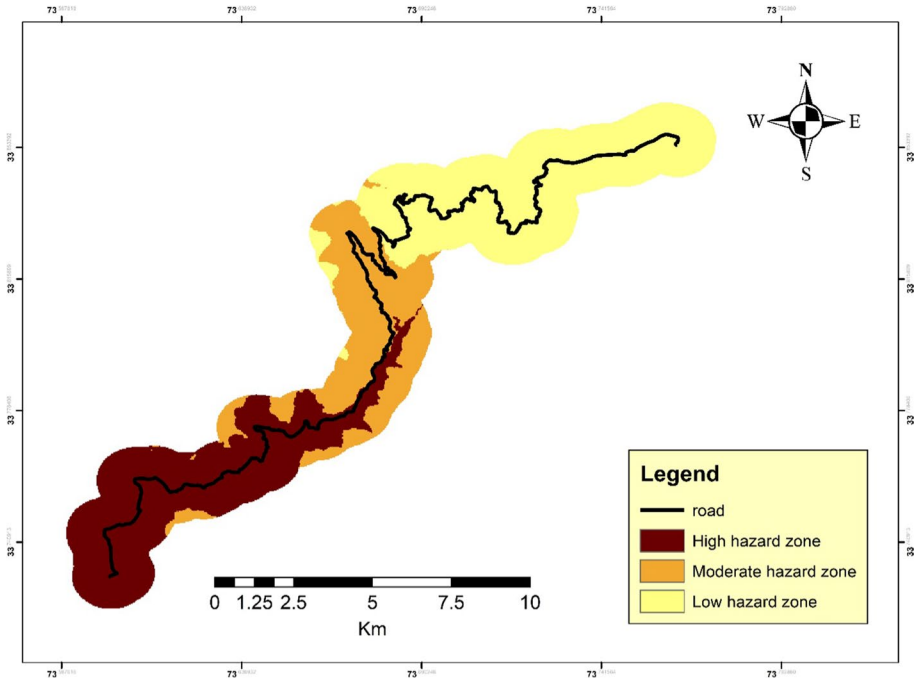| Classes	Area (ha)	Area (%)
High hazard zone	2221	36
Moderate hazard zone	1854	30
Low hazard zone	2093	34

Fig. 11 LHZ map of the study area

soils were predominant in the study area, and these materials are most vulnerable to the slope failure. Steeper slopes greater than 50° are most sensitive to landslides. Additionally, it has also been observed that high hazard zone and moderate hazard were nearby the fault line that reflects the landslide relation with the seismicity. During field survey, cracks were observed in the space of fault line that consequently activated the landslides.

From the above discussion, it was analyzed that climate of study area was primarily monsoonal that led to the rain-induced landsliding. Slopes were mainly fragile which increased the slope failures. In addition to the climatic and geological factors, anthropogenic activities were also responsible for the occurrence of landslide in the study area. Lack of proper land use planning and road construction along steep slopes increased the frequency and reactivation of landsliding in studied area. These devastating processes affect the transportation, communication and housing. It also affects the indigenous flora and fauna of the study area. To handle the landslide problem in study area, several organizations are working for minimizing the risks associated with landslide. But the problem is that these organizations are mostly focused on structural measures instead of sustainable measures. Therefore, there is a great need to devise methods to promote sustainable

measures considering local environment, geology, topography, land cover and rainfall pattern of an area.

3.3 Validation of LHZ map

The resultant map was validated by overlying the landslide inventory map on the LHZ map. Landslide inventory map was prepared by ground-truth survey. For ground-truth survey, GPS control points were taken on all sites where landslide event has occurred. Total of 40 landslide events were observed in the study area. Landslide distribution with respect to LHZ maps showed that 28 landslide events out of a total 40 occurred in the high hazard zone identified through weighted overlay analysis. The result showed good agreement between landslide occurrence and LHZ map.

4 Conclusion and recommendation

LHZ map was produced for Guoien Nullah road by application of AHP and weighted overlay analysis. Seven landslide activating factors were considered and analyzed for the creation of thematic data layers through GIS. AHP method was used for assigning weights to these factors, while the weighted overlay technique was utilized for the generation of hazard zonation maps. LHZ map classified the study area into three zones, i.e., high hazard susceptible zone, moderate hazard susceptible zone, and low hazard susceptible zone. The areas that were close to the fault lines and had slope angle greater than 50° were ascertained unsuitable for future development activities. Furthermore, the area with alluvium and colluvium soil was also found to be unsafe for construction purposes. In accordance with the obtained results, the study proposed that the area nearby Guoien Nullah road will likely to be more vulnerable to the landslide in the future. Thereby, it is recommended that a high hazard zone should not be used in the future for any construction activities. Deep-rooted vegetation in the region and retention walls along the road sides may reduce the impact and damages associated with landslides. Furthermore, this LHZ map will prove to be an information source on active and future landslides for locals, engineers, and land use planners to eradicate the damage that occurred because of the landslide.

Compliance with ethical standards

Conflict of interest The authors declared no conflict of interest.

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