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Research Article

Susceptibility Assessment of landslide Using AHP and Weighted Overlay Method, along Lower Topa-Kohala Bridge Portion of N-75 highway, Punjab, Pakistan

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ABSTRACT

Landslides are extensive and dangerous geological disaster processes that cause a number of casualties and economic losses around the world. Hence it has become the subject of interest to many researchers in different scientific disciplines. Murree is a popular tourist destination in Pakistan and because of inept geology, steep terrain, rising day-to-day urbanization, erosion, erratic land-use activities, and excessive rainfall in the rainy season triggering landslides in the Murree. A lot of socio-economic damages are triggered by regular landslides in the region. Therefore, mapping of the landslide susceptible region is essential for the local communities and government units. In the current study, landslide susceptibility assessment of the Lower Topa to Kohala bridge portion of N-75 highway (which is the only route to connect Pakistan with AJK) is done using GIS and Remote sensing techniques based on field investigation and previous literature. Nine causing factors including slope, aspect, curvature, lithology, normalised differentiation vegetation index, rainfall, distance from fault, road, and streams were analyzed. Weights were allocated to individual causative variables on the basis of their influencing power to the landslide initiation using AHP method. All the causative factors were merged into a single assessment index to produce research area susceptibility map using AHP command tool and Weighted Overlay Method in ArcGIS. The obtained map by AHP command tool shows high to very high 57%, moderate 19% and low to very low 24% while Weighted Overlay Method (WOM) shows high to very high 30%, moderate 49% and low to very low 21% landslide susceptibility of the overall area. The AHP command tool shows higher accuracy rate of 0.87 in the AUC technique. These landslide susceptibility maps will demonstrate to be a collection of awareness on dynamic and potential landslides for residents, engineers, and land-use authorities to reduce the destruction induced by landslides.

Keywords: Geological disasters; landslide susceptibility assessment; GIS; Remote Sensing; AHP; Weighted Overlay Method (WOM)

INTRODUCTION

The natural condition or process of causing economic loss, life loss or injuries to human life is called a natural disaster. Landslides are classified as the most damaging phenomena in geological disasters [1]. The consequences of landslides are equal to the effects of floods, cyclones, tsunamis, and, most importantly due to earthquakes [2,3]. By way of a general rule, almost all the natural hazards, particularly some stated above, offer a direct effect on landslides, however not the other way around. Landslides are largely generated *via* triggering and causing factors. Causing factors comprise slope, soil, relief, geology, geomorphology, drainage pattern, land-use/land cover, and weathering, whereas rainfall, seismicity, dynamic loads, and Climate change are triggering factors. Landslide phenomena have been the reason behind numerous fatalities and financial damages around the globe. About 16,000 people feel death Europe in the last century 1903-2004 [4], whereas in the other parts of the world individual activity can have a similar dimension (50,000 in Venezuela 1999, 29,000 in China, 2008) [5,6]. Economic losses from landslides

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have apparently increased as development spreads to hilly areas. Despite progress in landslide research, landslide activities are increasing and remain a challenging task with time because of the lack of proper mitigation and early prediction measures [7]. Pakistan is prenatal with anthropogenic and natural catastrophes that can impact people's lives and structures and significantly interrupt their economic growth. The Kaghan valley in Pakistan's Western Himalaya is prone to landslides, which remain a serious threat to cultivation, villages, highways, transport, and tourism [8]. The landslides triggered by the Kashmir earthquake have an estimated range of >7500 km [9]. Due to the Kashmir earthquake, a total of about 2500 landslides were caused these landslides caused around 26,000 mortalities directly or indirectly [10]. The Hattian Bala rock avalanche was the leading landslide connected with the earthquake that entirely devastated a village and blocked the Jhelum River tributaries, forming a dam. The reported deaths were around 1000 in this huge landslide and has a total volume of approximately 85 × 106 m3; whereas, the affected area is about 1.8 km [11]. The Atta bad rockslide on 4 January 2010 killed 19 people in the area, displaced 6,000 people, obstructed the Hunza River for five months, leading to approximately 14km of still existing natural lake, and submerged 19 km of the important Karakorum Highway (KKH) [12]. Despite of this high threat to the transportation and economic environment of northern Pakistan especially in Himalaya region, so far are only a few studies regarding hazard assessment of landslides available in the literature. Landslide events and damages have not been recorded on a regular basis. Different government agencies dealing with the landslide issue have not been found to maintain proper record of their undertakings and are not even ready to provide their inadequate material and statistics with researchers [13]. Though, because of the lack of availability of resources and the difficulty of the research and application issue, the study of landslides in Pakistan did not progress at an appropriate pace. In this study the Lower Topa-Kohala bridge portion of N-75 highway, Murree is taken as a study object, which is the only transportation route between Pakistan and AJK. Murree is an important tourist spot in Pakistan, and hundreds of tourists used to travel to Murree the whole year. In the Murree region, urbanization has increased in the past decades. Murree Mountains had once been covered with a dense forest of large leafy trees and shrubs. This natural vegetation is used to provide optimum stability of slopes and mitigation against erosion. With the growing population, the forest was decreased by cutting timber and firewood and humanizing new land. This, as well as the construction of new buildings and roads, contributed to a substantial reduction of natural vegetation. As the root system is destroyed, the colluvium deposits and also the shale or softer rocks begin to disintegrate easily. Exposed slopes are occasionally capable to endure the damaging consequences of rapid surface runoff after heavy rainfall and fail to frequently lose land cover and lastly develop into landslides. Excavation of slopes; particularly the toe of slope for building and widening of the existing roads and construction work along the road is a common phenomenon in this area. As the N-75 highway is the only transportation route between Pakistan and AJK; all kind of local and heavy transport use this route, the estimated daily total traffic is 7866 vehicles (small 4950, medium 2139 and big transport 720 respectively) [14]. This weakens the existing state of stresses and encourages landslides. For Landslide Susceptibility Assessment (LSA), it is required to undertake that the circulation of landslides is defined with the causal parameters of the landslides and the forthcoming landslides would take place with similar circumstances as previous landslides [14,15]. The landslide susceptibility zonation is the method of distributing an area into different groups based on the susceptibility score for a specific factor. In this study, nine landslide causing parameters based on the field investigation and published data were selected, i.e. slope, aspect, curvature, lithology, NDVI, Distance To Fault (DTF), Distance To Road (DTR), Rainfall, and Distance To Stream (DTS). The calculation was done for the nine causative factors respectively. The total causal parameters map was then combined depending on their respective susceptibility weight using Analytical Hierarchy Process (AHP) and the consequential landslide susceptibility map was generated using AHP command tool and Weighted Overlay Method (WOM) in ArcGIS software. The key objective of the study is to create Landslide Susceptibility Map (LSM) of the research area based on field investigation and published data, with the implementation of GIS and remote sensing techniques. All the work was interpreted in ArcGIS 10.3, developed by the Environmental System Research Institute (ESRI).

Study Area

The study area situated in the north-east of the capital territory of Islamabad along the N-75 Highway featured from Lower Topa to Kohala Bridge, Murree, Rawalpindi, Punjab, Pakistan. Geographically the research area lies between the latitude of N 33°54′0.34″ to 34°05′46.73″ and longitude of E 73°24′39.38″ to 74°28′41.59″. The overall road distance between Lower Topa and Kohala Bridge is about 34 km. Geologically, Murree is a mountainous tourist city situated in the Galyat area of the Pir Panjal Range of the Himalayan mountain range of Pakistan. The GIS-based geographical location of the research area is given in Figure 1. The research area shows elevation ranges from 520-2216m above sea level. Landslides often affect the study area, and particularly landslides occur during the rainy season that not only block transportation but also cause immense economic damages by destroying villages and shops in the region. According to the local people, landslides are become more common in the last few years and caused damages to the houses and shops along the road. The landslides points taken in the study area during the Field survey are shown in Figure 2 and damages caused by landslide (point 6, 9, 8, 26, 25) are shown in Figures 3 and 4. The majority of slope failures happen along roads and highways in Pakistan. The N-75 highways, especially the portion from Lower Toppa to Kohala bridge, have considerable economic and strategic importance because it is the only connected transportation source between Pakistan and AJK. The LSM of the study area and its implementation can highly minimize the socio-economic losses of the area.

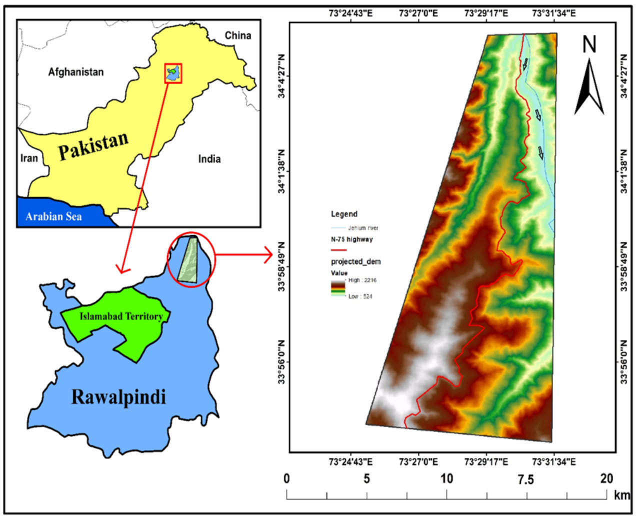

Figure 1: Geographical location of the research area and landslide points along Lower Toppa to Kohala bridge road, Murree.

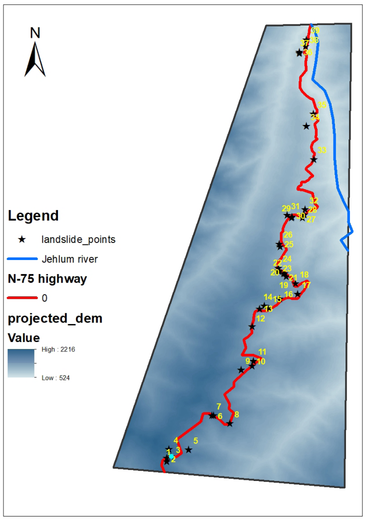

Figure 2: Landslide points taken during field investigation along the road.

Figure 3: Landslides locations along the Lower Topa to Kohala Bridge road. (a) Recently damaged local resident's houses by landslide, (b) a large slide happened few years ago caused damage to a petrol pump and few shops ((b1) cracks on the road shoulder (b2) remaining of damaged shops.

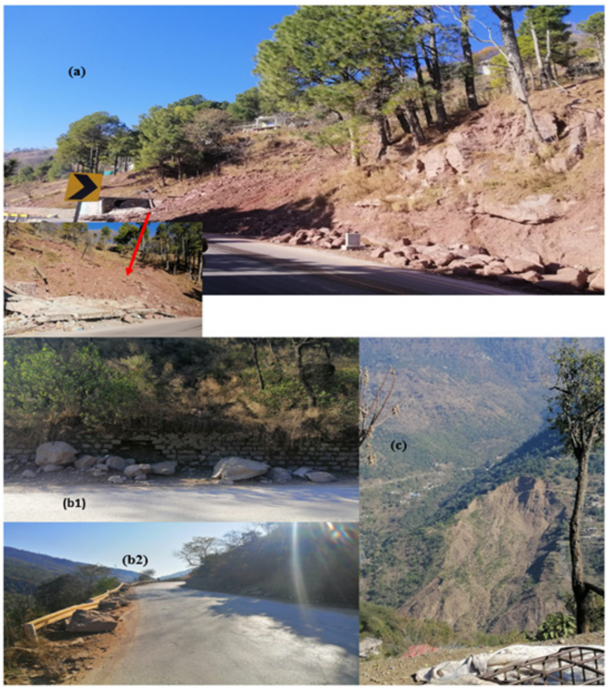

Figure 4: (a) recently occurred landslide's remaining on the left side of road, (b1,2) Damaged retaining wall on both side of the roads due to Rock fall (huge boulders) on the bank of Jhelum River, (c) A massive landslide on the opposite side of the road and left bank of Jhelum River.

Geological Settings Of The Area

The active seismic and tectonic structure of the study area is among the most significant factors leading to land sliding. The Murree region mainly consists of the Himalayan Mountains, and the Himalayan was formed during the Eocene period by the collision of the Indian Plate with the Eurasian plate across a fracture zone described as Main Mantle Thrust (MMT) [16,17], and it is the highest uplifting area on globe [18]. At the MMT, the deformation steadily spread southward from the early Eocene collision area and by Miocene period entered the Himalayan Mountains [19]. The Himalayan foothills are described as a collection of rocks bound to the north and south by major thrust faults, including the Main Frontal Thrust (MFT) and the Main Boundary Thrust (MBT). Proximately adjacent to the MBT, the Murree zone falls in an earthquake-prone area. At the Richter scale, the average earthquakes of magnitude 4-5 are reported. The deposited molasses siltstone and sandstone mainly produced by Murree and Kuldana formations of Oligocene and Miocene make up almost all of the Murree Mountains. The Murree Formation sandstone is reddish grey, multi-layered, medium-grained, cross-bedded, rigid, and compacted, forming 4-8 m thick sequences [20]. The sandstone series are interblended with red-pigmented siltstone and shale. Certain fine-grained lithology makes up most of the formation and provides a weak region for the faults. Land sliding and other mass movement occurrences are accumulated in the region due to poor component lithology, complex and extreme distortion aggravations in recent times by environmental and human activities such as deforestation, engineering developments, and population growth, etc. [21].The research area is structurally complex and sophisticated, deformed by MBT and the corresponding [22,23]. A southwest plunging syncline with Murree Formation lies at the center of the syncline is much of the mid-range on which the Murree Town is situated, and the beds plummeting towards the core of the ridge. This structure supplies the ridge with a degree of structural stability. Simultaneously, this arrangement renders the Murree range a large water reservoir, combined with the lithological composition of varying clay stone, siltstone and sandstone layers. This is obvious from the appearance at the toes of major sandstone perspectives of several springs and seepages [24]. This seepage also encourages slope failure of rock and soil structures, leading to the mass movement Figure 5. The study area geological map is shown in Figure 6.

Climate

Pakistan is situated on the western edge of the monsoon zone, whereas the Murree hills fall in the semi Continental's Highlands climate division. The weather is usually cooler at higher altitudes and warmer at lower altitudes. The fall and spring are short in the study area. The last 30 years (1990-2019) average annual rainfall of the study area was 740.94 mm, while the average temperature was 20.09°. The highest rainfall occurs in July, August, and September; the average monthly precipitation ranges from 33mm in November to 351 mm in July. The extreme temperature in June exceeds 30° while the least temperature in January drops to 4°. The humidity ranges from 27% in May to 80% in August.

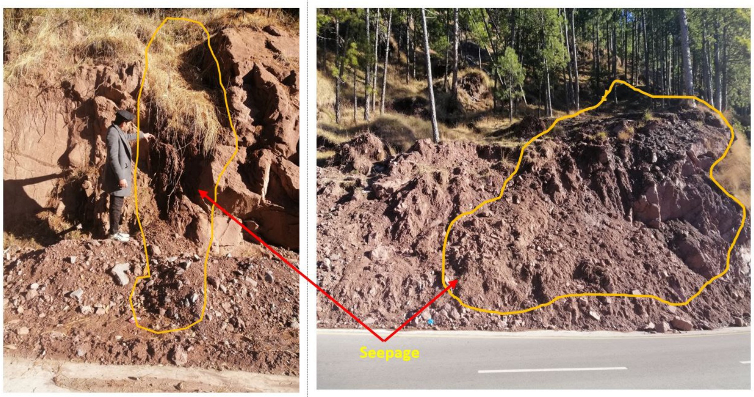

Figure 5: Seepage in the Formation at the right side of the road.

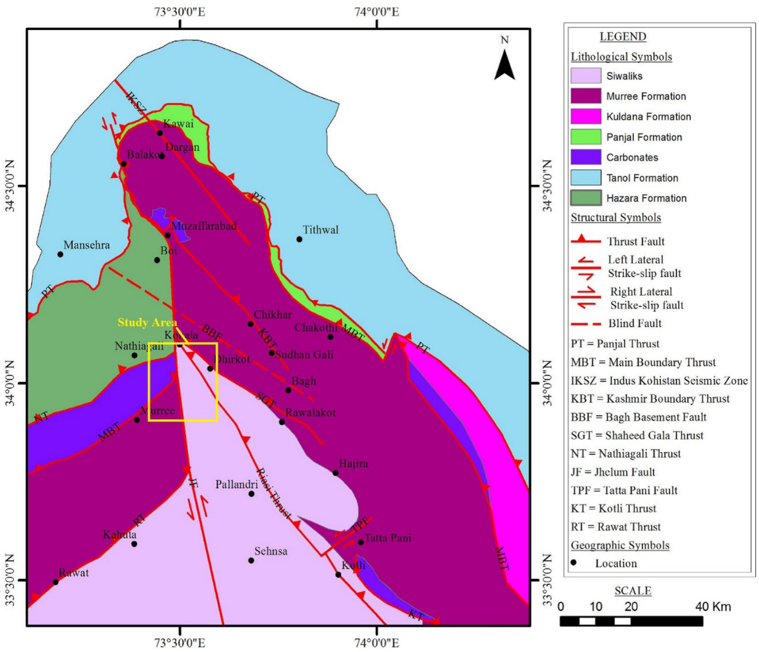

Figure 6: Geological map of the study area revised after [25,26].

MATERIALS AND METHODS

Assessment factors

An essential part of the LSA is the selection of causal variables since landslides are mainly caused by these variables. In addition, the findings of landslide susceptibility often depend on landslide causative factors. Such factors can differ in a few disparities from place to place. The causative factors were selected based on the field survey, Remote sensing techniques, and the previously published data in the present work. Recent advances in GIS software and increased computational ability make it conceivable to use a considerably large amount of independent variables in data-driven Landslide susceptibility assessment. For the current susceptibility assessment mapping of Lower Topa to Kohala Bridge road, a combination of significant morphological factors of slope instability together with geographical features and natural vegetation were selected. The landslide variables used in this study of landslide susceptibility are slope, aspect, curvature, lithology, NDVI, DTF, DTR, rainfall, DTS. The maps of an individual causative factor were developed using ArcGIS 10.3 software.

Slope

The slope is the indicator of steepness or the degree of inclination of a characteristic relative to the horizontal plane. Gradient, scale, inclination, and pitch area are used interchangeably with slope. The slope map was created from DEM using GIS spatial tool since the slope is linked directly to the landslide initiation and is often used to generate LSM. The aspect map indicates which side the slope is moving on. An aspect value of 0 implies that the north faces the slope. The aspect map was generated from the study area DEM using the ArcGIS spatial analysis tool. Map of curvature was also generated through DEM. Curvature map value varies from 13.96 -19.07.

Distance to fault

Landslides concentrated in the active fault are more susceptible to the landslide. The sites near the geological structures have shown high sensitivity to the landslide occurrence that not only influences the surface shape but also leads to the permeability of the soil resulting in the collapse of the slope. DTF is extracted from the geological map of the research area. Fault lines are buffered at the interval of 100m in ArcGIS 10.3. The DTF is divided into five classes: <100, 100-200, 200-300, 300-400,>400.

Lithology

Lithology performs a vital part in the slopes instability. Lithology map was prepared from the available literature and field investigation of the research area. The published work of the research area also comprises the work of GSP [22- 27]. The study area starting from the Lower Toppa to the Kohala bridge road mainly consists of the Murree Formation of the Miocene age [28]. Major lithological characters of the Murree formation are as follows: Mesozoic sedimentary rocks, Proterozoic meta-clastic rocks, Rawalpindi group, and Tertiary-Paleogene.

Normalized difference vegetation index

The Normalized Difference Vegetation Index Referred to as NDVI is believed to be a significant causing variable in LSA studies [29,30]. In general, the NDVI value varies from -1 to 1; the heavier the vegetation cover, the greater the NDVI value. The following formula can determine the value of the NDVI.

NDVI=(NIR-Red)/(NIR-Red)

The NDVI map was generated from Landsat-8 Imagery downloaded from Earth explorer by USGS.

Distance to road

Road network in the mountainous regions threatens the slope stability. Road cuttings and other anthropogenic activities destabilize the rock masses, which ultimately results in landslides. The road network of the region is acquired from the Map Cruzin website. The DTR is buffered at an interval of 150 meters and classified into five classes in ArcGIS 10.3 software. The classes are <150, 150-300, 300-450, 450-600, and >600.

Distance to streams

The influence of the stream also has an aggressive role in destabilizing the slope geometry. It includes the erosion of material from the toe of the slope and saturation of sliding material. The DTS is generated on Aster DEM by using Arc-Hydro tools. Buffering at the 400-meter interval was prepared to know the effectiveness of streams on landslide activities. <400, 400-800, 800-1200, 1200-1500, and >1500.

Rainfall

Rainfall is a crucial causative factor for all kind of landslide initiation. Data picked up from Pakistan Metrological Department for the year 2019 were interpolated by means of Inverse Distance Weighted (IDW) to calculate the area's rainfall rate. The obtained maps of all nine causative factors is given in Figure 7.

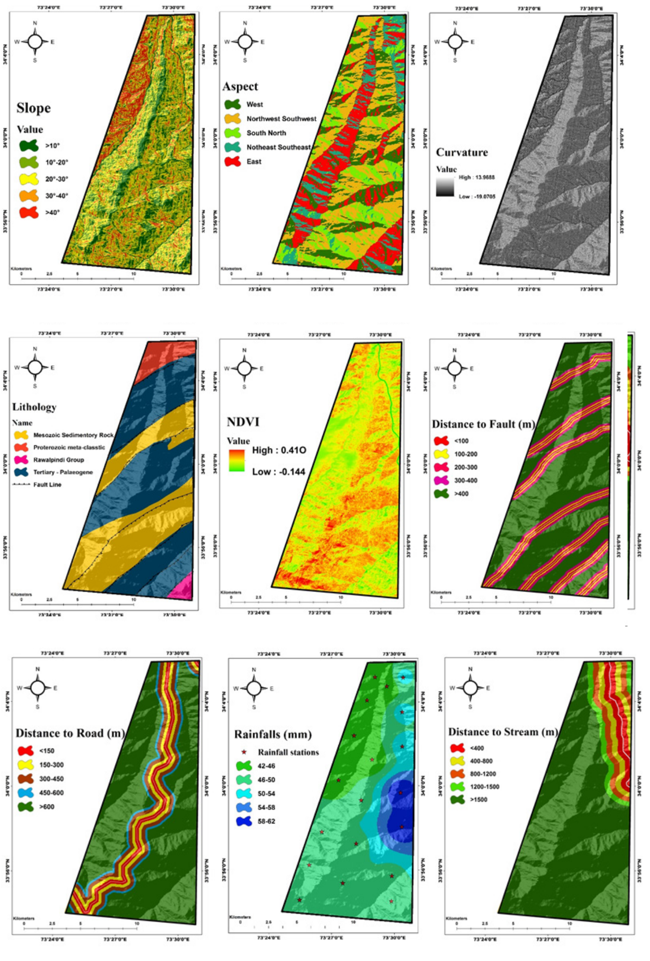

Figure 7: Landslide causative factors maps of Slope, Aspect, Curvature, Lithology, NDVI, DTF, DTR, Rainfall, and DTS.

Landslide susceptibility mapping

Landslide susceptibility is a spatial probability of landslides taking into account the cause of past proceedings [31]. It mainly relies on the knowledge of inclined movements and control variables [32]. To date, many researchers have undertaken to identify prospective landslide susceptible areas over the assessment of accountable factors [33-37]. The landslide susceptibility maps can be generated based on quantitative and qualitative methods. The Initial research study [38] was mainly quantitative, using landslides and their influencing factors for decisive, numerical correlations and deterioration analysis. Despite the region's threatening landslides, no recorded data in most areas regarding landslide susceptibility is available to assess and mitigate landslide hazards. In this context, safety factors are provided to infer deterministic methods, measured based on the engineering parameters. Statistical approaches are preferred in more recent research, seeking to create associations between the spatial distribution and control factors of a landslide. This includes analytical hierarchical processes [39,40], bivariate and multivariate techniques [41], logistic regression, and neural networks [42,43], fuzzy logic [44], etc. These methods have been verified to be improved choices for relatively broad and diverse regions. Furthermore, there are some other techniques, e.g., support vector machine [45], spatial multi-criteria evaluation [46], index of entropy [47,48] which can be used for data mining, for landslide susceptibility assessment, to overwhelmed inadequacies in the above techniques. Landslide susceptibility assessment contains descriptions of the degree of slope movements that can affect terrain and also the occurrence of the landslide in a region under local ground environments [49]. The beginning of GIS and Remote Sensing in research studies made it much easier to map the susceptibility to landslides [50-53] Because of the effectiveness of the AHP method; we used the Analytical Hierarchy Process method to create the pairwise comparison of the affecting variables. Two methods are being used to produce the research area's susceptibility assessment map, including the AHP command tool and the weighted overlay method in ArcGIS. The preliminary and most significant principle for carrying out the research objective is the collection and development of attributes which will be identified as Conditional Factors, which area is considered responsible for helping to make the study area susceptible to the Landslides. The maps of all the independent variables are measured and created in ArcGIS and now to combine and merge them in a single assessment index according to their assigned weight in order to produce study area susceptibility models. Lastly, to verify their accuracy, examination and findings need to be drawn. Where Area under curve map will give the accuracy of our model, these are to be discussed below.

Analytical Hierarchy Process

Analytic Hierarchy Process referred to as AHP, has been used in the current study, which is the most commonly accepted method for scaling the weight of factors by building a pairwise judgement of the causative factors whose entries represent the intensity with which one variable dominates over the other. AHP is a process based on decision theory in which it is necessary to compare each criterion from a set of choices or alternatives. It indicates the most accurate methodology for calculating the weight of a criteria and estimation of relative magnitude of factors through pairwise comparison with the help of individual experts and experience. It indicates the importance of a certain factor in landslide assessment by co-relating with other factors through a statistical comparison. The scores given are based on reasonable prioritization of the factor for inducing susceptibility of landslide and depend on the estimation of experts following the evaluation scale given by Saaty. The grading of comparative factors is done by allotting weight ranges between 1 and 9. Where 1 is of equivalent significance and 9 is the drastic importance of a particular factor over others (Table 1).

Table 1: Pairwise comparison 9-point rating scale in AHP, after Saaty [55].

Dominant values	Description	Explanation
1	Equal importance	Two factors contribute equally
3	Moderate importance	judgement slightly favour one factor over another
5	High prevalence	judgement highly favour one factor over another
7	Very high prevalence	Activity is very highly favoured over another
9	Extremely high prevalence	The evidence favouring one activity over another is of highest degree possibility
2,4,6,8	Intermediate values	used when comprises is needed

Though the comparisons in AHP are assigning by expert judgement, but still there could be inconsistency found in calculations. The consistency is derived in AHP by coherence ratio (Table 2), which is given by [54]

Table 1: Pairwise comparison 9-point rating scale in AHP, after Saaty [55].

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

RI= random consistency index.

$CR=CI/RI$

Where

$CI= (\lambda_{max}-n)/n$

The consistency ratio will be calculated in order to find the continuity of the pairwise compared weights. The uniqueness of the AHP method is that it provides CR as a relationship between the degree of consistency and inconsistency [57]. The suitable value of CR is 0.1 for all large matrices, i.e., n>5. Therefore, a CR of 0.1 or lesser is of reliable importance [55-58], however, a CR above 0.1 needs to review the matrix's conclusions. In the current study, AHP was used to assign weight to the causative factors, classes of the causative variables map and the generation of final susceptibility assessment map of the Lower Topa-Kohala bridge portion of N-75 highway was done with the help of ArcGIS using the AHP command tool.

Weighted overlay method

The weighted overlay method was also applied in the current study to obtain the LSA map. This method usually uses individual factor thematic raster layers that are overlaid to create a composite map based on their weights. The weights are provided based on the individual factor's comparative importance [59]. In the present work, the thematic layers of all causing variables were added using the ArcGIS weighted overlay tool for LSA mapping.

RESULTS

Assigning weights to the causative factors

In the multi-parameter analysis, one of the fundamental challenges in evaluating each factor's relative value or weight and its influence, in our case, landslide susceptible regards the other. This is an issue requiring human judgment augmented by mathematical instruments. As all conditional factors discussed till now cannot be weighted correspondingly for the susceptibility assessment, a weighted approach must be used where the comparative significance of the parameters determines the weightage. One of the major benefits of using AHP is rearranging the complication of data set by the hierarchy with a pair-by-pair comparison between two variables, therefore minimizing weighting inaccuracy while ensuring that different data processing is consistent. One benefit of AHP is allowing the validation of pair consistency. However, this method can vary from one expert to another, based on expert opinion, judgment, and ranking of the causative factor and this is therefore a minor drawback. Many researchers in the world used the AHP method in their studies to assess landslide susceptibility mapping. In which researchers mainly used AHP only to allocate the weighting variables for landslide causative factors, but in this study, AHP was used for both weighting factors and landslide susceptibility assessment based on causal parameters. Each causative factor was assigned weight over the other variable by the pairwise judgment of the AHP, and the results obtained are shown in Table 3. The obtained weight was then measured using methodology. The criteria weights of the causative factors are Slope 0.360, Aspect 0.192, Curvature 0.137, Lithology 0.095, NDVI 0.075, DTF 0.051, DTR 0.04, Rainfall 0.029, and DTS 0.022 % respectively. The consistency ratio is the measurement of how consistent the judgments are. In this study, the calculated CR is 0.088, which is below 0.1. The pairwise comparison ratio specifies a good consistency level, standing sufficient to distinguish the factors weight. The revision of the preferences matrix will be needed if the CR value is more than 0.1. Landslide Susceptibility map using AHP command tool After the calculations of the assigned rank to the causative variables, the LSA map was prepared using the AHP command tool in ArcGIS. For the generation of LSA map, all the causative variables were added according to criteria weightage level in the AHP tool. The final map of landslide susceptibility was classified into five classes, including very low (10%), low (14%), moderate (19%), high (39%), and very high (18%) of the overall research area. The LSA map generated by the AHP tool is shown in Figure 8.

Landslide susceptibility map using weighted overlay method

In the weighted overlay method, as the weight calculated by AHP were reclassified based on criteria weight to each parameter according to their importance in LSS equaling to the overall value 100%, in which slope have been given the highest weight of 36% and DTS being assigned the lowest weight with 2%. After applying the AHP process on the

Data maps of all the causative factors, the resulting map was created with the help of the spatial analysis tool of ArcGIS 10.3 using the weighted overlay method. The generated map was then classified into five classes very low (14%), low (07%), moderate (49%), high (17%), and very high (13%) of the overall research area shown in Figure 9.

Area under curve

The area under curve (AUC) technique is being used to predict the validity of the LSA map. The area under curve is a graphical representation of binary operating classes, which determines project accuracy. AUC was generated by comparing the generated map using ArcGIS software and the GPS landslide points taken in the field investigation of the study area. A total of 38 points were taken in the field for validation purposes, showing different types of landslides. These points are taken as the true-positive rate compared with the maps developed by the AHP command tool and the WOM in ArcGIS as the false-positive rate. Graphical representation of AUC explains the accuracy of mapping. The area under curve shows the map obtained with AHP command tools gives higher accuracy value of 0.87 shows in Figure10, which above the minimum value of 0.6 and is considered accurate for landslide susceptibility mapping.

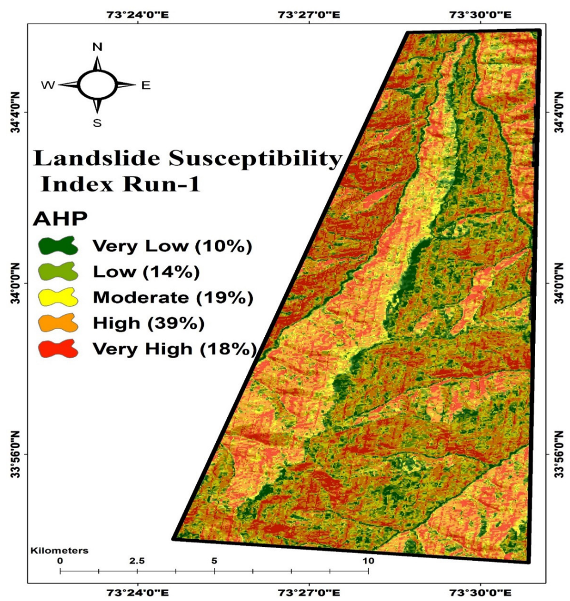

Figure 8: Landslide susceptibility assessment using AHP command tool.

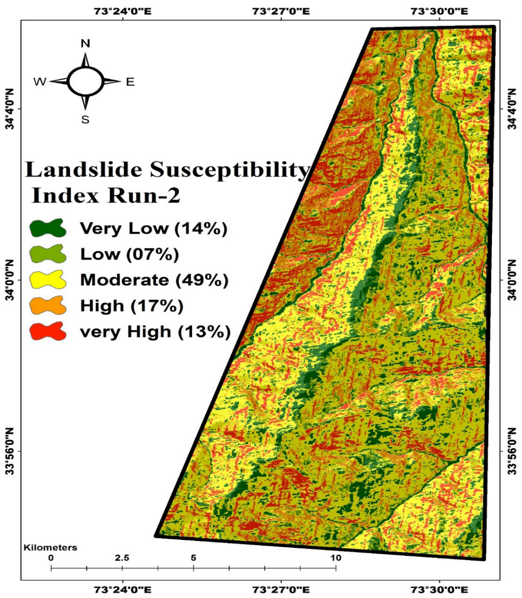

Figure 9: Landslide susceptibility assessment using Weighted Overlay Method.

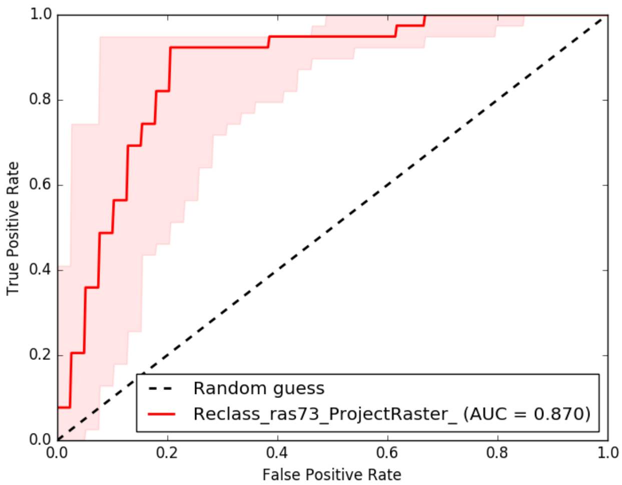

Figure 10: Area under Curve (AUC) graph of the study area.

CONCLUSION

Murree area is one of the most landslide susceptible areas in Pakistan. The N-75 highway passes through Murree and is a strategically important traffic route connecting Islamabad with AJ&K. Due to the frequent happening of the landslide in the Lower Topa-Kohala bridge portion of N-75 highway; it often induces road blockage and other socio-economic harms to the region. LSA mapping and zonation are essential for engineering and economic developments in the region. A one day field investigation was arranged, and a total of 38 landslides GPS points were recorded on the site. Another important stage in the LSA is the selection of landslide causative variables. Nine causative factors, including aspect, curvature, slope. DTR, DTS, DTF, lithology, rainfall, and NDVI were selected for current LSA. The slope, aspect, and curvature were extracted from the DEM of the study area using ArcGIS 10.3. Besides these databases, DTR, DTS, DTF, and lithology maps of the research area were prepared with available published literature. The NDVI map was extracted from Landsat-8 Imagery downloaded from Earth Explorer. After determining factor maps of landslide susceptibility, the weights were assigned to the causative variables on the basis of their influencing power to the landslide initiation. The pairwise comparison was made using the AHP method, and weight was assigned to the causative factors. These independent variables were measured and merged into a single assessment index according to their given weight in order to produce research area susceptibility models. In this study, two methods were used to generate the Landslide susceptibility map, including the AHP command tool and the WOM in ArcGIS. The final results of the landslide susceptibility map by the AHP command tool indicate 57% of the overall area is under high to very high susceptibility zone, 19% is moderate, and 24% is under low to very low susceptibility. Whereas the map generated with the WOM shows that 30% of the total area is under high to very high susceptibility, 49% moderate, and 21% percent is under low to very low landslide susceptibility. The AUC technique was used to measure the accuracy of the maps. The AUC graph was generated by comparing the generated map and the landslide GPS points taken during the field investigation. The AUC graph shows the map obtained with AHP command tools gives a higher accuracy value of 0.87. Based on the obtained results, it is recommended that all types of future development should be completely prohibited or done with all precautionary measures in the high to very high susceptibility zones. Deep-rooted plantation and retaining walls along the roadsides maybe helpful in reducing the landslide causes. In addition, this landslide susceptibility map will demonstrate to be a collection of awareness on dynamic and potential landslides for residents, engineers, and land-use authorities to reduce the destruction induced by landslides.

REFERENCES

1. Tariq S, Gomes C. Landslide environment in Pakistan after the earthquake-2005: information revisited to develop safety guidelines for minimizing future impacts. J Geogr Nat Disasters. 2017;7:1-1.
2. Varnes DJ, David CM. Landslide: Investigation and Mitigation (Chapter 3: Landslide Types and Processes). Proc Natl Acad Sci U.S.A. 1996:36-75.
3. Fell R, Lacerda W, Cruden DM, Evans SG, LaRochelle P, Martinez F, et,al. A suggested method for reporting a landslide. Bull Eng Geol. 1990:5-12.
4. Nadim F, Kjekstad O, Peduzzi P, Herold C, Jaedicke C. Global landslide and avalanche hotspots. Landslides. 2006;3(2):159-173.
5. Petley D. Global patterns of loss of life from landslides. Geology. 2012;40(10):927-330.
6. Kjekstad O, Highland L. Economic and social impacts of landslides. InLandslides–disaster risk reduction. 2009.
7. Van Westen CJ, Van Asch TW, Soeters R. Landslide hazard and risk zonation—why is it still so difficult?. Bull Eng Geol Enviro. 2006;65(2):167-184.
8. Akbar TA, Ha SR. Landslide hazard zoning along Himalayan Kaghan Valley of Pakistan—by integration of GPS, GIS, and remote sensing technology. Landslides. 2011;8(4):527-540.
9. Kamp U, Growley BJ, Khattak GA, Owen LA. GIS-based landslide susceptibility mapping for the 2005 Kashmir earthquake region. Geomorphology. 2008;101(4):631-642.
10. Mahmood I, Qureshi SN, Tariq S, Atique L, Iqbal MF. Analysis of landslides triggered by October 2005, Kashmir Earthquake. PLoS currents. 2015;7.
11. Dunning SA, Mitchell WA, Rosser NJ, Petley DN. The Hattian Bala rock avalanche and associated landslides triggered by the Kashmir Earthquake of 8 October 2005. Eng Geol. 2007;93(3-4):130-144.
12. Khan H, Shafique M, Khan MA, Bacha MA, Shah SU, Calligaris C. Landslide susceptibility assessment using Frequency Ratio, a case study of northern Pakistan. Egypt J Remote Sens Space S 2019;22(1):11-24.
13. Khan AN, Collins AE, Qazi F. Causes and extent of environmental impacts of landslide hazard in the Himalayan region: a case study of Murree, Pakistan. Nat Hazard. 2011 May;57(2):413-434.
14. P. NHA, Data Collection Survey on Road Landslide Measures in Pakistan, vol. Final repo. Citeseer, 2019.
15. Lee S, Talib JA. Probabilistic landslide susceptibility and factor effect analysis. Environ Geol. 2005;47(7):982-990.
16. R. A. K. Tahirkheli, "The India-Eurasia suture zone in northern Pakistan: Synthesis and interpretation of recent data at plate scale," Geodyn. Pakistan, pp. 125–130, 1979.
17. Coward MP, Rex DC, Asif Khan M, Windley BF, Broughton RD, Luff IW,et.al. Collision tectonics in the NW Himalayas. Geological Society, London, Special Publications. 1986;19(1):203-219.
18. Zeitler PK. Cooling history of the NW Himalaya, Pakistan. Tectonics. 1985;4(1):127-151.
19. Gansser A. Geology of the Himalayas.1964.
20. Mughal MS, Zhang C, Du D, Zhang L, Mustafa S, Hameed F, et.al. Petrography and provenance of the early miocene murree formation, himalayan foreland basin, muzaffarabad, pakistan. J Asian Earth Sci. 2018;162:25-40.
21. Neiderer S, Schaffner UR. Landslide problems and erosion control in Murree and Kohat tehsils of Rawalpindi Dist. Results fact-finding Mission. Swiss Dev Coop Minist Foreign Aff Govt Switz. 1989.
22. Chambers AF. Kinematics of the frontal Himalayan Thrust Belt, Pakistan, and the external western Alps, France.
23. Iqbal M, Bannert D. Structural observations of the Margala hills, Pakistan and the nature of the Main Boundary Thrust. Pakistan J Hydrocarb Res. 1998;10:41-53.
24. Niederer S, Wagner A, Khan SR, Rafiq M. Murree erosion control: results of the facts-finding mission. SDC, Minist Foreign Aff Gov Switz. 1989.
25. Wadia DN. The geology of Poonch State (Kashmir) and adjacent portions of the Punjab. Mem Geol Surv India. 1928;51:185-370.
26. Khan MR, Hameed F, Mughal MS, Basharat M, Mustafa S. Tectonic study of the Sub-Himalayas based on geophysical data in Azad Jammu and Kashmir and northern Pakistan. J Earth Sci. 2016;27(6):981-988.
27. Latif MA. Explanatory notes on the Geology of South Eastern Hazara, to accompany the revised Geological Map. Jahrb der Geol. 1970;15.
28. Farooq S, Malik MH. Landslide hazard management and control in Pakistan-a review. 1996.
29. Elkadiri R, Sultan M, Youssef AM, Elbayoumi T, Chase R, Bulkhi AB, et al. A remote sensing-based approach for debris-flow susceptibility assessment using artificial neural networks and logistic regression modeling. IEEE J Sel Top Appl Earth Obs Remote Sens. 2014;7(12):4818-4835.
30. Li Y, Chen J, Zhang Y, Song S, Han X, Ammar M. Debris flow susceptibility assessment and runout prediction: a case study in shiyang gully, Beijing, China. Int J Environ Res. 2020;14(3):365-383.
31. Guzzetti F, Carrara A, Cardinali M, Reichenbach P. Landslide hazard evaluation: a review of current techniques and their application in a multi-scale study, Central Italy. 1999;31(1-4):181-216.
32. Yalcin A. GIS-based landslide susceptibility mapping using analytical hierarchy process and bivariate statistics in Ardesen (Turkey): comparisons of results and confirmations.catena.2008;72(1):1-12.

33.Lee S, Chwae U, Min K. Landslide susceptibility mapping by correlation between topography and geological structure: the Janghung area, Korea. Geomorphology. 2002;46(3-4):149-162.

34.Süzen ML, Doyuran V. A comparison of the GIS based landslide susceptibility assessment methods: multivariate versus bivariate. Environ Geol. 2004;45(5):665-679.

35.Komac M. A landslide susceptibility model using the analytical hierarchy process method and multivariate statistics in perialpine Slovenia. Geomorphology. 2006 Mar 1;74:17-28.

36.Shahabi H, Hashim M. Landslide susceptibility mapping using GIS-based statistical models and Remote sensing data in tropical environment. Sci. Rep. 2015.

37. Basharat M, Shah HR, Hameed N. Landslide susceptibility mapping using GIS and weighted overlay method: a case study from NW Himalayas, Pakistan. Arab. J. Geosci. 2016;9(4):1-9.

38.Nilsen TH, Wright RH, Vlasic TC, Spangle W. Relative slope stability and land use planning in the San Francisco Bay region, California. 1979.

39.Saleem J, Ahmad SS, Butt A. Hazard risk assessment of landslide-prone sub-Himalayan region by employing geospatial modeling approach. Nat Hazards. 2020;102(3):1497-1514.

40.Trinh T, Wu D, Huang J, Luu BT, Nguyen KH, Le HQ. Application of the analytical hierarchy process (AHP) for landslide susceptibility mapping: A case study in Yen Bai province, Viet Nam. 2016.

41. Kavzoglu T, Kutlug Sahin E, Colkesen I. An assessment of multivariate and bivariate approaches in landslide susceptibility mapping: a case study of Duzkoy district. Nat Hazards. 2015;76(1):471-496.

42.Fressard M, Thiery Y, Maquaire O. Landslide susceptibility assessment by logistic regression in the Pays d'Auge plateau (Normandy, France): improvement of a procedure in a hilly valley context. In European Geosciences Union General Assembly. 2011.

43.Yesilnacar E, Topal TA. Landslide susceptibility mapping: a comparison of logistic regression and neural networks methods in a medium scale study, Hendek region (Turkey). Eng. Geol. 2005;79(3-4):251-266.

44.Pradhan B. Use of GIS-based fuzzy logic relations and its cross application to produce landslide susceptibility maps in three test areas in Malaysia. Environ Earth Sci. 2011;63(2):329-49.

45.Huang Y, Zhao L. Review on landslide susceptibility mapping using support vector machines. Catena. 2018;165:520-529.

46.Nsengiyumva JB, Luo G, Nahayo L, Huang X, Cai P. Landslide susceptibility assessment using spatial multi-criteria evaluation model in Rwanda. Int. J. Environ. Res. Public Health. 2018;15(2):243.

47. Hong H, Chen W, Xu C, Youssef AM, Pradhan B, Tien Bui D. Rainfall-induced landslide susceptibility assessment at the Chongren area (China) using frequency ratio, certainty factor, and index of entropy. Geocarto Int. 2017;32(2):139-154.

48.Bednarik M, Magulová B, Matys M, Marschalko M. Landslide susceptibility assessment of the Kra ovany–Liptovský Mikuláš railway case study. Phys Chem Earth, Parts A/B/C. 2010;35(3-5):162-171.

49.E Brabb EE. Innovative approaches to landslide hazard and risk mapping. 1984.

50.Jia N, Xie M, Mitani Y, Ikemi H, Djamaluddin I. A GIS-based spatial data processing system for slope monitoring. Int Geoinf Res Dev J. 2010;1(4):1.

51. Karimi Nasab S, Ranjbar H, Akbar S. Susceptibility assessment of the terrain for slope failure using remote sensing and GIS, a case study of Maskoon area, Iran. Int Geoinf Res Dev J. 2010;1(3):1-3.

52.Pradhan B. Manifestation of an advanced fuzzy logic model coupled with Geo-information techniques to landslide susceptibility mapping and their comparison with logistic regression modelling. Environ Ecol Stat. 2011;18(3):471-493.

53.Zhang W, Chen JP, Wang Q, An Y, Qian X, Xiang L, He L. Susceptibility analysis of large-scale debris flows based on combination weighting and extension methods. Nat hazards. 2013;66(2):1073-1100.

54.Thomas PG, Doherty PC. The analytic hierarchy. 1980.

55.Saaty TL. Decision making with the analytic hierarchy process. Int J Serv Sci. 2008;1(1):83-98.

56.Kolat C, Ulusay R, Suzen ML. Development of geotechnical microzonation model for Yenisehir (Bursa, Turkey) located at a seismically active region. Eng. Geol. 2012;36-53.

57. Chen CY, Lee WJ. Topographic features and the initiation of debris flows. 2010.

58.Malczewski J. GIS and multicriteria decision analysis. 1999.

59.Saaty TL. What is the analytic hierarchy process?. 1988.