Advanced Geomatics
http://publish.mersin.edu.tr/index.php/geomatics/index
e-ISSN: 2791-8637

Landslide Risk Assessment using Geo-spatial Technique: A study of District Abbottabad, Khyber Pakhtunkhwa, Pakistan

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Keywords

Landslides,
Risk,
GIS,
Remote Sensing,
Weighted overlay,
Zonation.

Research Article

Received : 07.04.2023
Revised : 08.08.2023
Accepted : 12.09.2023
Published : 30.09.2023

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Abstract

The study focused on identifying the causes and landslide-prone areas in Abbottabad District of Northern Pakistan. Remote sensing data, including NASA's Shuttle Radar Topographic Mission's (SRTM) Digital Elevation Model (DEM) and Landslide-8 imagery, were used in combination with geographic indices to identify the factors of landslides, such as slope, aspect, elevation, vegetation cover, hydrology, SAVI, and land cover change. The weighted overlay technique was used to assign weights to map layers and find the risk zones in the study area. The study revealed that the region is at risk of landslides due to high rock, sloppy areas, and built-up expansion. The major cluster of landslide risk is in the western and southern parts of the region, which are also more populated. The results and landslide susceptibility maps can be used to better understand the existence of landslides and for mitigation purposes, but field surveys are necessary for better predictions. Overall, the study provides valuable information for relevant authorities to prioritize landslide mitigation efforts in the region.

1. Introduction

Landslides can have devastating effects on both the natural environment and human settlements (El-Rabbany, 2016). They can result in loss of life and property damage, disrupt transportation and communication networks, and cause long-term environmental damage (Lynn, 2006). Therefore, it is important to understand the factors that contribute to landslides and to develop strategies to mitigate their impact (Schuster et al., 1986; Phillips et al. 2021). In addition to deforestation and excessive water, other factors that contribute to landslides include steep slope angles, weak or unstable rock or soil, seismic activity, human activities such as construction or mining, and natural processes such as erosion and weathering (McColl ,2022; Jindal et al. 2023). Landslides can also be triggered by a combination of factors, such as heavy rainfall following a period of drought (Shi Min, 2015).

There are several methods for predicting and mitigating landslides, including geological mapping, slope stabilization techniques, and early warning systems (Ju et al. 2020). Prevention strategies can include maintaining natural vegetation cover, controlling erosion, limiting development in high-risk areas, and implementing appropriate land-use planning and zoning regulations (Javed, 2019; Cherkez et al. 2021). The use of GIS and RS in landslide risk assessment and management has become increasingly common in recent years, as these tools provide a powerful means of analyzing large volumes of spatial data and identifying areas at high risk of landslides (Conners, 2019; Deaana, 2019; Thigale, 2006; Tarun, 2019; Sonia, 2017)). Remote sensing data from satellites such as Landsat 8 can be used to generate high-resolution imagery and elevation data, while GIS software can be used to process and analyze this data to identify potential landslide risk factors such as slope,

Cite this;

Gull, A., Liaqut, A. & Mahmood, S. (2023). Landslide Risk Assessment using Geo-spatial Technique: A study of District Abbottabad, Khyber Pakhtunkhwa, Pakistan. Advanced Geomatics, 3(2), 47-55.

aspect, soil type, and land use (Dai and Lee, 2001). Various statistical models have also been developed to predict landslide occurrence based on these risk factors, including logistic regression, artificial neural networks, and fuzzy logic. These models can be used to generate landslide susceptibility maps, which can be used by local authorities to inform decision-making and policy planning efforts related to disaster management (Clerici et al., 2002; Akgun and Serhat, 2008).

The northern area of Pakistan, with its rough terrain, heavy rainfall, and seismic activity, is particularly susceptible to landslides, which can have significant impacts on the local economy and society. Therefore, it is essential to identify areas at high risk of landslides and take appropriate mitigation measures to reduce the potential impacts. Landslides are a significant geological hazard in mountainous regions, and their occurrence is influenced by a variety of factors. It is important to understand and address these factors to minimize the impact of landslides on both the natural environment and human settlements (Akbar, 2011). This aims to assess landslide risk in the study region using GIS indices and other causative factors. The resulting landslide susceptibility map will be a valuable resource for local government authorities to help inform their decision-making and policy planning efforts related to disaster management in the region. Overall, the use of GIS and RS in landslide risk assessment and management is an important tool for reducing the potential impacts of landslides on human settlements and infrastructure.

2. Materials and Methods

2.1. Study Area

Abbottabad District has been selected as study area that lies between latitude of 34°10'7.5"N and a longitude of 73°13'17.39"E in Khyber Pakhtunkhwa (Figure 1). This district is dominated by the mountains and hills and Kunhar and Jhelum rivers enters Abbottabad District from the North so that center of region is still marshy (SEMDA, Abbottabad Development Authority). The climate of Abbottabad is temperate with an average minimum temperature 0.5°C and maximum temperature 13.2°C. (PMD, 2019). This region has been frequently or severely affected by the land sliding due to moderately soil erosion as a result of heavy snowfall and frequent rains.

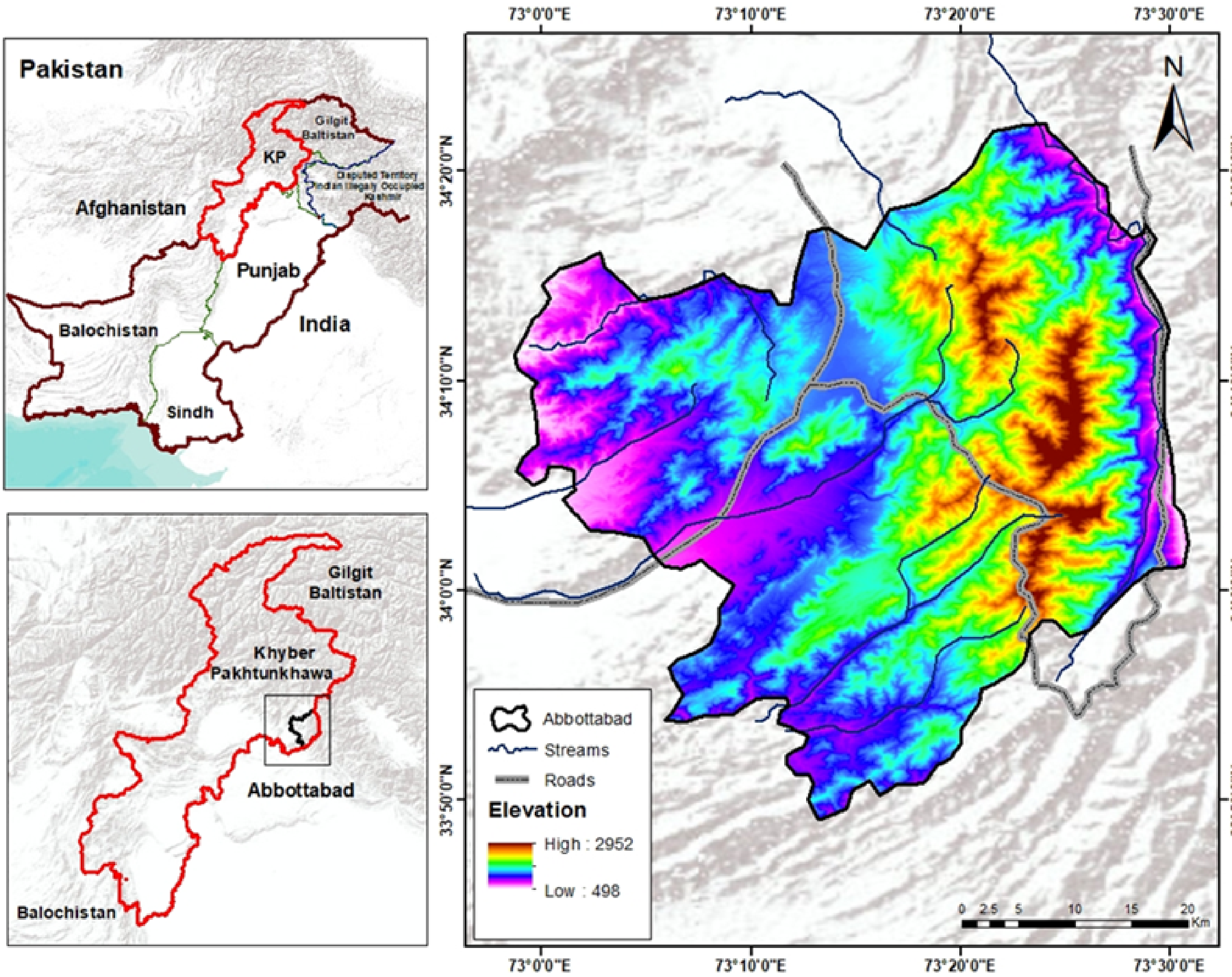

Figure 1. The experimantal setup.

2.2. Data Sources

The selected input parameters for landslide risk assessment were elevation, slope and aspect. The spatial layers of these parameters were extracted from Shuttle Radar Topography Mission (SRTM) based DEM having 30m spatial resolution. As suggested by Lee et al. (2004), Geological structures and formations also influence the genesis of landslide, were digitized using Geological map acquired from Geological Survey of Pakistan (GPS). Satellite images of Landsat 8 (06 July, 2022) were acquired from Earth Explorer open source geo-database. Supervised image classification was applied to extract the land cover classes as suggested by Siraj et al. (2023) and Saleem and Mahmood (2023).

Normalized difference water index (NDWI), Normalized difference vegetation index (NDVI) and Soil adjusted vegetation index (SAVI) were combined in GIS environment to form landslide catalog to carry out landslide hazard assessment after (Nefeslioglu et al., 2008). The most commonly used indices are NDVI is used for vegetation cover density (Javed, 2007). The NDWI is used to determine the presence of moisture in soil cover. Higher NDWI values indicate sufficient moisture, while a low value indicates water stress (Javed, 2019). SAVI is used in the adjustment of the Normalized Difference Vegetation Index to correct for the effect of soil intensity when vegetative cover is little (Clerici et al., 2002). Variations in land cover control the spatial distribution of landslides along with other conditioning parameters (Malek et al., 2015).

Generally, vegetation tends to resist the erosion process whereas bare rock or soil is more susceptible to slope failure. Slope angle is an important geomorphic factor responsible for initiation of slope movements, to be considered for preparation of landslide susceptibility maps. Steep slopes are more susceptible to failure as compared to gentle ones. The Abbottabad district demonstrates variation in topography ranging from steep to gentle slopes, high plains to narrow gorges and high cliffs (Evans, 1980). Therefore, slope, aspect, geological map and different calculated indices of the study area were required to prepare risk map.

2.3. Landslide Hazard Zonation

Weighted overlay analysis is a common technique used in GIS (Geographic Information Systems) to combine and analyze multiple spatial datasets. In this approach, different layers or indices are assigned weights based on their relative importance or contribution to the final output. The weighted sum raster is then generated by adding up the weighted values of each layer at each location in the study area. This approach allows for the integration of different factors or variables that may influence a hazard or risk and helps to identify areas that are more susceptible or vulnerable to the hazard.

For creating landslide hazard map using a weighted overlay analysis approach was applied. The different indices such as NDVI, NDWI, SAVI, land use/land change, slope, and aspect were used to classify and assign weights to them based on their importance (Table 1). The weights were then used in the weighted overlay analysis to create a susceptibility map. The final weighted sum raster was created using the weighted sum overlay tool, and the raster was then divided into five different hazard zones using the equal interval method based on judgment.

Table 1. Factors Ranks

Sr No.	Factors	Ranks
1	Slope	20
2	Aspect	10
3	Elevation	10
4	Land Cover	20
5	Normalized Difference Vegetation Index (NDVI)	10
6	Normalized Difference Water Index (NDWI)	20
7	Soil Adjusted Vegetation Index (SAVI)	10

3. Results and Discussion

It is important to identify potential landslide-prone areas in advance in order to reduce the damage caused by this natural hazard. To prepare a landslide hazard zonation map, all the major factors that play a vital role in landsliding should be taken into account. The resulting map can then be used to estimate the vulnerable area and the potential impact of any future landslide event. The detail is given in the following sections.

3.1. Causative Factors

3.1.1 Slope and Aspect

Slope and aspect play an elementary role in material flow as slope provides speed and aspect indicates the direction of that steepness. Figure 2 indicates the slope angles from 9.177 to 57.08. The highest slope angles are most favorable for landslide. Slopes with different aspects differ in solar radiation intensity, which affects a multitude of factors, including temperature difference, evaporation capacity, vegetation cover.

Map of aspect indicated the total range of the values between -1 to 359. 85 (Figure 3). The highest and lowest value that show the western and eastern zones of the region. The value of aspect shows the flow of land sliding is worst throughout the wet season.

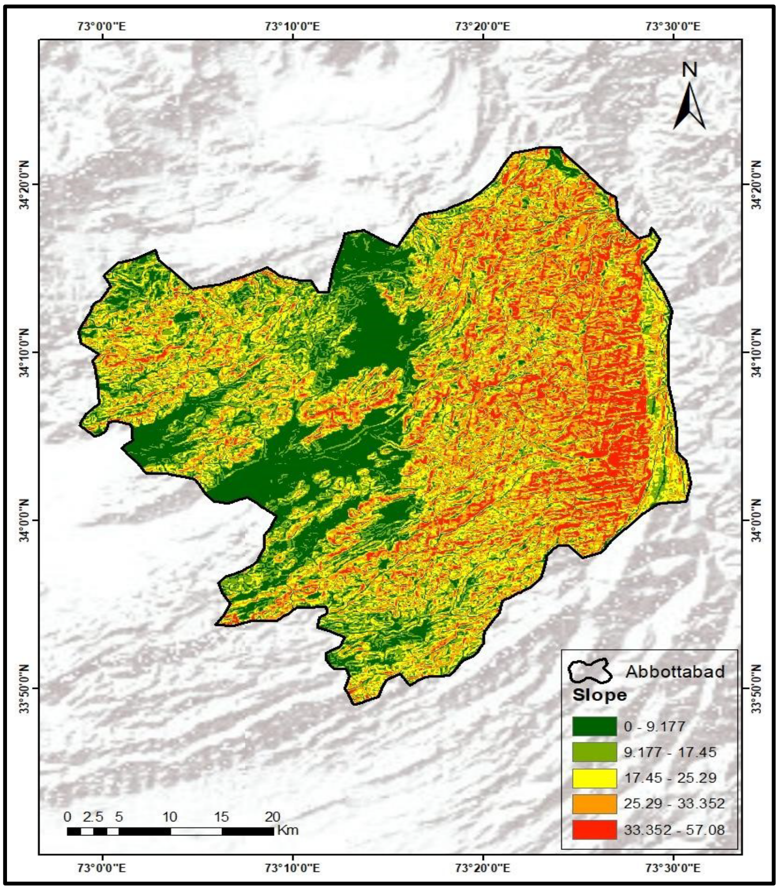

Figure 2. Slope of Abbottabad District.

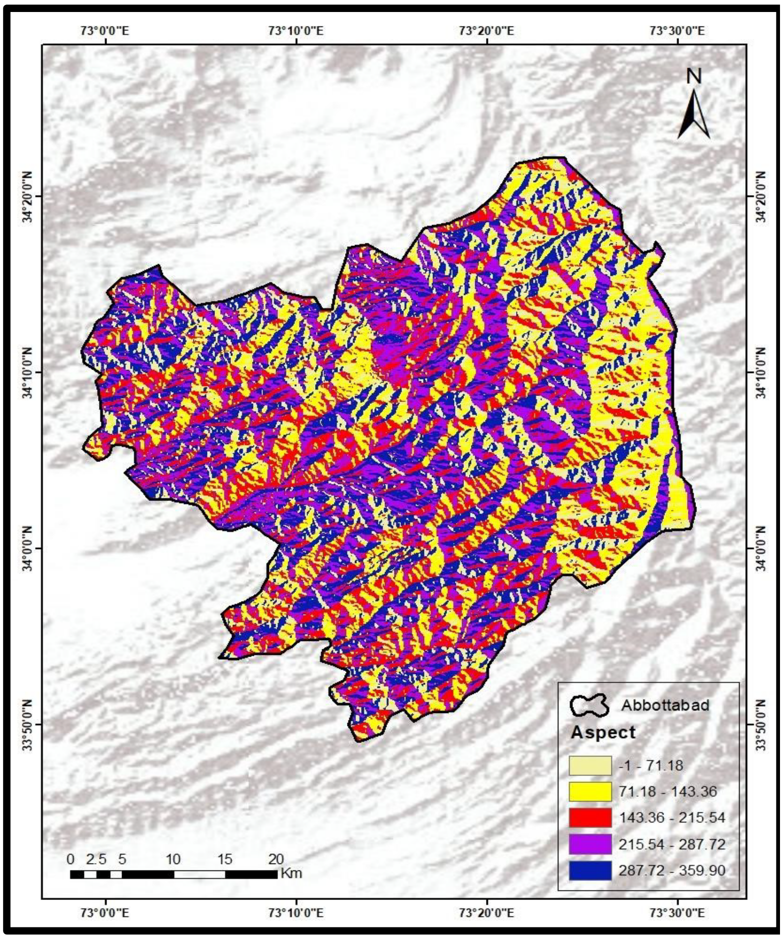

Figure 3. Aspect of Abbottabad District

3.1.2 Geology

Further, geology, is important in term of earth structure of Abbottabad district shown in Figure 4. Generally, the structure in this area are developed as a result of compression and the entire zone is part of the Lesser Himalayas. Khairabad Fault runs across the Abbottabad Block which trends in northeast-southwest direction. Mostly NE-SW trending folds are present, which have been disturbed by dip-slip faults. Stratigraphy of this region ranges from Infra Cambrian to Mio-Pliocene. The whole study area consists of different kind of sedimentary rock that is less resisting against earthquake and other earth movements. Southern side made of Paleogene and cretaceous sedimentary rock and northern side mostly comprised of meta-sedimentary rocks (Jaffery C, 2015).

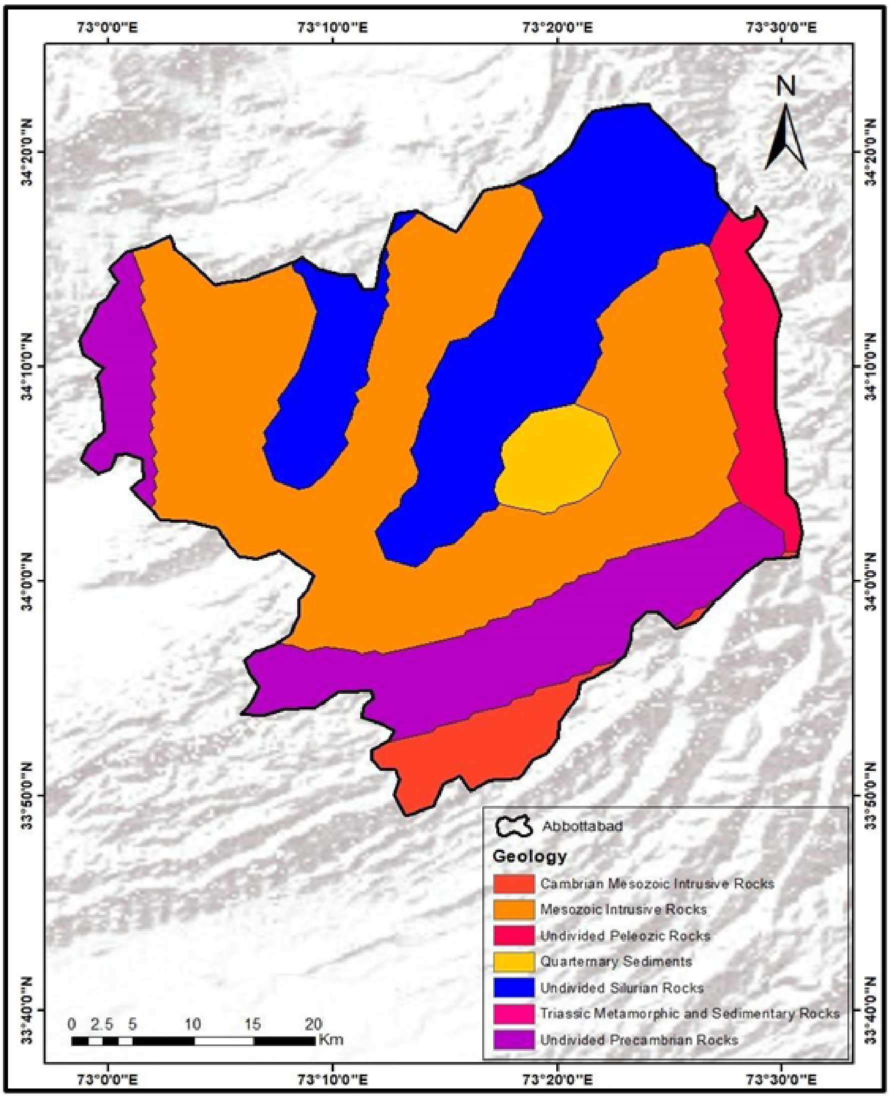

Figure 4. Geological Map of Abbottabad District

3.1.3. Indices

Figure 5 indicate the values of NDVI in the study area, there is observable change in vegetation cover the value ranges from -0.07 to 0.42. The minimum value -0.07 to 0.16 of Normalized Difference Vegetation cover was found in the northeast to southeast and central part of the study area. The probability of landslide occurrence in that part of region is relatively high as the higher values 0.42 shows the richer and healthier vegetation in region. Study area has many small tributaries and receive high rainfall in both season (summer and winter) so, in figure 6, the maximum value of NDWI 0.13 shows the higher probability of landslide occurrence in the whole region. while, minimum value -0.22 shows the low water content where the possibility of landslide occurrence is low. Figure 7 illustrates the soil brightness in the study area where vegetation low. The SAVI index is found to be a significant footstep that can refer to active soil-vegetation systems from remotely sensed data. The maximum value 0.04 shows the high intensity of soil and minimum value -0.11 shows the low intensity of soil in the region.

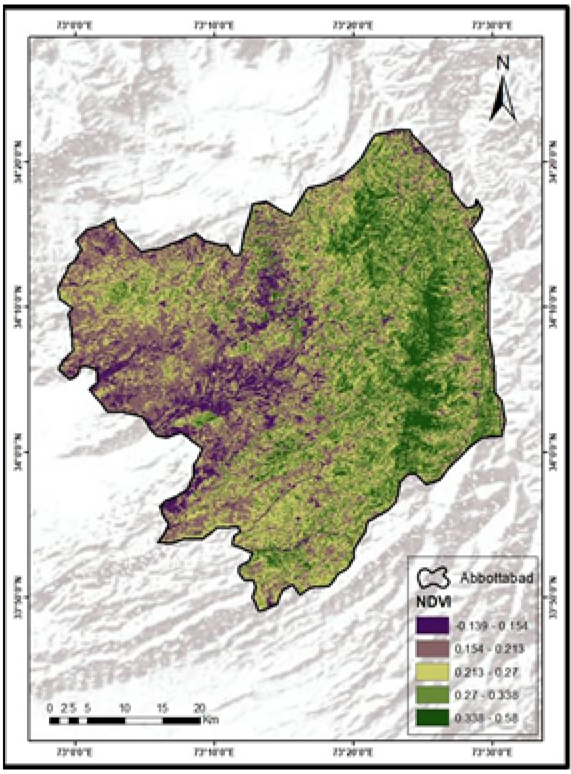

Figure 5. NDVI map of Abbottabad District

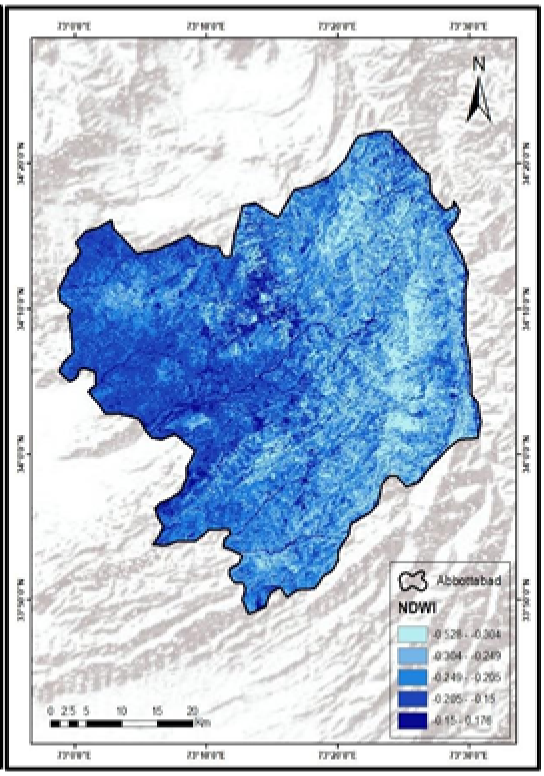

Figure 6. NDWI Map of Abbottabad District

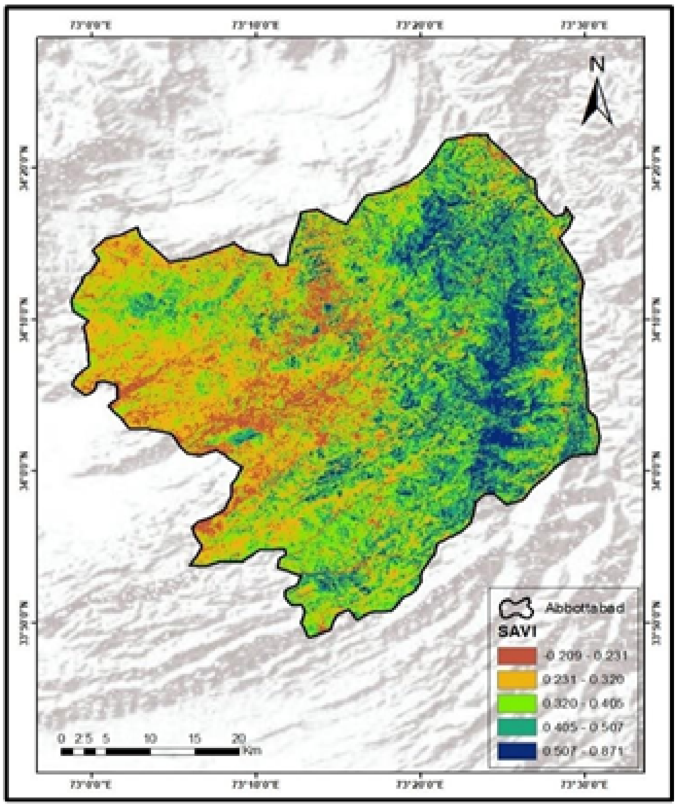

Figure 7. SAVI of the Abbottabad District

3.1.4. Land Cover

Variation in land cover control the spatial distribution of landslides along with other conditioning parameters which includes Vegetation, slope, hydrology. Changes in land cover influence the hydrological condition of slopes, leading to slope instability. Figure 8 shows the variation in Land Cover in the study area. The red shade in central part of the region indicates the built up surrounded by rocks and vegetation. The blue color in the region indicates the water and pink color shows which composed of bare Soil. Green color indicates the vegetation cover in study area.

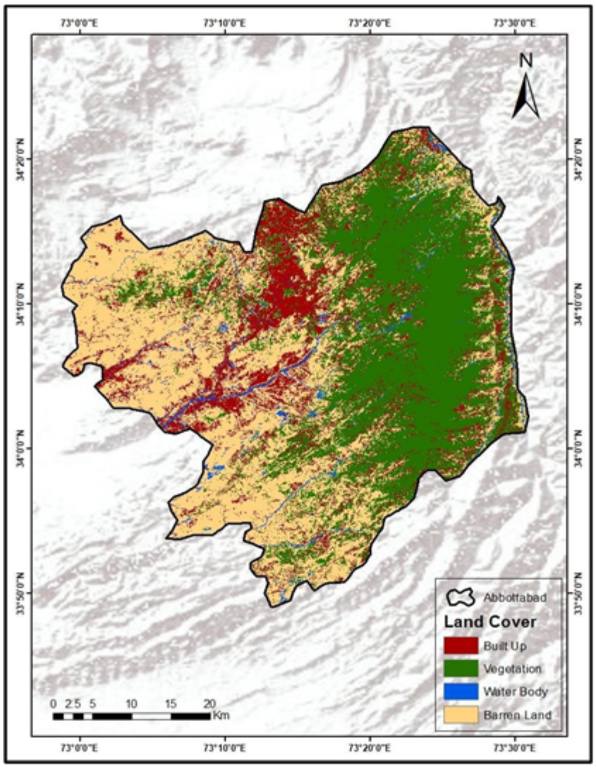

Figure 8. Land Cover of Abbottabad District

3.1.5. Risk Zonation

All above indices maps of study area were needed to mapped the final risk zonal map.

LSI (Landslide susceptibility index) in ArcGIS was a very dominant method used to allocate weight to six parameters. All were reclassified and assigned equal weights in percentages mention in table 1. The result of landslide risk zone mapping was used to detect the landslide prone areas in Abbottabad District. Figure 9 plainly show the landslide high risk areas in western part of the study region, that are the areas less vegetation, high water content and exposed soil. As far as geological structure, whole area made-up of meta-sedimentary rocks that are less resisting rocks against earth movement. The map was divided into five regions are shown in the Table 2 that show the landslide susceptibility index values (Figure 9).

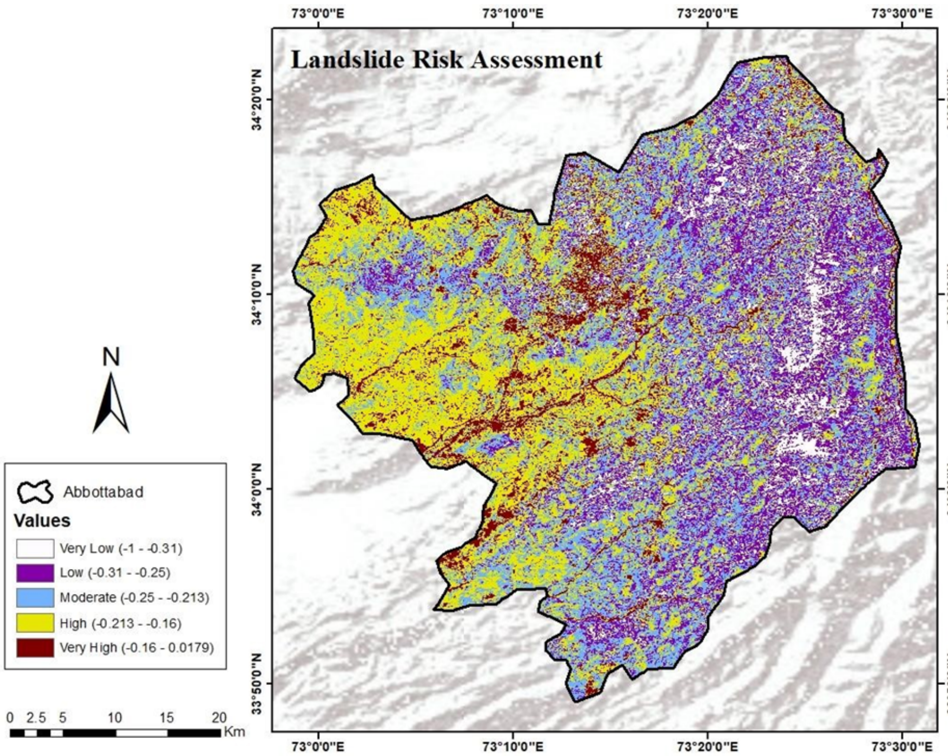

Figure 9. Landslide risk Zonation in Abbottabad District

4. Discussion

It is evident that landslides pose a significant threat to population and development in mountainous regions, particularly in developing countries like Pakistan. The unavailability of longer and precise rainfall and landslide records, along with under-reporting of landslide damages, is a significant problem in determining landslide risk in the region. However, recent studies have employed Remote Sensing and GIS techniques like the weighted overlay method to detect landslide hazard areas and create landslide risk maps.

Studies like Batool (2021) and Javed (2019) have highlighted the need for comprehensive research on various aspects of landslides in Pakistan and have provided valuable insights into the causes and consequences of landslides in the region. The use of science in risk assessment and risk management, along with embedding landslide studies within a sociopolitical framework, has resulted in a new paradigm for landslide risk assessment and management.

Creating landslide risk maps is an important step in understanding and mitigating the potential danger in specific areas. By identifying vulnerable areas, relevant authorities can prioritize mitigation efforts and take steps to protect local communities from potential landslides. During western depression and monsoon seasons, when landslides are more likely to occur, it is especially important to prioritize efforts to mitigate the risk in vulnerable areas and to ensure that local communities are relocated to safe zones. This can help to prevent loss of life and property damage caused by landslides.

In addition to the above recommendations, it is also important to establish a comprehensive landslide risk management plan for the identified vulnerable areas in Abbottabad District. This plan should involve various stakeholders, including local communities, government authorities, and disaster management departments, to ensure a coordinated effort in reducing the risk of landslides. The plan should also prioritize the implementation of measures such as slope stabilization, land-use planning, and early warning systems. Public awareness campaigns should also be conducted to educate the local communities about the risks associated with landslides and the measures they can take to reduce their vulnerability. Finally, continued research and monitoring of the landslide risk in the region is necessary to update the risk management plan and improve the accuracy of the landslide susceptibility map.

Overall, such a study is crucial for understanding the vulnerability of human lives and for taking appropriate measures to reduce the impact of landslides. By identifying potential landslide-prone areas and high-risk zones, it is possible to implement mitigation strategies that can save lives and reduce property damage in the event of a landslide.

5. Conclusion

The study's conclusion highlights the importance of understanding landslide susceptibility in order to prevent and reduce the risk of landslides. The use of GIS and thematic data layers to produce a landslide susceptibility map for the Abbottabad District provides valuable information for engineers, geologists, and land use planners to make informed decisions about future construction and development in the region. More research is needed to understand landslide effects in the region, the use of Remote Sensing and GIS techniques and the creation of landslide risk maps can aid in landslide risk assessment and management efforts in Pakistan.

The identification of the western and northwestern parts of the region as high and very high susceptible zones is particularly important for decision-making regarding future construction and development. These areas should be avoided or require careful geotechnical investigation before any development takes place.

The study's recommendation for further research on the gender distribution of the population and the type of landslide could improve the accuracy and specificity of the susceptibility map, and thus increase the effectiveness of mitigation efforts. Additionally, the study highlights the potential for early warning systems to mitigate the effects of landslides and encourages investment in mitigation efforts by society and technologists.

Author contributions

Anum Gull: Data curation, Writing-Original Draft Preparation, Validation, Control and Validation
Anum Liaqut: Conceptualization, Methodology, Software, Data curation, Writing, Visualization
Shakeel Mahmood: Investigation, Software

Conflicts of interest

There is no conflict of interest between the authors.

Statement of Research and Publication Ethics

Research and publication ethics were complied with in the study.

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