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# Geo-Visualization of Debris Flow Susceptibility in District Chitral, North-West of Pakistan

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Debris flows are a recurrent environmental hazard in hilly regions and significantly impact socioeconomic development in Pakistan. This study aims to conduct debris flow risk zonation using remote sensing data, including NASA's Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) and Landsat-8 imagery. These data were combined with geographic indices to identify debris flow factors such as slope, aspect, elevation, vegetation cover, and land cover changes like NDWI and NDVI. The weighted overlay technique was employed to achieve the study's objective in the target area. The classes were ranked from most to least favorable, with numerical weights assigned based on each factor's importance in debris flow occurrence. A composite map was then developed using the weighted overlay analysis to represent the significance of each factor. The resulting debris flow risk zonation map categorized the area into four classes: very high-risk, high-risk, moderate-risk, and low-risk zones. The villages located in the very high-risk zone include Mulkoh, Mastuj, Reshun, Shegram, Terich Gol, Rogar, Asurat, Boni, Brep, and Rech Tockhow, which have been frequently affected by hazards over the past decade. While the results and landslide susceptibility maps provide valuable insights for understanding landslides and planning mitigation measures, field surveys are essential for more accurate predictions. Overall, the study offers important information for authorities to prioritize landslide mitigation efforts in the region.

**Keywords:** Debris Flow, Chitral, Weighted Overlay Analysis GIS, Risk, Remote Sensing.

## Introduction:

Debris flows are typical natural hazards triggered by intense rainfall or snowmelt in mountainous areas, often causing significant losses [1]. Even localized debris flow events can lead to widespread and prolonged disruptions, particularly on transportation routes. The Sichuan-Tibet Highway, a major connection between the mainland and Tibet, is prone to debris flow disasters due to its unique geographical and geological environment [2][3][4]. Risk assessment, an important technique for hazard mitigation, provides valuable information for decision-making and administration [5][6]. Pakistan is susceptible to physical and hydro-meteorological disasters [7], with debris flow being one of the natural disasters that result in human losses and damage to property and infrastructure [7]. The magnitude and frequency of debris flows have increased due to more frequent torrential rainfall events. In 2016, disastrous debris flows occurred with varying effects due to differences in topography, surface lithology, land cover, and population density [8]. Heavy rainfall is a major factor in triggering debris flow, which is a geomorphic event closely related to slope and stream channels [9].

Debris flow risk reduction has been a significant topic of research globally. Various models have been used, and contemporary studies continue to employ multiple experimental approaches to assess risk and calculate debris flow intensities and magnitudes [10]. Risk refers to the negative impacts that cause substantial losses from natural or human-induced hazards. Modern risk reduction analysis evaluates the impact of hazards on the environment, considering event occurrence, elements exposed to risk, the level of damage, population at risk, and the cost of goods in the affected area [11]. The impacts of risk are categorized into primary, secondary, and tertiary effects [12]. Over the last decade, the incidence of natural hazards has increased worldwide, largely due to urbanization and climate change, with metropolises being especially vulnerable [13]. Debris flow, commonly occurring in hilly areas, often happens abruptly with high velocity, posing life-threatening risks. It is also one of the least predictable natural hazards [14], typically originating in steep gullies or hilly regions and often occurring in severe weather conditions. Debris flow is also known as mudflow [15].

Debris flow involves the rapid downslope movement of large masses of debris, driven by water, sediment, and slope gradient. There are two types: confined debris flows, which occur in indented channels and may evolve into avalanche slides, and unconfined debris flows, which occur in non-scored channels with sparse vegetation [16]. Debris flow triggers can be classified into preliminary factors (e.g., slope failure, extreme weather, weak rocks, low vegetation) and activating factors (e.g., intense rainfall, earthquakes, high groundwater levels) [17].

Pakistan frequently experiences disasters that cause human, economic, social, and environmental losses. The years 2005, 2007, 2009, 2010, 2011, 2012, 2014, 2017, and 2022 were particularly unfortunate in its history. Khyber Pakhtunkhwa has been affected by flash floods, avalanches, earthquakes, and internal displacement, with Chitral being especially vulnerable to flash floods, debris flows, avalanches, and earthquakes [7]. Since 2007, the frequency of avalanches has increased [18], and recent studies show that floods and debris flows are the two most active hazards in Chitral [19]. This increase in frequency is linked to climate change [20]. This paper assesses debris flow hazards in Chitral, located in the eastern Hindu Kush of northwest Pakistan. Geological, hydrometeorological, and topographic analyses were conducted to identify debris flow triggers. Globally, societies have faced hazardous events for as long as civilization itself [21], and debris flows remain a significant threat to human life, property, infrastructure, and hilly regions [22]. Debris flows cause extensive damage and loss worldwide, with one global survey reporting 213 debris flow events between 1950 and 2011, resulting in 77,779 fatalities. According to the Center on Epidemiology of Disasters, landslides alone account for 17% of global fatalities. The median number of people affected by debris flows is 165, with South America and Asia having the highest median, highlighting the vulnerability of developing countries to these hazards due to poverty, weak governance, and corruption [23].

One study compared historical data from two debris flows in adjacent, unburned basins in the San Bernardino mountains of Southern California and concluded that larger basins produce more water-enriched and higher-velocity debris flows [24]. Another study documented 3,290 debris flow events in Sichuan province, southwestern China, recognizing the spatiotemporal distribution of debris flows. Using meteorological and topographical data, the province was categorized into "slight," "moderate," and "very severe" regions concerning debris flows [25]. Pakistan's location along plate boundaries makes it highly vulnerable to natural hazards, including earthquakes, floods, landslides, and waterlogging. In the last three decades, geological factors, climate change, and urbanization have been major contributors to natural hazards, affecting about 75% of households in Pakistan [26].

Multi-Criteria Analysis (MCA) is a recent method employed by researchers to assess hazards using a multi-criteria approach. The main purpose of MCA is to create vulnerability maps for risk reduction. MCA studies focus on causative factors, including natural triggers like rainfall, geology, slope, aspect, earthquakes, land use, and land cover. Slope influences debris flow speed, while land use and land cover determine the extent of damage, with vegetated areas being less vulnerable. Land use and cover are categorized into five classes: forest, agricultural, barren, built-up, and water areas. Precipitation is another key trigger for debris flow [27]. Although debris flows are difficult to predict, several techniques, including regression analysis, GIS methods, artificial neural networks, mathematical calculations, and similarity-based hazard assessments, offer platforms to forecast debris flow events and develop early warning systems.

Debris flow risk assessments often use frequency-magnitude analysis, consequence analysis, and numeric scenario modeling to gauge the severity of debris flow events. Quantitative Risk Assessment (QRA) is a recent technique for evaluating landslide risk, first used in Hong Kong. GIS methods are also commonly used in risk assessments. The debris flow hazard assessment framework is a valuable tool for researchers and engineers in risk reduction and mitigation planning.

Geohazards in the Karakoram have been the subject of several studies, but the neighboring eastern Hindu Kush remains largely unexplored due to its inaccessibility. Initial descriptions of Quaternary sediments in the region were provided by early researchers, but most subsequent studies focused on reconstructing the glacial history of the region. Quaternary terraces in the Chitral valley were analyzed in terms of their origin and stratigraphic relationships. One study described debris-flow deposits in the eastern Hindu Kush, including a first-hand account of a debris-flow event on August 14, 1975, at Reshun, northeast Chitral. This paper focuses on debris-flow hazards in Chitral, northern Pakistan, and uses "debris-flow" as a term to cover sediment concentrations above 40% by weight, including both debris-flows and debris floods. The paper also presents an assessment of debris flow hazards in district Chitral, eastern Hindu Kush, Pakistan.

## Study Area:

District Chitral is located in northwest Pakistan, extending from 71°2' to 73°8' E longitude and 35°3' to 36°9' N latitude (Figure 1). Chitral, the largest district of Khyber Pakhtunkhwa, lies at the base of Tirich Mir, the fifth-highest peak in the world. Summers in Chitral are hot, with maximum temperatures in the lowlands, while higher elevations remain cool. Spring weather brings mild rainfall and occasional snow, and autumn is generally pleasant. The highest recorded summer temperature in Chitral was 36°C in July. Chitral's livelihood is heavily dependent on agriculture and natural resources, and the Chitral-Mastuj Valley is home to three of the world's largest mountain ranges [28].

The Hindu Kush range extends to the west, the Hindu Raj range to the east, and the Shandur Karakoram range lies in between. The region contains numerous peaks over 20,000 feet. Due to its harsh weather, topography, and geographical location, Chitral is highly susceptible to natural disasters, including flash floods, soil erosion, avalanches, landslides, earthquakes, and droughts. Climate change has exacerbated these issues, with avalanches and flash floods becoming more frequent. According to the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report, global surface temperatures have risen, and Chitral is clearly experiencing these effects. Chitral is one of the highest areas in the Khyber Pakhtunkhwa province, with elevations ranging from 1,094 meters at Arandu to 7,726 meters at Tirich Mir. Tirich Mir is the highest peak in the Hindu Kush, standing at 7,708 meters. The terrain of Chitral is mountainous, with forests covering about 4.8% of the land [19].

The climate in Chitral is temperate, with winter rains caused by western disturbances occurring between December and March. The mean annual temperature is 16°C, with minimum average temperatures of 8°C and maximum averages of 24°C. Winter temperatures often fall below freezing. The district receives 451 mm of annual rainfall, with heavy snowfall in the surrounding mountains during winter [29][30].

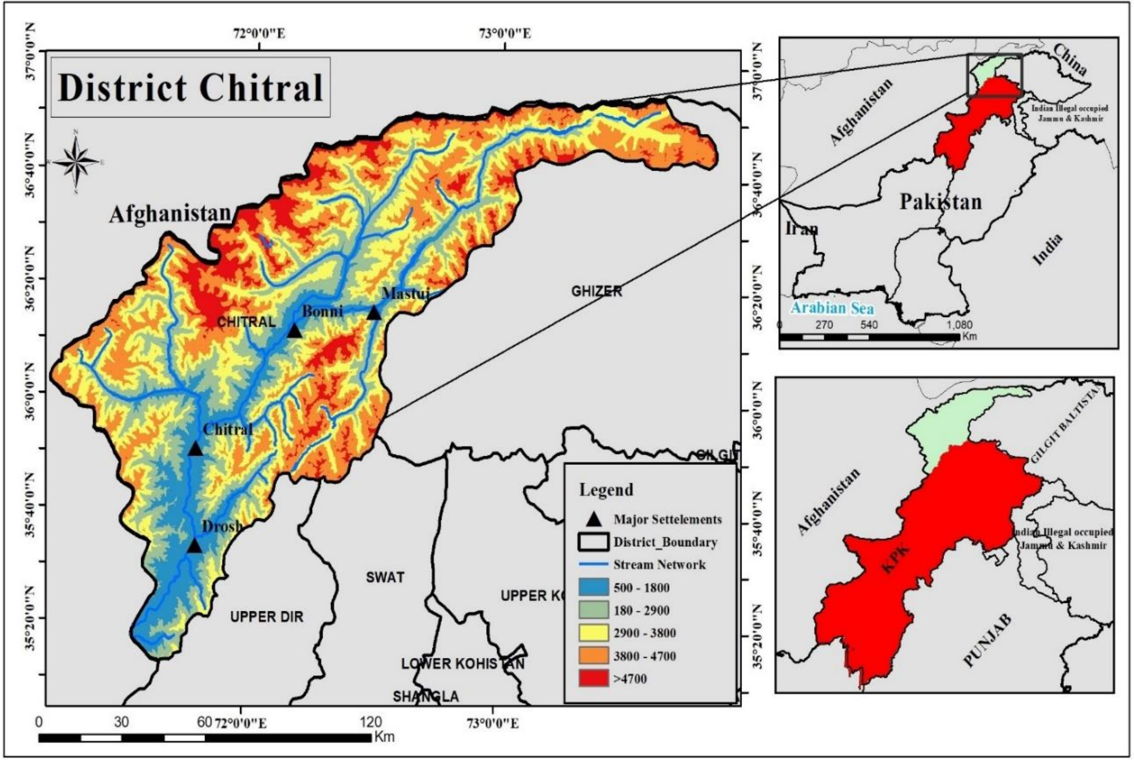

**Figure 1:** Location of Study Area

**Research Methodology:**

The following methodology was adopted to achieve the objectives of this research. The selected variables for the study included precipitation, geology, slope, aspect, curvature, earthquake activity, land use, land cover, distance from roads, and distance from fault lines. Meteorological data were collected from multiple sources to ensure accuracy.

**Data Source:**

The key input parameters for assessing debris flow included elevation, slope, and aspect. Spatial layers for these parameters were derived from Shuttle Radar Topography Mission (SRTM)-based Digital Elevation Model (DEM) with a 30m spatial resolution. Satellite images from Landsat 9 (06 July, 2023) were obtained from the Earth Explorer open-source geodatabase. Supervised image classification was applied to extract land cover classes as suggested in [31]. In GIS, the Normalized Difference Water Index (NDWI) and Normalized Difference Vegetation Index (NDVI) were combined to create a debris flow catalog for hazard assessment. NDVI was used to evaluate vegetation cover density, while NDWI measured moisture levels in soil cover. Higher NDWI values indicated sufficient moisture, while lower values pointed to water stress. Land cover variations, along with other parameters, influence the spatial distribution of debris flow. Generally, vegetation resists erosion, while bare rock or soil is more prone to slope failure. Slope angle is a crucial factor for initiating slope movements and is essential in preparing landslide susceptibility maps. Steeper slopes are more likely to fail compared to gentler ones. Abbottabad district presents varied topography, from steep to gentle slopes, high plains to narrow gorges, and high cliffs. Consequently, slope, aspect, geological maps, and different calculated indices of the study area were essential for risk map preparation.

ArcGIS was employed to digitize satellite imagery. Land use and land cover data were further classified into categories like forest, built-up areas, barren land, water areas, and agricultural land. Precipitation data were interpolated using ArcGIS, and watershed delineation was conducted with ArcGIS 10.8. The watershed delineation was done to calculate slope and aspect for further analysis. Spatial data were prepared to generate a vulnerability map using Multi-Criteria Analysis (MCA) and GIS tools. Watershed delineation was performed using a DEM of Chitral derived from SRTM DEM with a 30m spatial resolution, downloaded from the USGS online geodatabase.

**Evaluating Debris Flow Vulnerability:**

In the second phase, MCA and GIS techniques were applied to evaluate debris flow vulnerability in the area. GIS tools were used to manage, produce, and analyze spatial data. A debris flow vulnerability map was created to identify zones with the highest and lowest risk. The risk zones were classified into four categories: acceptable, moderate, undesirable, and unacceptable.

**Weight Overlay Analysis:**

Weighted overlay analysis is a common GIS technique used to combine and analyze multiple spatial datasets. In this approach, different layers or indices are assigned weights based on their relative importance to the final output. The weighted sum raster is generated by summing the weighted values of each layer across the study area. This method integrates various factors that may influence hazards or risks, helping to identify areas more susceptible or vulnerable. For creating a landslide hazard map, a weighted overlay analysis was applied. Indices like NDVI, NDWI, land use/land cover, slope, and aspect were classified and assigned weights based on their significance (Table 1). These weights were then applied in the weighted overlay analysis to develop a susceptibility map. The final weighted sum raster was divided into four hazard zones using the equal interval method based on expert judgment.

**Table 1:** Debris Flow Causative Factors Weight

| Factors | Factor Classes | Weight of each classes |
|---|---|---|
| **Rainfall (mm)** | <50 | 1 |
| | 50-100 | 2 |
| | 100-150 | 3 |
| | 150-200 | 4 |
| | >200 | 5 |
| **Slope** | 0-5 % | 1 |
| | 5-15 % | 2 |
| | 15-30 % | 3 |
| | 30-55 % | 4 |
| | 55-80 % | 5 |
| **Land use** | Forest | 1 |
| | Agriculture | 2 |
| | Barren land | 5 |
| | Built up | 3 |
| | Water body | 4 |
| **Earthquake** | < 2 Magnitude | 1 |

| | | |
|---|---|---|
| | 2.1-3 | 2 |
| | 3.1-5 | 3 |
| | 5.1-6 | 4 |
| | > 6 | 5 |
| **NDWI** | <0 | 1 |
| | 0 - 0.20 | 2 |
| | 0.20 - 040 | 3 |
| | 0.40 - 0.60 | 4 |
| | >0.60 | 5 |
| **NDVI** | <0 | 1 |
| | 0 - 0.15 | 2 |
| | 0.15 - 030 | 3 |
| | 0.30 - 0.45 | 4 |
| | >0.45 | 5 |
| **Distance to Road (m)** | <50 | 5 |
| | 50-100 | 4 |
| | 100-150 | 3 |
| | 150-200 | 2 |
| | >200 | 1 |
| **Distance to Stream (m)** | <50 | 5 |
| | 50-100 | 4 |
| | 100-150 | 3 |
| | 150-200 | 2 |
| | >200 | 1 |
| **Distance to Fault (km)** | <10 | 5 |
| | 10-20 | 4 |
| | 20-30 | 3 |
| | 30-40 | 2 |
| | >40 | 1 |
| **Aspect** | <50 Flat | 1 |
| | 50 -100 North | 2 |
| | 100- 150 East | 3 |
| | 150-200 South | 4 |
| | >200 West | 5 |
| **Elevation (m)** | <1000 | 1 |
| | 1000-2000 | 2 |
| | 2000-3000 | 3 |
| | 3000-4000 | 4 |
| | >4000 | 5 |
| **Frequency of Events** | <5 | 1 |
| | 5 to 10 | 2 |
| | 10 to 15 | 3 |
| | 15 to 20 | 4 |
| | > 20 | 5 |

**Source: Authors**

**Results and Discussion:** Chitral is a highly active region in Pakistan, vulnerable to life-threatening hazards such as flash floods, debris flows, and avalanches. Studies in Chitral reveal that floods and avalanches are the most frequent and significant hazards affecting the area. Figure 3 illustrates the total number of debris flow events across various villages. The village of Khot has experienced six debris flow events between 1976 and 2021, while Sher Shal faced only one debris flow event. Sher Shal is also known for a significant avalanche event in 2017, which resulted in 9 deaths, 4 injuries, and the complete destruction of 19 houses. Data indicates that Khot is the most frequently impacted village, whereas Sher Shal is the least affected. Golen and Charun rank as the second most affected villages (Table 2).

**Table 2:** Debris Flow Events and Effected Villages

| Sr. No. | Year | No. of Events | Effected Villages |
|---|---|---|---|
| 1 | 1956 | 4 | Breshgram, Ochu, Susum, Brep |
| 2 | 1974 | 3 | Murdan, Madaklasht, Bresgram |
| 3 | 1975 | 3 | Susum, Booni |
| 4 | 1978 | 6 | Mastuj, Akari, Garamchashma, Mardan,Brep, Wajiue |
| 5 | 1982 | 3 | Boroghul, Parwak, Reshun |
| 6 | 1984 | 4 | Parwak, Khot, Domil, Shagram |
| 7 | 1985 | 5 | Sorlaspur, Momi, Terich, Chapali, Gobore |
| 8 | 1988 | 3 | Khot, ReckTorkhu, Gobore |
| 9 | 1990 | 3 | Terich, Warijue,Bresgram |
| 10 | 1992 | 3 | Yarkhoon, Melp, Herchin |
| 11 | 1996 | 4 | Bang, Ochu, Susum, Lone |
| 12 | 2000 | 4 | Ayun, Yarkhoon, Shagram, Bang |
| 13 | 2004 | 5 | Madaklasht, Charun, Chapali, Golen, Khot |
| 14 | 2005 | 15 | Sorlaspur, Momi, Mastuj, |
| 15 | 2006 | 4 | Ashtre, Booni,Brep, Borogul |
| 16 | 2007 | 17 | Begusht,Mardan, SeenLasht, Brep, Bresgram, Morder, |
| 17 | 2011 | 1 | Riri village, Oveer valley, upper Chitral, Churan |
| 18 | 2012 | 1 | Chitral, Mustung, Besti |
| 19 | 2015 | 6 | Rumbur, Bumburet,Barenis, Chityral, Booni, Chitral river,Rashun, Goal Village. Drosh, Sheshi Koh Valley,Green Lasht |
| 20 | 2016 | 2 | Chitral, Gahirat, Arkari |
| 21 | 2017 | 4 | Garam Chashma, Chitral, Rech Valley, Booni,Lowari Tunnel , Traps 14 SAMBU Company Members |

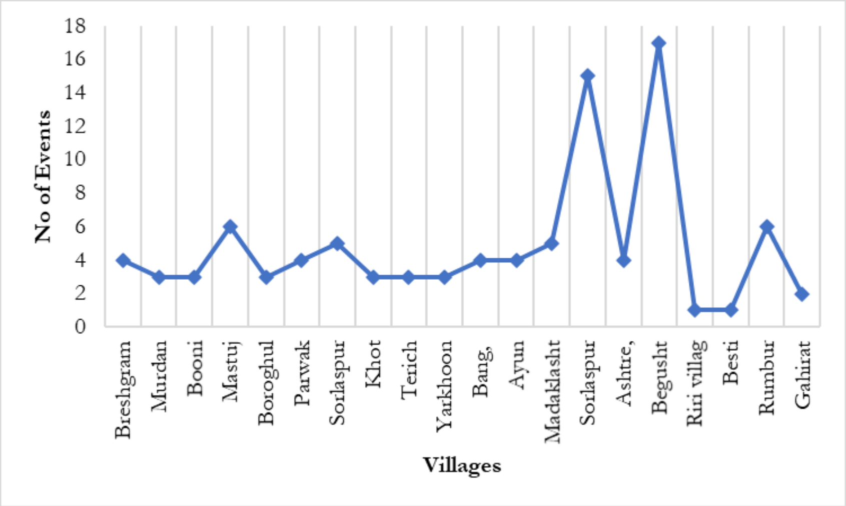

**Figure 2:** Villages with number of events of debris flow

It is crucial to identify potential debris flow-prone areas in advance to mitigate the damage caused by this natural hazard. Figure 2 displays the number of debris flow events in various villages. In preparing a debris flow hazard zonation map, all major factors contributing to debris flows must be considered. This map can then be used to estimate vulnerable areas and predict the potential impact of future debris flow events. The details of these factors are provided in the following section.

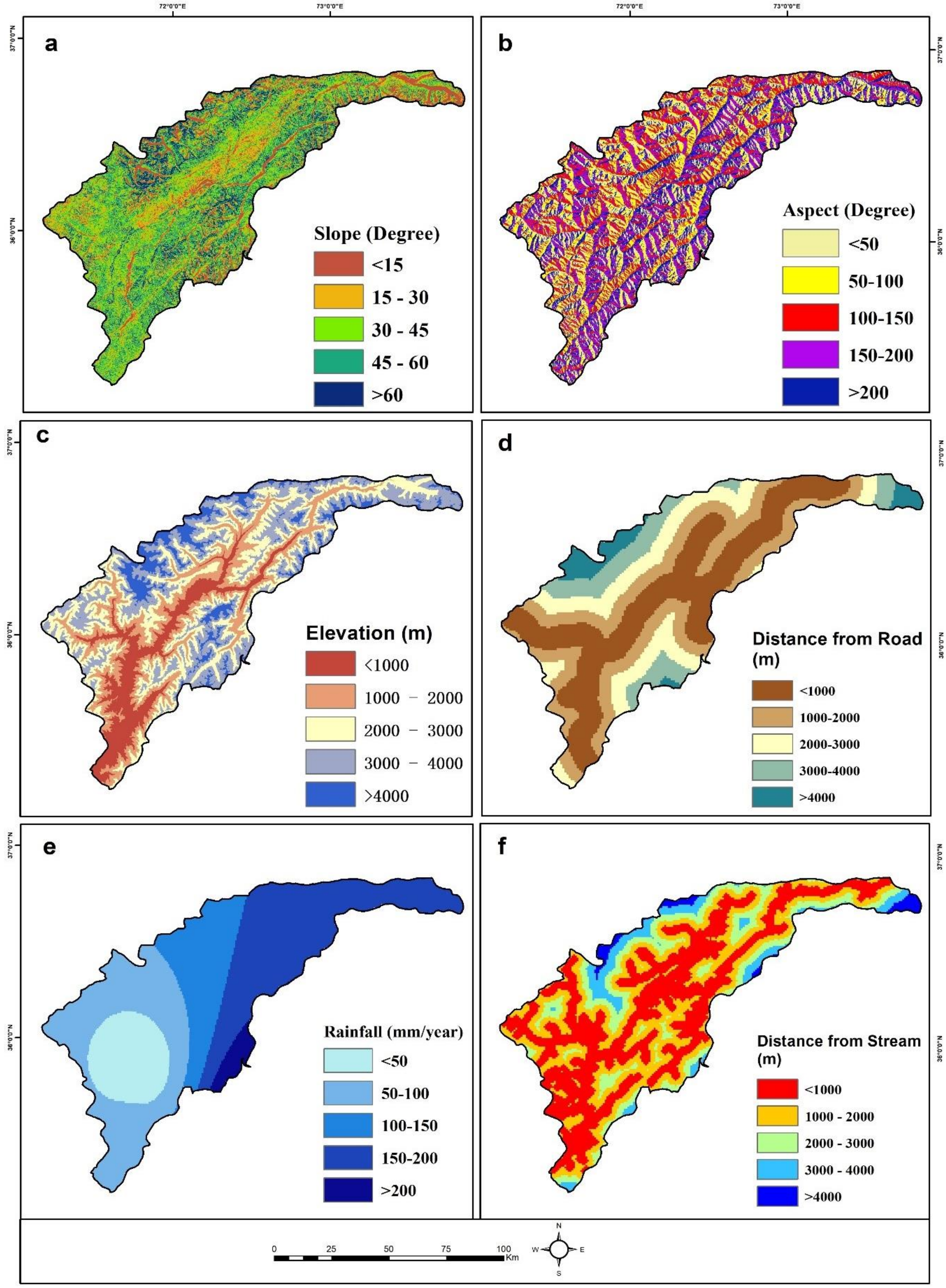

**Figure 3:** Maps of Debris flow conditioning factors: land use (a), slope (b), aspect(c), elevation (d), distance to road (e), Rainfall (f), distance to stream

**Causative Factors:**

The natural causative factors include precipitation, slope, aspect, earthquake, and land use/land cover. Classes were created for each factor, and rankings were applied from 1 to 5, with 1 representing the highest value and 5 the lowest. ArcGIS 10.8 was used to convert this data into GIS layers.

**Rainfall:**

The spatial distribution of rainfall was determined using the spline interpolation method in GIS. Classes were created using the weighted overlay analysis.

**Slope:**

Slope is a critical factor as it determines the speed of debris flow and is expressed as a percentage. The slope classes were generated using the DEM of the study area.

**Aspect:**

Figure 3b shows the aspect map, which indicates that most of the study area has moderate to high aspect values ranging from 50 to 200. This map highlights the slope orientations, where areas with higher aspect values tend to have a greater impact on landslide hazard levels.

**Elevation:**

The elevation map was created by classifying elevation into five categories. The observed elevation ranges from <1000 m to >4000 m. Higher elevations are found in the northern, northeastern, and intermediate southern marginal areas, while the southernmost region has lower elevations, as shown in Figure 3c.

**Distance from Road:**

The proximity of the study area to roads is represented by high-density values of >4000 m in Figure 3m, while the rest of the area shows low-density values of <1000 m. A network of roads passes through the central and southern marginal regions, making these areas the ones with the highest road densities. Slopes near roads are more susceptible to landslides, and the risk decreases gradually as the distance from roads increases.

**Land Use and Land Cover:**

Land use and land cover are crucial factors in debris flow risk assessment. Areas with more vegetation tend to experience less damage. Land use and land cover are categorized into five classes: forest, agricultural area, barren area, built-up area, and water bodies.

**The Normalized Difference Wetness Index (NDWI):**

The NDWI map classifies values between the observed minimum of <0 and the maximum of >0.60. Areas covered by snow, glaciers, or ice show high NDWI values, while the southwestern part of the study area has comparatively low NDWI values, as depicted in Figure 4j.

**Normalized Difference Vegetation Index (NDVI):**

Positive NDVI values, up to a maximum of 0.5 as shown in Figure 3f, indicate healthy vegetation of varying intensities, while negative NDVI values suggest no vegetation. Slopes with dense vegetation are less prone to landslides due to reduced exposure to soil erosion, while areas with little to no vegetation are more vulnerable. Most of the study area exhibits low to moderate vegetation cover.

**Earthquake Activity:**

The entire study area is marked by medium seismic activity. Earthquakes can affect slope stability by causing cracks in rocks, allowing rainwater to seep in, which can eventually lead to rock failure.

**Distance from Fault:** The region contains several faults, as shown in Figure 4h. The fault map is categorized by distance into high fault values of <1000m and low fault values of >4000m. Areas closer to faults are more prone to debris flows and landslides. The northeastern and central parts of the study area have high fault density, increasing the risk in these regions.

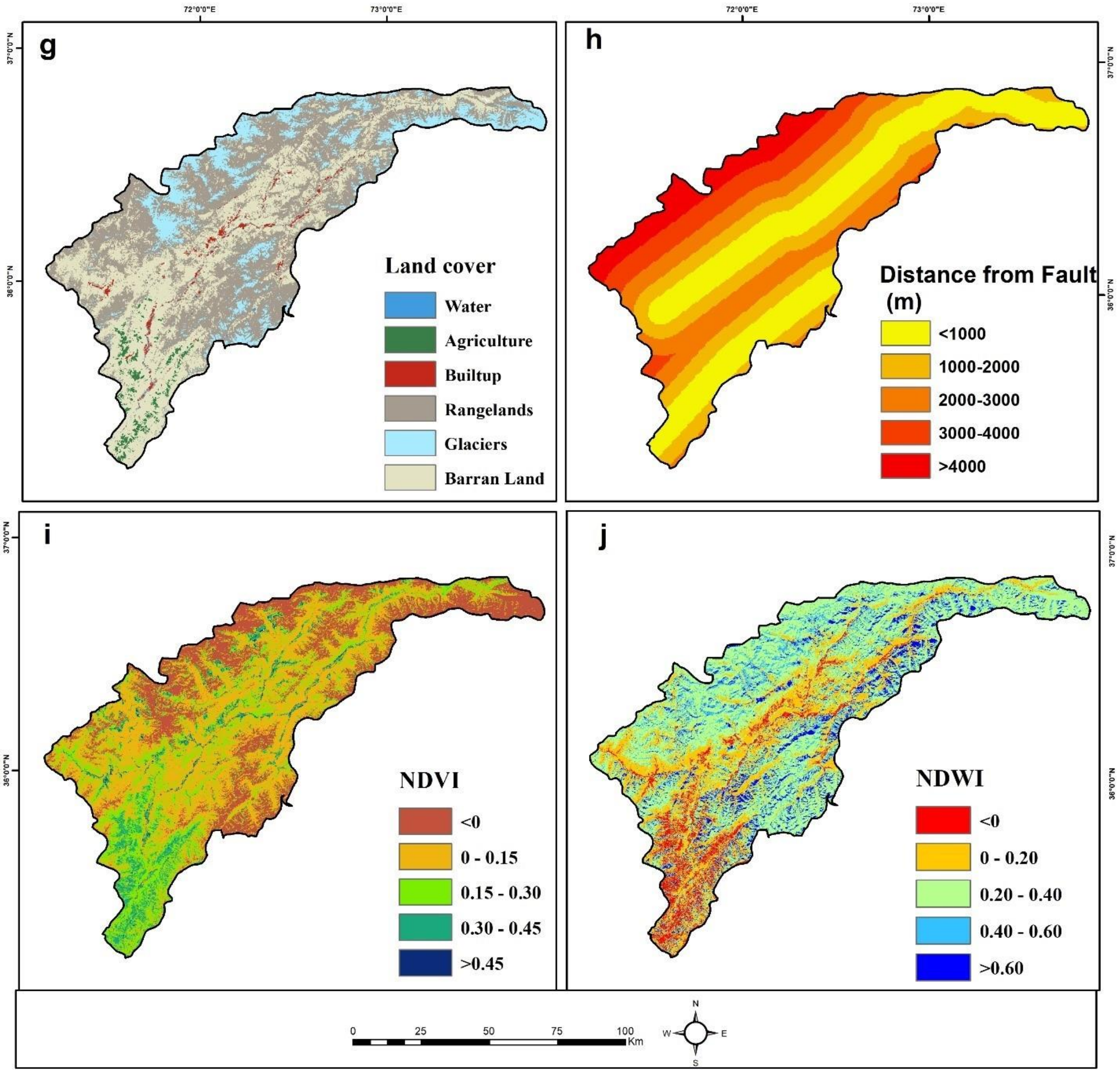

**Figure 4:** Maps of Debris flow conditioning factors: (g), land use (h), distance to fault, (i), NDVI (j), NDWI

**Risk Zonation:**

Debris flow hazards are frequent in the study area, but certain regions are more vulnerable due to their location within high-risk zones and the influence of causative factors. In ArcGIS, twelve parameters were used for debris flow hazard mapping, all reclassified and weighted equally, as shown in Table 1. The resulting debris flow risk zone map highlights debris-prone areas in the Chitral District. The regions bordering Gilgit are in low-hazard zones, while those near the Afghanistan border range from low to moderate risk. Central Chitral lies in a very high-risk zone (Figure 5), with the southern part covering 436.82 sq. km identified as high-risk due to factors such as low vegetation, high water content, and exposed soil. The villages at highest risk include Drosh, Mastuj, Reshun, Shegram, Terich Gol, Rogar, Asurat, Boni, and Brep Rech. This debris flow risk map was created using Weighted Overlay Analysis in the GIS environment.

**Table 3:** Area Effected by Debris Flow

| S. No | Risk Zone | Effected (Area sq.km) |
|---|---|---|
| 1 | High | 436.832494 |
| 2 | Moderate | 8385.719017 |
| 3 | Low | 5291.607864 |
| | **Total** | **14114.15938** |

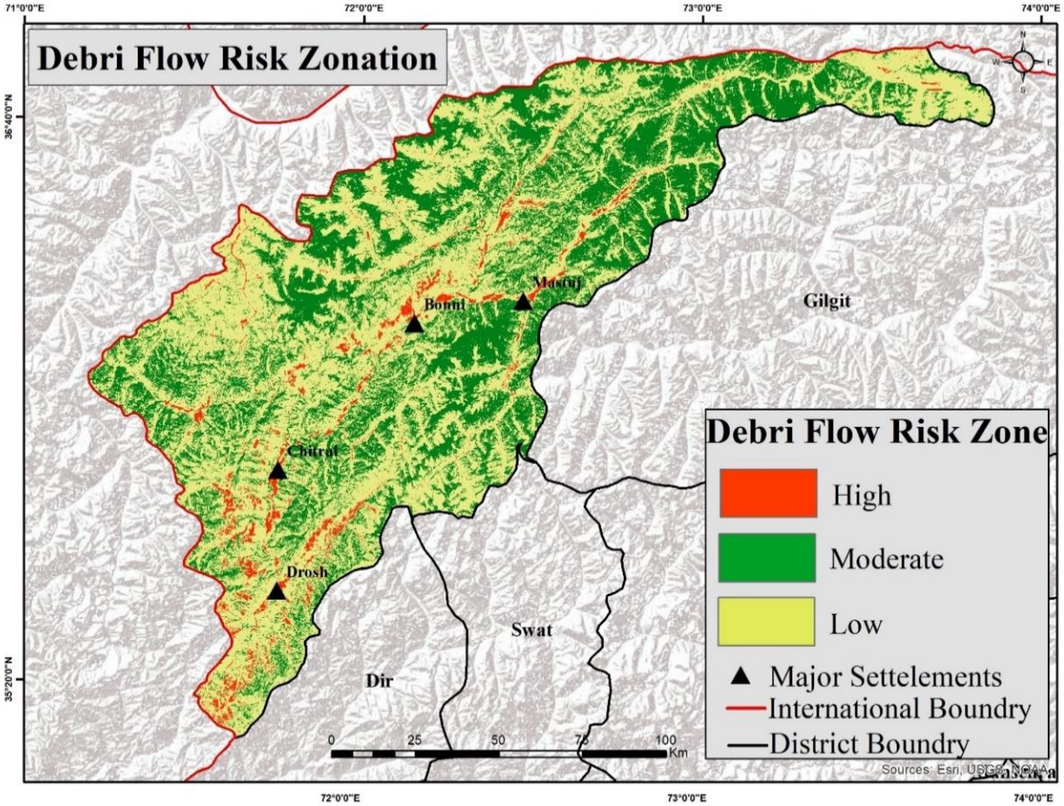

**Figure 5:** Debris flow risk Zonation in Chitral District

**Discussion:**

It is evident that debris flows pose a significant threat to populations and development in mountainous regions, especially in developing countries like Pakistan. The lack of precise and long-term rainfall and landslide records, coupled with under-reporting of debris flow damages, creates challenges in assessing the risk in the region. However, recent studies have utilized Remote Sensing and GIS techniques, such as the weighted overlay method, to identify debris flow hazard areas and produce risk maps. These studies highlight the need for comprehensive research on various aspects of debris flow and landslides in Pakistan, providing valuable insights into their causes and consequences. Integrating scientific risk assessment with a sociopolitical framework has introduced a new paradigm in debris flow risk management. Creating landslide risk maps is crucial for understanding and mitigating potential dangers in specific areas. By pinpointing vulnerable zones, authorities can prioritize mitigation efforts and take steps to protect local communities. Understanding the dominant causative factors of debris flows is essential for determining local landscape evolution and minimizing the risk of life loss. As shown in Figure 4, proximity to roads was the most significant factor contributing to debris flow initiation in Chitral, acting as a proxy for human engineering activities. Previously, the impacts of human activities were rarely considered in susceptibility models, where road construction and slope attachments increased the burden on slopes. Slope gradient and average annual rainfall ranked second and third in importance. The combination of sudden rainstorms and steep slopes eroded the surface, likely increasing the susceptibility of these areas to debris flows. Higher slope regions, with sparse vegetation and weathered rocks, are more prone to debris flow, as unstable rocks and soil particles are easily dislodged. Rainfall's impact is closely linked to surface vegetation, as precipitation influences vegetation cover. The least significant factor was the distance from faults, aligning with earlier research. Studies have also shown that the region is highly susceptible to soil erosion [32]. During western depression and monsoon seasons, debris flows are more likely to occur, making it crucial to mitigate risks in vulnerable areas and ensure that local communities are relocated to safer zones to prevent loss of life and property damage. In addition to the above recommendations, it is essential to establish a comprehensive landslide risk management plan for vulnerable areas in Chitral District. This plan should involve stakeholders such as local communities, government authorities, and disaster management departments to coordinate efforts in reducing debris flow risks. Prioritizing measures like slope stabilization, land-use planning, and early warning systems is key. Public awareness campaigns should be conducted to educate communities about landslide risks and the actions they can take to reduce their vulnerability. Ongoing research and monitoring of landslide risk in the region are vital to updating the risk management plan and improving the accuracy of debris flow susceptibility maps. Such efforts are crucial for understanding human vulnerability and implementing strategies to reduce the impact of landslides, ultimately saving lives and reducing property damage.

## Conclusion:

Debris flow is a common phenomenon in Chitral, driven by variations in geology, weathering processes, steep slopes, and rainfall. Chitral's land use and land cover include agricultural land, alpine pastures, forests, snow cover, glaciers, and barren land. The study emphasizes the importance of understanding debris flow susceptibility in the region. The proximity to rivers plays a significant role in the distribution of debris flows, with most occurrences observed in the central zone of Chitral. The villages at very high risk include Mulkoh, Mastuj, Reshun, Shegram, Terich Gol, Rogar, Asurat, Boni, Brep, and Rech Tockhow. Using GIS and thematic data layers to produce a debris flow susceptibility map for Chitral District provides critical information for engineers, geologists, and land use planners, helping them make informed decisions about future construction and development. More research is necessary to fully understand the effects of debris flow in the region. Identifying the southern and central parts as high and very high susceptibility zones is crucial for guiding future construction, as these areas should be avoided or undergo thorough geotechnical investigations before development. The study also recommends further research on the population's gender distribution and the types of debris flow, which could enhance the accuracy of susceptibility maps and improve mitigation strategies. Additionally, the study highlights the importance of early warning systems to mitigate the effects of debris flow and encourages investment in such mitigation efforts by society and technology experts.

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