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Analysis of snow avalanche causes and damages in District Chitral, Pakistan

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Abstract

Avalanches are a major problem in the Central Asian area, which includes the Karakorum, Hindu Kush, and Pamir ranges. Avalanches are frequently caused by the glaciers of Chiantar, Tirchmir, and Atrak near Chitral district. This study investigated the causes of avalanches in Chitral using data from the Digital Elevation Model (DEM) acquired from USGS. High-resolution Shuttle Radar Topography Mission (SRTM) DEM (30 m) from USGS was used to examine the causative factors such as elevation, slope, aspect, and hill shade. The objectives of the study were to determine the causes of natural avalanches, evaluate the amount of damage caused between 2010 and 2020, and provide a distribution map that shows the danger zones. Using GIS technology, it was discovered that the length and steepness of the slope, together with the lack of summit trees, were the main causes of large avalanches in Chitral. Avalanche hotspots throughout the last ten years were identified on the distribution map that resulted. Forecasters can identify danger areas and describe scenarios with the use of this information. The avalanche inventory map helps policymakers create preventative measures for risky locations in Chitral, which helps with risk management.

1. Introduction

Large glaciers that split off from their main bulk and tumble rapidly downward are typically the source of a snow avalanche. (Davies and McSaveney, 2002). In the winter, it is a serious hazard to individuals living in mountainous places and infrastructure i.e., buildings, roads (McClung and Schaerer 2006). Slope failure is controlled by the relationship between snow qualities and meteorological conditions (Mahboob et al. 2015). The structure and strength of snow layers, which are influenced by external variables such as wind, precipitation, and temperature, dictate the stability of an avalanche. Throughout the winter, the snowpack accumulates and is composed of several layers with highly changeable physical characteristics that are subject to variations in heat, water vapor concentration, and radiative fluxes brought on by shifting weather patterns. (Piacentini et al., 2020).

Snow avalanches in mountainous regions result in large financial losses and a high death toll. The kind of terrain, the weather, the presence of thick snowpacks over weak layers, and outside triggers are all factors that favor avalanche formation. These outside elements, which include explosions, earthquakes, passing skiers, and crumbling cornices, can add weight to the snowpack or cause it to break apart and trigger avalanches. (Podolskiy et al., 2010).

A secondary consequence of the destructive propagation of snow avalanches may be the massive deposition of surface rock and plant fragments that have traveled and piled alongside the debris from the avalanche. (Choubin et al., 2020). The accumulation of such snow-rock-debris and the mass wasting caused by snow avalanches have more detrimental long-term impacts. The accumulation of such snow-rock debris and the mass wasting brought on by snow avalanches result in more catastrophic long-term damage (Wesselink et al., 2017; Eckerstorfer and Malnes, 2015). The worldwide snow avalanche regime has been seen to be shifting during the past ten years (Oleinikov and Volodicheva, 2019). One of the main factors cited for raising the frequency and irregularity of occurrences as well as their risk and destruction is climate change. (Laute and Beylich, 2018).

In alpine regions around the world, avalanches represent a major risk to people, structures, and transportation systems. In Switzerland, avalanches claim the lives of 25 people on average every year; most of these deaths happen during winter sports activities and

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they regularly cause damage to infrastructure (Techel et al., 2015). In March 2012 and again in February 2015, a significant avalanche cycle hit mountain villages in Central Asia (Pakistan, Afghanistan, and Tajikistan), destroying towns, killing livestock, and killing hundreds of people. (Chabot and Kaba, 2016). Since 1950, Austria has seen almost 1,600 fatal avalanches, with an average of 30 fatalities year. In the past 55 years, the backcountry and off-piste have seen almost two thirds of all avalanche deaths (Höller 2007).

Around 172 people were killed and over 2 miles of road were buried in February 2010 when 17 avalanches that began in the southern approaches of the Salang Pass in the Hindu Kush Mountain range were caused by powerful winds and rain, according to World Atlas. A large number of cars were crushed by the avalanche and left to rot in frigid coffins, while other cars were forced into the valley's death jaws. A similar sequence of destructive avalanches struck four districts in the northeastern area of Afghanistan in February 2015. In the province of Panjshir, some 60 miles northeast of Kabul, over 100 houses were destroyed by avalanches. The trucks and rescue workers who were en route to the affected areas had difficulties due to heavy snowfall and fallen trees, which hindered their ability to reach the villages. A little over 310 persons lost their life in the accident (Ancey, 2016).

The biggest snow glacier in the world is located in Northern Pakistan, many hundred kilometers away from the glacier, across higher terrain and inside the severe shaking zone of the Hindu Kush. As of right present, there is no infrastructure in place to monitor seismic snow avalanches. (Khan et al., 2013).

2. Method

2.1. Data Collection

In this research, secondary data were used to achieve the desired objectives. The secondary data were acquired from concerned government departments and other private organizations. Digital Elevation Model (DEM), having 30m resolution, was obtained from the United States Geological Survey (USGS). The imagery data of the affected areas of Chitral were obtained by Landsat-8. The data related to damages by avalanches in the past were obtained from National Disaster Management Authority (NDMA) and, other sources. Some statistical data were acquired from other research articles, newspapers etc.

2.2. Data Processing

On the DEM of Chitral, analytical methods like as elevation, slope, aspect, and curvature were used to provide a visual result of the reasons of avalanche. Three rasters were required for the current study work flow. The pixel values in this DEM are in feet. In addition, the DEM values were used to derive the slope and aspect. Tables depicted the consequences of the avalanches in past years as well as the severity of the avalanches. A distribution map was created to depict the key avalanche hotspot regions in Chitral.

2.3. Study Area

Chitral is situated between 35°14′00′′ and 36°56′00′′ N and 71°11′00′′ and 73°42′00′′ E. Its surface area is 14,850 km^2. Geographically, Gilgit Baltistan's Ghizer District and the Swat District are located on the eastern side of Chitral. On the southern side of Chitral is Upper Dir; on the western side borders Afghanistan. Chitral is the largest of the districts that make up Khyber Pakhtunkhwa (KP), which is located in northwest Pakistan (Khan, 2013). Chitral stands at one of the highest elevations in the KP province. The Chitral area of Northern Pakistan traverses the Hindukush Range in the SW Pamir Syntaxis (Nusser, 2001).

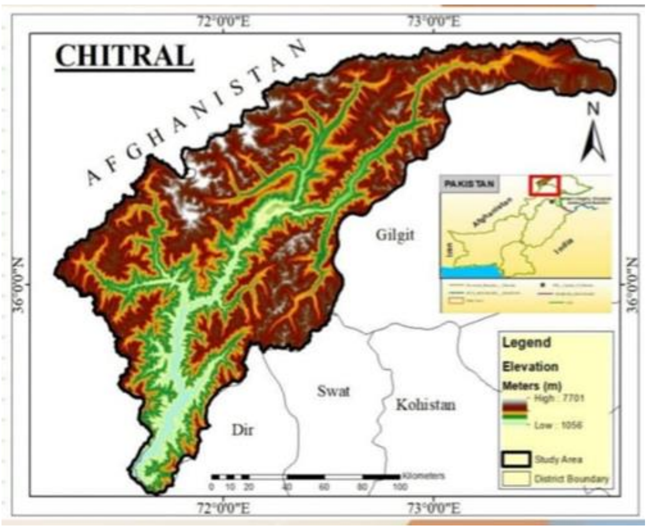

Figure 1. Location of the study area.

The climate in Chitral is moderate, with pleasant summers and extremely cold winters. Summer temperatures range from 22 to 24 degrees Celsius, while winter temperatures range from -4 to -6 degrees Celsius. Chitral has a moderate climate, with westerly winds that bring rain predominating from December to March throughout the winter. 16 degrees Celsius is the average annual temperature, with an average minimum temperature of 8 degrees and a high temperature of 24 degrees. Winters are cold, with January being the coldest, while summers are hot, with July being the hottest. (Ashraf et al., 2012).

3. Results

3.1. Analysis of Causative Factors

3.1.1. Slope

Slope angle is the principal factor that influences and causes avalanche release. To the second DEM raster, the Slope Function was appended. Specifically, a slope range of 30 to 50 degrees—that is, greater than 30 degrees and less than 50 degrees, respectively—was selected as the pixels-based value for essential slope-tolerance for this local function. Slope angles are one of the general parameters for avalanche vulnerability owing to slope. Avalanche initiation zones are systematically identified between 30 and 50 degrees (often even 60 degrees) as both wet and dry surfaces may be covered. The avalanche occurrence in this location is caused by the Chitral's slope degree, as indicated by the findings of the assessment's tilt study.

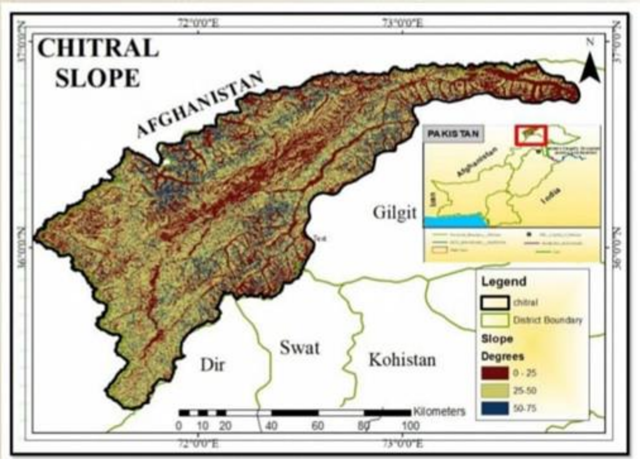

Figure 2. Slope of Chitral.

3.1.2. Elevation

While height doesn't directly affect the likelihood of snow avalanches, it does have an impact on the metrological factors that determine the stability of the snowpack. Consequently, height continues to be a crucial topographical factor in assessing avalanche danger in a spatial sense. Moreover, the wind speed increases in response to altitude changes, which increases the quantity of snowfall the wind produces. Elevation standards often include 4000 meters or above. It has been observed that most of the ice cover accumulates above 4000 m in Eastern Hindukush (between 4000 and 5500 m) since the study-area districts are in the HKH range. Therefore, in Chitral, height is a key factor in initiating the snow cover that leads to the Avalanche.

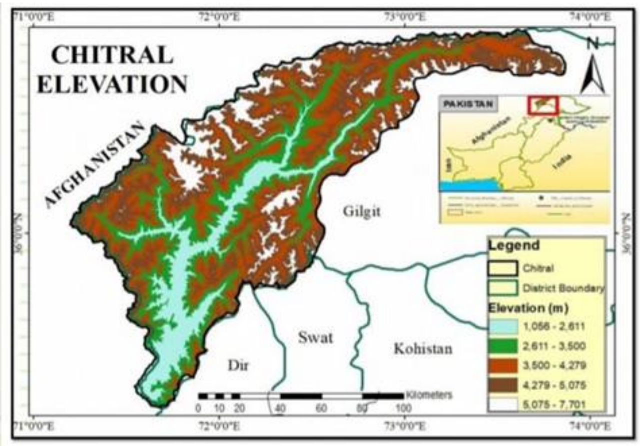

Figure 3. Elevation of Chitral.

3.1.3. Aspect

Using the Aspect Function, the original DEM raster was processed. Selected pixels were assigned an aspect of 112.5 to 202.5 (Aspect: Southeast & South), which means that they were greater than 112.5 degrees and less than 202.5 degrees, respectively. The values under investigation represent the Southeast aspect geographically because sun radiation rapidly focuses on certain aspect parts of the landscape, leading to the melting of ice.

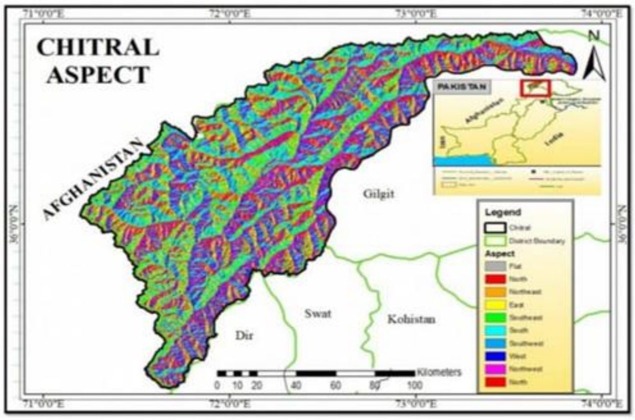

Figure 4. Aspect of Chitral.

3.1.4. Hillshade

The haded relief, or hillshading, technique adds a lighting effect to a map by taking into account variations in the studied area's height. To improve the visibility of the terrain, it mimics the sun's effects on hills and valleys, including shadows, shading, and lighting.

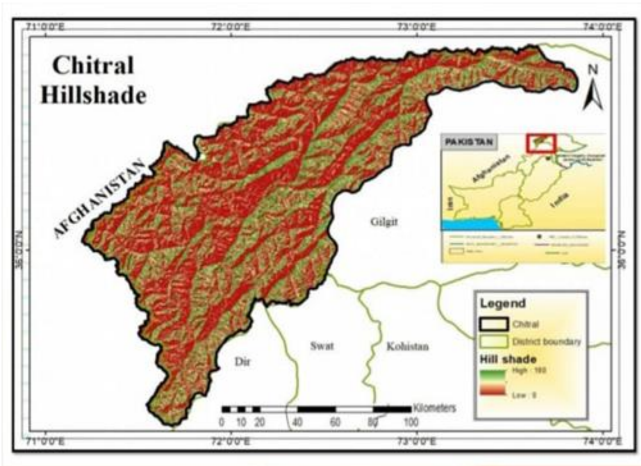

Figure 5. Hillshade of Chitral.

3.2. Analysis of Damages

Date of Avalanches	Locations	Effects
12-January-2011	Arkari Valley	12 people killed, 5 houses damaged
19-March-2016	Karimabad	19 people trapped, few vehicals were trapped because of the blockage of roads
22-March-2016	Susom Village	2 students killed
28-March-2016	Karimabad	6 injured, few cattles killed
27-January-2017	Sher shal village	15 people killed, many injured
05-February-2017	Karimabad	10 people killed
19-February-2017	Lowari tunnel	14 persons trapped 7 died
01-January-2017	Lowari top	2 persons killed
17- February-2017	Rech valley	1 death
18-February-2017	Reach valley	8 people killed, 10 injured,7 houses damaged
04-November-2018	Drosh	Four persons killed

Figure 6. Locations, dates and effects of avalanches.

There was insufficient data available on damages during the preceding 10 years. Google Scholars and

DAWN news provided the previously stated information of large-scale avalanche accidents in the Chitral area. The figures presented above indicate the timing and extent of the principal avalanche occurrence. Based on data, 2017 was the most catastrophic year in the preceding decade since most of the avalanches happened in Chitral.

3.3. Inventory map of Avalanches

The map below depicts the distribution of the key avalanche incidents and the regions in Chitral that are the biggest avalanche hotspots.

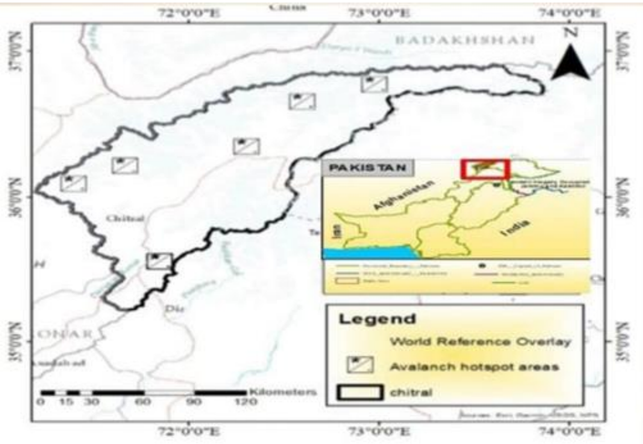

Figure 7. Main hotspot of Avalanches in Chitral.

4. Discussion

Records of avalanches from ranges including peaks over 7000 meters are not accessible. However, extreme altitudes and notable vertical relief above the terrain and snowline indicate certain common features. Near high mountain summits, winter weather with cold, dry snow is always predictable. The prolonged duration of snowpack instability is suggested by cold temperatures. Elevated altitudes indicate elevated solar radiation under clear sky conditions, which can rapidly exacerbate instability and potentially generate natural avalanches or increase the probability of human activation.

In some circumstances, there may be a greater chance for snow entrainment to generate bigger masses due to the steep vertical relief above the snowline. According to data from several sources, avalanches of significant size begin to deposit on slopes of around 10°, while snow avalanches begin to discharge on slopes between 25° and 55° (McClung, 2013).

Humans often misjudge avalanche instability, which leads to many accidents. (McClung and Schaerer, 2006). The results of icefalls are generally unpredictable. Risk management must be used if icefalls need to be crossed in order to avoid placing an excessive number of people in danger in one location at a time, including possible camp sites. The fact that snow avalanches caused by icefall have been a significant cause of fatalities makes forecasting more challenging. It may be argued that when the monsoon loads the accumulation zone, glacier mobility increases, even though there is no data to support this theory in terms of mortality rates.

5. Conclusion

In order to develop snow avalanche causes, the current study used a novel and integrative approach inside GIS by including crucial topography characteristics. The results show that there is a moderate to high risk of avalanche hazard in several areas of the study's target districts in Pakistan's northern zone. The analysis of avalanches in Chitral both geographically and temporally exposed a number of avalanche-related problems and damages. But the study also pinpointed the main natural avalanche sources in Chitral, and the main avalanche hotspot sites are shown on a map based on the majority of avalanche incidences in the region's districts. Additionally, elevation and related significant topographic data were extracted using SRTM DEM data with a 30-m spatial resolution used in this study; however, for optimal outcomes, high-resolution DEM is recommended.

Recommendations

- Non-structural methods
- Avalanche zoning
- Artificial Triggering
- Afforestation
- Structural Defenses

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