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Landslide Susceptibility Mapping In Tadian, Mountain Province

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Abstract
Landslides are significant natural hazard in Tadian, Mountain Province, posing substantial risks to life, property, and infrastructure. This study aimed to develop a comprehensive landslide susceptibility map for Tadian using Logistic Regression analysis in R Studio and Geographic Information System (GIS) technology. Various factors influencing landslide occurrences were analyzed, including historical landslide locations, aspect, elevation, lithology, land cover, precipitation, slope, soil texture, NDVI, road network, and river network. Data collection involved gathering historical landslide records, topographic and geological maps, remote sensing data for land cover and NDVI, meteorological precipitation records, and
infrastructure maps. These datasets were integrated into GIS to produce thematic maps representing each factor. Logistic Regression analysis was then performed to model the probability of landslides based on these inputs, resulting in a landslide susceptibility map depicting the locations of the susceptible zones.
The results indicated that steep slopes, high precipitation, specific lithological units, and proximity to roads and rivers significantly increase landslide susceptibility. Conversely, areas with dense vegetation showed lower susceptibility, highlighting the protective role of forest cover. The model's accuracy was validated against historical landslide data, demonstrating a strong correlation between predicted landslide risk zones and past landslide occurrences. Given these findings, the study concludes that logistic regression and GIS are effective tools for landslide susceptibility mapping, providing valuable insights for risk assessment and management. The generated map serves as a critical resource for local authorities and planners in Tadian, guiding land use planning, infrastructure development, and disaster preparedness.
Recommendations include enhancing monitoring systems, implementing slope stabilization measures, promoting reforestation, educating communities about landslide risks further researches on the other factors considered in the study. Regular updates to the susceptibility map, incorporating new data and advanced modeling techniques, are essential for ongoing risk mitigation.
This research contributes to a deeper understanding of landslide dynamics in Tadian, ultimately aiding in the development of strategies to enhance community resilience and safety in the face of natural hazards.

INTRODUCTION

Background of the study

The Philippines being a locus of tropical cyclones, tsunamis, earthquakes and volcanic eruption, floods, and landslide, is a hotbed of disasters. These natural hazards inflict loss of lives and costly damage to property (Lagmay et al., 2017). Further studies said that steep slopes, fractured lithology's and intense precipitation were recognized to have led to the occurrence of landslide. These natural hazards and their cause are presented to contribute to the understanding of how weather systems evolve and what the corresponding effects are on the ground (Yumul et al., 2012).
Mapping past and current landslide occurrence and delineating the areas where landslides may occur in the future, and evaluating the associated risk to population, infrastructure and property is of the utmost importance to land use planning, engineering works design and civil protection programs which aim to minimize human and material losses due to these calamities. Records have shown that in Southeast Asia, steep hill slopes, seasonally dry periods, excessive rainfall intensities and unstable soils are the main causes of frequent landslides (Douglas, 1999).
Studies said that it is a clear perception that landslide risk management cannot be treated in isolation rather it should be a part of community development. In this context, it is essential to build a community's capacity to understand their vulnerabilities, strategies, activities and the role they could play in managing landslide risks without relying on external entities. Therefore, the proposed community-based landslide hazard-mapping technique can be a good solution for addressing current issues. The approach will not only focus on the effective development and application of FHM but also it will correct the defects of the top-down

approach in disaster planning and also encourage all stakeholders' participation in an integrated and sustainable manner (Osti, 2008).

Landslide risk has increased all over the world during recent decades, because of the uncontrolled urban sprawl by fast population growth and accelerated economic development (Huang, et. al.,2015). Landslide and other mass movement such as rock falls can be triggered by heavy precipitation within a certain period of time. This is usually associated with significant amount of rainfall within a certain period of time. Landslide are one of the destructive geological processes that cause not only massive damage to roads, bridges, houses, and natural resources but also lead to loss of life. Because of these threats (Wang, et. al., 2015), a comprehensive landslide susceptibility map should be produced to reduce the possible damages to people and infrastructure.

Landslide can be predicted and mapped out more easily and the potentially affected people within the known vulnerable areas can be alerted in advance to avert more damages. However, these naturally occurring disasters are not without mitigation measures. The utilization of geomatics technologies can have a significant contribution to disaster mitigation. The integration of GPS, RS data, and GIS mapping can help mitigate the effect of any natural disaster. The GPS disaster management applications that are associated with preparedness and mitigation measures usually involves landslide and flood disaster prevention. Mitigation involves any activity that minimizes the impacts of disaster within potentially vulnerable areas while preparedness involves the activities that facilitates the preparation for response to disaster occurrence.

Corvajal et al. (2014) used the process of remote sensing and geographic information systems (GIS) to generate a susceptibility map by implementing the weights of evidence method in Nueva Colombia, Chiapas, Mexico. Remote sensing provides data and information which is particularly interesting to explore in data-sparse conditions especially for developing countries (World Meteorological Organization, 2013).

A geographic information system (GIS) as defined by the Westminster College (ND) is a computer-based tool for mapping and analyzing feature events on earth. GIS technology integrates common database operations, such as query and statistical analysis, with maps. Using the geographical information system (GIS) analysis provides a powerful tool to model landslide hazards for their spatial analysis and prediction (Daneshvar et. al., 2010).

The use of remote sensing and GIS can be very useful in the study of hydrology and water resources due to their high accuracy and speed as accuracy and time are two vital components of disaster modeling (Khosravi et. al., 2016).

GIS application had been appraised by Saini & Kaushik (2012) as a method used for reproducing, analyzing and integrated spatial data to prepare a hazard risk map which not only defines the susceptibility of each settlement to inundation but also provides means for assessment of flood risk in terms of loss of life, crop land and property. Geo-information techniques have proven their usefulness for the purposes of early warning and emergency response (Bandrova, Zlatanova, & Konečný, 2012). These techniques enable us to generate extensive geo-information to make informed decisions in response to natural disasters that lead to better protection of citizens, reduce damage to property, improve the monitoring of these disasters, and facilitate estimates of the damages and losses resulting from them.

In October 30, 2018, during the onslaught of Typhoon Rosita, a landslide buried three (3) buildings of the Department of Public Works and Highways-Mountain Province Second District Engineering Office (DPWH-MPSDEO) and some nearby structures at Sitio Ha'rang, Banawel, Natonin, Mountain Province and leading to the death sixteen (16) individual.

Also, during the earlier years, another devastating disaster occurred in Mountain Province in the evening of October 8, 2009. A killer mudslide caused by the unabated strong rains of Typhoon Pepeng struck at Kayan, Tadian, Mountain Province leaving forty (40) people dead and six (6) injured.

These tragedies underline the need for more extensive disaster-preparedness as the province is prone to landslide and erosions. Erosion-mitigating measures have to be adopted (Province of Mountain Province official website).

The assessments of landslide hazard and susceptibility are the relative spatial probability of a new landslide occurring in the future (Remondo, et. al., 2003 and Daneshvar, et. al., 2010), and their assessment in the given area should normally be based on the analysis of instability factors. Using the software geographic

information system (GIS) for data analysis and remote sensing application for data gathering provides a powerful and more precise tool to model the landslide hazards for their spatial analysis and prediction.
It is therefore of great significance to develop a landslide susceptibility map of the municipality of Tadian that would help provide details on the landslide prone areas and identify some precaution and mitigation measures in times of flood and landslide calamities.

Objectives of The Study
The central concern of this study is to develop a landslide susceptibility map of the municipality of Tadian by the using logistic regression method in R studio ang Geographic
Information System. The specific objectives are as follows:
1. To evaluate the landslide susceptibility of each barangay in the municipality.
2. To provide data for people information and planning and policy development.

METHODOLOGY

Research design
Qualitative research design was used in the study. Descriptive research method was used to discuss the gathered facts and essential information acquired from data. This is appropriate to describe the present condition of the municipality of Tadian in terms of the different parameters in assessing landslide susceptibility.

Locale and time of the study
This study was conducted during the year 2023 at the municipality of Tadian which is geographically located at the southwest part of Mountain Province within 16059'44" N latitude and 120049'13" E longitude. It is inside the Cordillera Autonomous Region which is concluded by the region's Mines and Geosciences Bureau (MGB) as having a soil that is susceptible to erosion due to days of continuous rains every year. Due to its geographical characteristics; unplannedurbanization and proximity, Tadian had also become vulnerable to landslide.

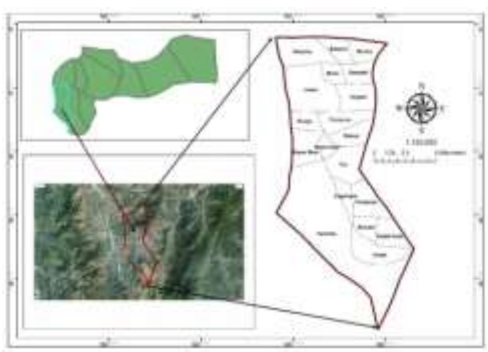

Figure 2. Study Area Location Map

Instrumentation
To construct the landslide susceptibility map, a variety of data were collected from different sources. Historical landslide occurrence data were sourced from government records, geological surveys, and historical archives, providing a foundational understanding of past events. Topographic data, including Digital Elevation Models (DEMs), were obtained from the Copernicus Digital Elevation Model (DEM), also known as COP-DEM to derive crucial information on elevation, slope, and aspect. Copernicus.eu is an Earth observation program of the European Union which gathers and processes data from a network of satellites and ground stations to monitor the environment. Geological and soil data, such as lithology and soil texture maps, were collected in

the Geological Map of the Cordillera Administrative Region (Scale of 1:400,000) from the Bureau of Soil and Water Management (DENR-CAR), which helped assess the impact of rock types and soil properties on slope stability. Landcover data was accessed from the geoportal of
National Mapping and Resource Information Authority (NAMRIA) of the Philippines
(https://geoportal.gov.ph/). The NDVI (Normalized Difference Vegetation Index) were derived from satellite imagery, such as those taken from the satellite Landsat 8 through the EarthExplorer.usgs.gov (a platform maintained by the U.S. Geological Survey) to evaluate vegetation cover's role in landslide prevention. Climate data, particularly precipitation records, were gathered from a website offering a freely available database of high-resolution global climate data like worldclim.org. to understand the correlation between rainfall patterns and landslides. Additionally, infrastructure data, including road and river network maps, were sourced from data.humdata.org, a platform by the Humanitarian Data Exchange (HDX), to assess human activity's impact on slope stability.

Data collection

Several types of data like Landcover, Lithology, Soil Texture, River Network, RoadNetwork, Aspect, Slope, Precipitation, NVDI, and Historical Landslide Occurrence Location were chosen as
assessment factors in the landslide susceptibility. Each factor has a certain weight which contributes to the determination of the susceptibility levels of each barangay in the municipality. The susceptibility mapping of landslides was done using R Studio and GIS.

The data and inventory mapping were based on the Digital Elevation Model (DEM) from the satellite
image taken by the Landsat 8. Using this DEM, the effective factors on landslide potential, such as the slope, land cover, rivers, and roads were generated, and compiled for data analysis and interpretation in a Geographic Information System (GIS) platform.

Validation and gathering of elevations, locations, and actual photos of landslide-affected areas were conducted during the actual ground survey with the aid of Handheld GPS, and Geo- tagging devices.

Treatment of Data

The data analysis utilized Geographic Information System (GIS) software such as ArcGIS to spatially analyze and visualize the collected data. GIS technology enabled the creation of thematic maps for each factor, which were then integrated to develop the comprehensive landslide susceptibility map. R Studio, a powerful statistical programming environment, was used to perform logistic regression analysis. This statistical method was instrumental in modeling the probability of landslide occurrences based on the various input variables.

Logistic regression was employed to model the likelihood of landslides, considering the diverse factors influencing slope stability. Thematic mapping in GIS facilitated the creation of individual maps for each contributing factor, such as slope, precipitation, and land cover, visually representing their spatial distribution and intensity. These thematic maps were then overlaid and integrated through GIS to produce the final landslide susceptibility map, identifying susceptible zones.

The validation of the susceptibility map was a critical step to ensure its accuracy and reliability. Historical landslide occurrence data were used to validate the model, comparing predicted high-risk areas with actual past landslide locations to verify the model's predictions. Cross-verification methods were also employed to ensure consistency and robustness of the results, confirming the validity of the findings through alternative methods and datasets. This comprehensive approach to validation ensured the susceptibility map's reliability as a tool for risk assessment and management.

RESULTS AND DISCUSSION

This chapter presents the outcomes of the landslide susceptibility analysis for Tadian, Mountain Province. Utilizing Logistic Regression and Geographic Information System (GIS) technologies, the results are discussed in relation to various environmental, geological, and human factors. The chapter details the creation of the landslide susceptibility map, validates the model using historical data, and explores the implications of the findings for risk management and land use planning.

Land Susceptibility

The landslide susceptibility map for Tadian, Mountain Province was analyzed using the Logistic Regression method in R Studio and Geographic Information System. The following data were gathered and analyzed to come up with the susceptibility map: Historical Landslide Occurrence Location, Aspect, Elevation, Lithology, Landcover, Precipitation, Slope, Soil Texture, Normalized Difference Vegetation Index (NDVI), Road Network, and River Network.

The Logistic Regression method was employed to analyze the relationship between the probability of landslide occurrences and the identified factors. Each factor was spatially analyzed using GIS to produce thematic maps, which were then integrated to develop the final susceptibility map.

Logistic regression modeling was performed to produce a more improved result of prediction. The logistic regression algorithm of the R program calculated the probability of landslide occurrence and non-occurrence in Tadian, Mountian Province. The generated plot in Figure 2 shows the ensembled response curves from the single model response curves. These response curves are the graphical representation of the relationship between the response (landslide occurrence) and the predictor variables (factors). The flatline means there is no correlation between the response and predictor variable. A downward and upward sloping means the relationship between the response and predictor variables is decreasing and increasing, respectively.

The models were then evaluated and projected to create a binary landslide susceptibility map. Further, the maps were processed for proper layout and presentation as shown in the succeeding figures.

Historical Landslide Occurrence

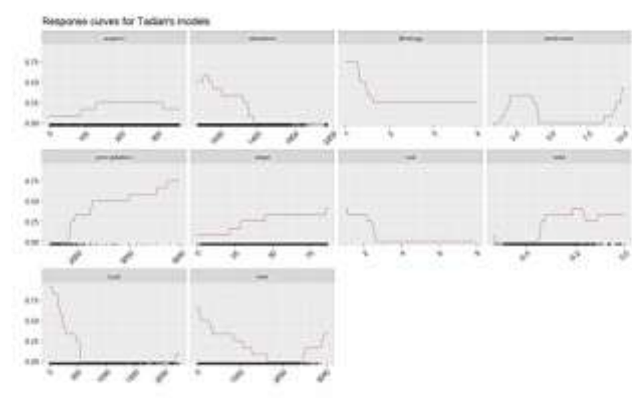

Figure 2. Response curves

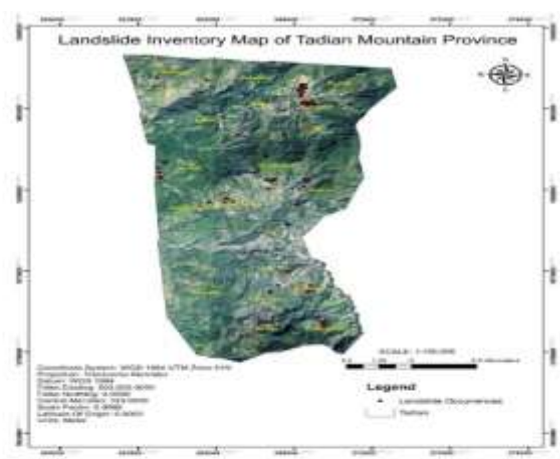

Figure 3. Landslide Inventory Map of Tadian, Mountain Province

The historical landslide occurrence is shown in Figure 3. Historical data on landslides were crucial in validating the model. The areas with past occurrences showed a high correlation with current susceptibility zones, confirming the reliability of historical data in predicting future landslides.

The response variable containing the landslide points, and the predictor variables were loaded in R studio to generate the plot shown in Figures 5 to 23.

Aspect and Elevation

These topographic factors significantly influenced landslide susceptibility. Slopes facing certain directions (aspect) and specific elevation ranges were more prone to landslides. For instance, slopes facing the direction of prevailing winds and higher precipitation were more susceptible. The aspect and elevation map of Tadian, Mountain Province is shown in Figures 4 and 5 respectively.

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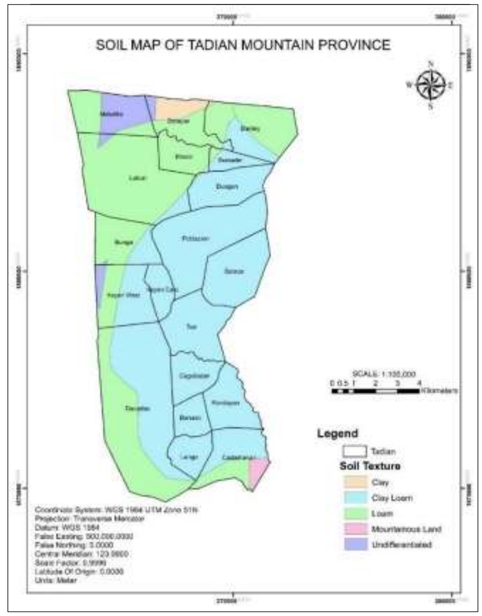

Figure 4. Aspect map

Figure 5. Elevation map

Landslide risk in Tadian, Mountain Province is influenced by the direction a slope face. South-facing slopes, ranging from 130 to 310 degrees on a compass, receive the brunt of the sun's rays in the Philippines, located in the Northern Hemisphere. This translates to drier conditions on these slopes compared to those facing north. As the south-facing soil dries out, it can crack and lose its cohesiveness, making it more susceptible to landslides. The study suggests that this effect is most prominent on south-facing slopes in Tadian, with a predicted peak susceptibility of 25% (Figure 2). This findings on the impact of seasonal drying on landslide susceptibility complement and strengthen the established research of Douglas (1999). Douglas mentioned that when the dry season ends and heavy rainfall returns, the already weakened and cracked soil becomes saturated with water. This water infiltration further reduces internal friction within the soil and increases its weight. With the weakened structure and increased weight, the likelihood of a landslide on a steep slope significantly rises.

The response curve of elevation to landslide susceptibility plots the elevation values on the x-axis and the landslide susceptibility index on the y-axis as shown in Figure 2. Areas with higher elevation of 1400 to 2200 meters above mean sea level and greater distance from roads and residential areas are generally less susceptible to landslides. While lower-elevation areas (0-1200 meters above mean sea level) with steeper inclines are more prone to landslides due to increased gravitational forces pulling down on the soil and rock. Locations with the highest susceptibility have an elevation lower than 1000 meters above mean sea level. The susceptibility in these areas ranges between 50% and 75%.

Lithology and Soil Texture

The geological composition (lithology) and soil texture played a vital role in determining landslide susceptibility. Regions with softer rock formations and finer soil textures exhibited higher susceptibility due to their lower shear strength and higher water retention capacity. The lithology and soil texture map of Tadian, Mountain Province is shown in Figures 6 and 7 respectively.

The numerical value in the x-axis index reflected in the lithology response curve defined the type of rocks in the lithology map (Figure 2). Number one (1) in the response curve represent the quarternary volcanic and recent types of rock. Quaternary volcanic rocks and recent sedimentary deposits are most susceptible to landslides, with a potential of up to 75%. This vulnerability is due to their weak and

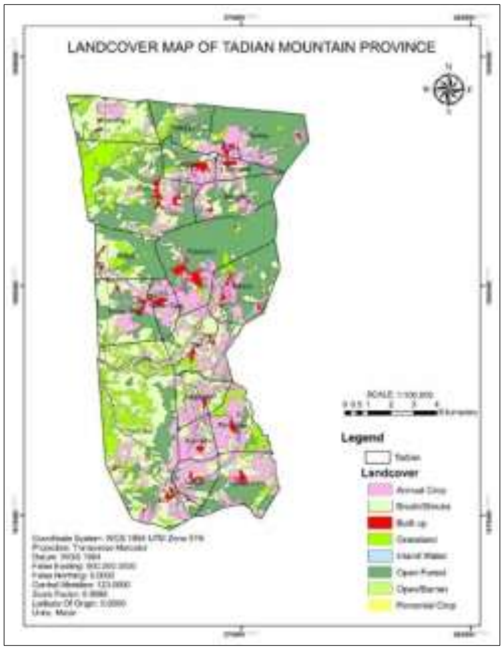

Figure 6. Lithology map of Tadian, Mountain Province

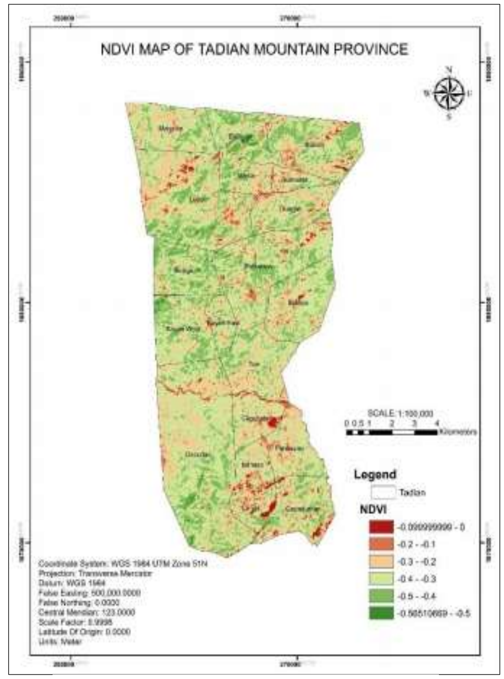

Figure 7. Soil texture map of Tadian, Mountain Province

often clay-rich composition, which allows water infiltration and leads to slope instability. This study's finding aligns with and expands on the work of Yumul et al. (2012). While Yumul et al. (2012) focused on identifying the general factors leading to landslides (steep slopes, fractured rock, intense precipitation), this study delves deeper into the specific rock types that pose a greater risk. Other rock types, including (2) Neogene intrusive rocks, (3) Early to Middle Miocene rocks, and (4) Cretaceous to Paleogene rocks, exhibit a lower susceptibility of 25%.

Using the soil response curves the relationship between soil properties and landslide risk is shown (Figure 2). Curve number two (2) on the x-axis represents undifferentiated and mountainous soil, the most landslide-prone type with a susceptibility of 25% to 50%. This vulnerability stems from two factors: the unknown characteristics of undifferentiated soil and the inherent instability of steep slopes found in mountainous areas. The combination of these factors, coupled with potentially high rainfall in the absence of specific soil data, makes undifferentiated mountainous soil highly susceptible to landslides.

However, other rock types, such as loam (4), clay loam (6), and clay (4) soils, demonstrate least susceptibility to landslides in the designated study areas in Tadian, Mountain Province.

Landcover and NDVI

Vegetation cover, as indicated by landcover types and NDVI, had a mitigating effect on landslide susceptibility. Areas with dense vegetation showed lower susceptibility, highlighting the importance of forest cover in stabilizing slopes. The generated landcover and NDVI maps of Tadian, Mountain Province is shown in Figures 8, and 9 respectively.

The land cover response curve is shown in Figure 2. This translates information from a land cover map into landslide susceptibility. Values on the x-axis from 0 to 5 represent areas most prone to landslides (25-50% susceptibility), including perennial crops, open/barren land, open forests, and inland water. This also applies to value 10, which encompasses bushes, shrubs, and annual crops.

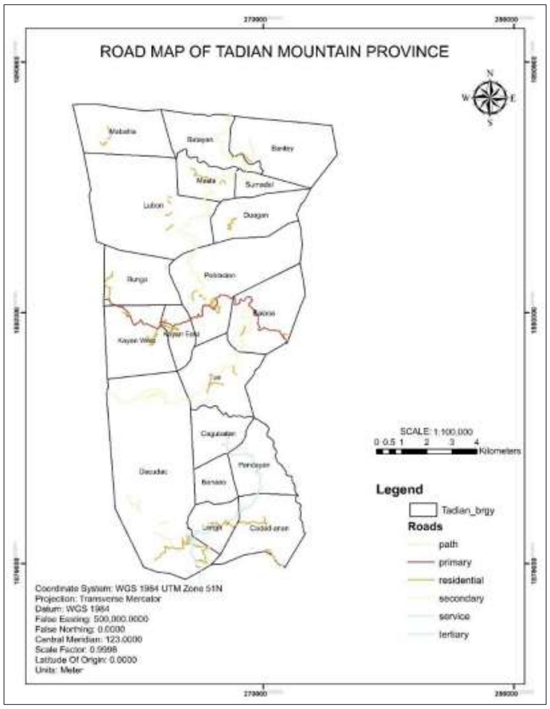

Figure 8. Landcover map of Tadian, Mountain Province

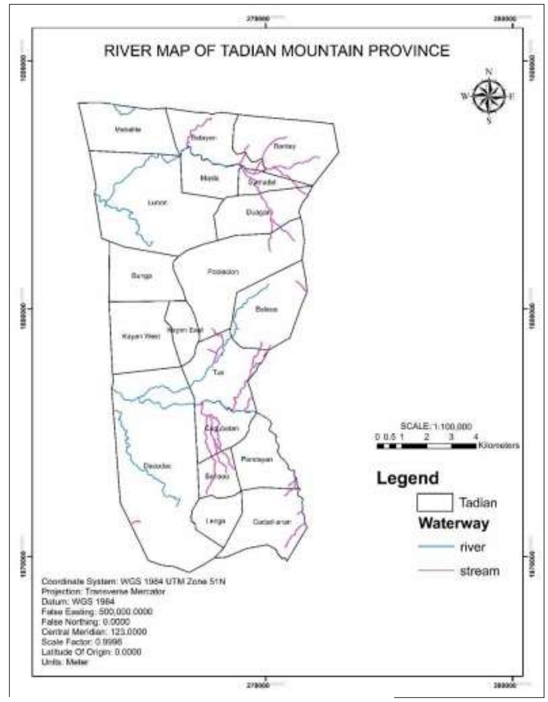

Figure 9. NVDI map of Tadian, Mountain Province

These land covers offer weak slope reinforcement due to shallow root systems, increasing landslide risk. Open water bodies are susceptible to erosion from waves and even underwater landslides. While shrubs can provide some protection, their effectiveness depends on density and root structure. In contrast, other land covers like grasslands and built-up areas (values between 5 and 7.5) show no susceptibility to landslides.

The number legend in the NDVI map shown in Figure 2 is a way to visualize the health and density of vegetation. Higher numbers, usually closer to 1, indicate areas flourishing with plant life, while lower numbers suggest sparse vegetation, bare ground, or even water. Negative values as seen mostly in the map point to areas with human-made structures or low vegetation cover.

As NDVI approaches zero, signifying a decline in vegetation cover, the risk of landslides actually increases. In the result of the NDVI response curve shown in Figure 15, it is not the complete absence of vegetation (NDVI of 0) that's most worrisome, but the zone just before that, around -0.2 NDVI. Here, even though some vegetation might be present, it's likely unhealthy and offers minimal soil stabilization. This critical zone sees a peak in landslide susceptibility, reaching 25-50%.

Precipitation

High precipitation areas corresponded with increased landslide susceptibility. The logistic regression analysis confirmed precipitation as a critical factor, with heavy rainfall events significantly raising the risk of landslides. Figure 10 shows the precipitation map of Tadian, Mountain Province.

Also, the response curve of precipitation to landslide susceptibility is shown in Figure 2. The study reveals a generally increasing trend: as rainfall depth increases, so too does the risk of landslides (highest with 75% susceptibility). This vulnerability stems from Tadian's steep slopes and its undifferentiated and mountainous soil type weakens with excess water. The region's monsoonal climate with heavy rainfall seasons pushes precipitation levels closer to a critical point where landslides become much more likely.

The findings from both this study and previous research by Wang et al. reveal a strong alignment in understanding the factors contributing to landslides. Both studies emphasize the
significant role of water in triggering these events. While Wang et al. focused on the general influence of heavy rainfall on mountainous regions, this current study delves deeper, quantifying the link between rainfall

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depth and landslide risk. Similarly, both studies acknowledge the role of specific regional characteristics in exacerbating landslide dangers.

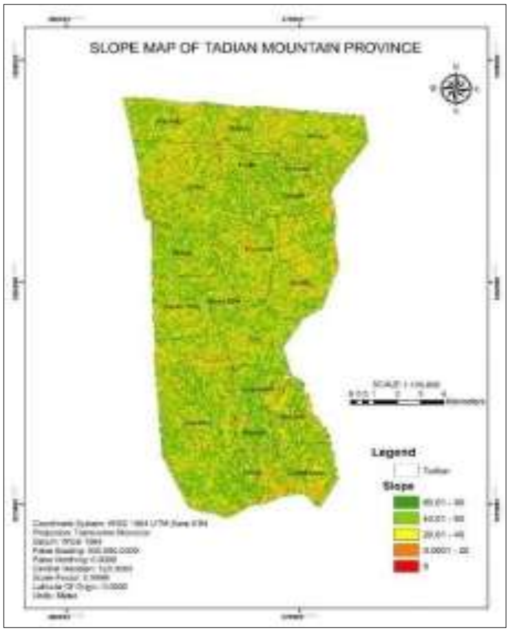


Figure 10. NVDI map of Tadian, Mountain Province

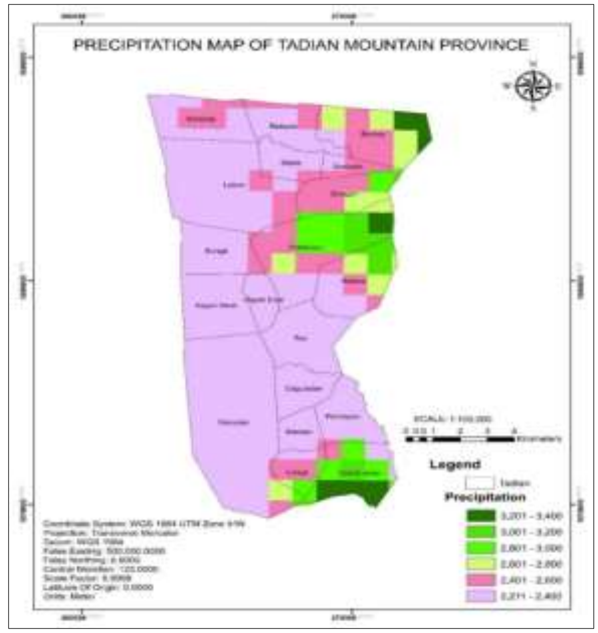


Figure 11. Slope map of Tadian, Mountain Province

Steeper slopes were found to be more susceptible to landslides, consistent with the general understanding that slope angle is a primary factor in slope stability. With the data gathered in this study, the generated slope map of Tadian, Mountain Province is shown in Figure 11.

This study confirms a well-known fact: steeper slopes are more likely to experience landslides. The steeper the slope, the stronger the pull it exerts on soil and rock, pushing them down. Interlocking grains of soil on a gentle slope resist downward force by leaning on each other. But on a steeper slope, gravity wins, reducing the effectiveness of this internal friction and making landslides more probable. Soil type likewise matters as clay-rich soil, with less internal friction, is especially risky on steep slopes. The amount of water in the soil is another factor. Saturated soil loses its internal strength further increasing landslide risk. Vegetation also plays a role wherein healthy vegetation helps anchor the soil and makes slopes more stable. Steeper slopes with sparse vegetation are particularly vulnerable (Highland & Bobrowsky, 2008). The research identifies a critical zone where the risk becomes more severe – slopes with a 25-50% susceptibility range as shown in Figure 2.

Road and River and Network

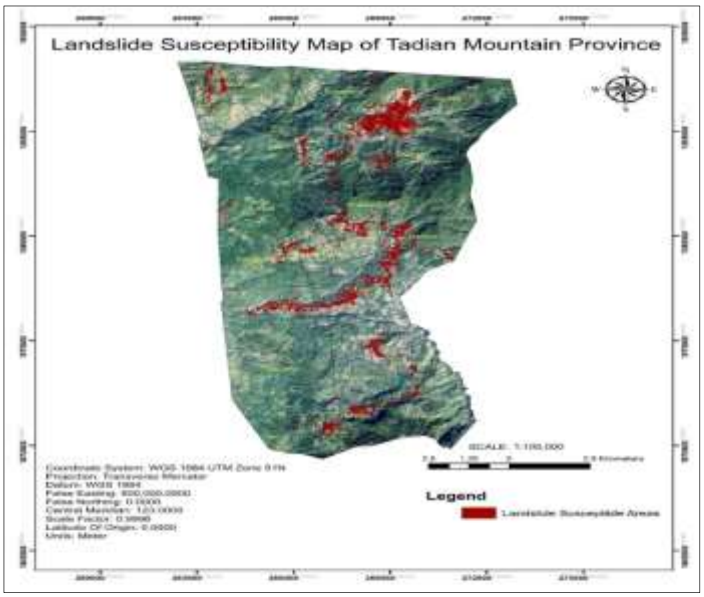
Proximity to roads and rivers also influenced landslide susceptibility. Roads often disrupt natural drainage patterns and destabilize slopes, while rivers can erode their banks and contribute to slope failures. The road and river network maps of Tadian, Mountain province are shown in Figures 12 and 13 respectively. to roads are much more likely to experience landslides, with some zones reaching a critical susceptibility level of as high as 75%-100% as shown in Figure 2. This heightened risk is caused by road construction practices. When roads are built, slopes are often cut into, which removes the soil and vegetation that naturally hold the hillside together. Road construction can also disrupt natural drainage patterns, potentially causing water to accumulate near the road and further weaken the soil. The leftover materials from construction, often piled up on the slopes, can become unstable and contribute to landslides as well.

The situation is amplified by Tadian's mountainous terrain with steep slopes. Steeper slopes are inherently more susceptible to landslides in the first place, and road construction can significantly increase this risk.

The response curve in Figure 2 revealed a link between rivers and landslides. The data show areas bordering rivers face a double threat. The first zone, right next to the rivers (within 1000 meters), has 50-75%

susceptibility to landslides. This vulnerability stems from the rivers themselves. As rivers flow, they erode their banks, removing the soil and vegetation that hold the slopes together. The rivers also raise the water table in nearby areas, making the soil weak and prone to failure, especially during heavy rains. The Tadian's mountainous landscape with steep slopes adds another layer of risk. Earthquakes, frequent in the Philippines, can further destabilize these already weakened riverbanks and trigger landslides.
Further, the situation gets even more complex further away from the rivers. Even at distances exceeding 2400 meters, the susceptibility remains high (50-75%).

Land Susceptibility Map
The landslide susceptibility map as shown in Figure 14 depicts the zones susceptible tolandslide. The susceptible zones are primarily located in areas with steep slopes, high precipitation, certain lithological units, and proximity to roads and rivers.



‘ *Figure 12. Landslide susceptibility map of Tadian, Mountain Province*

The red plots on the map reveal the areas susceptible to landslides. Locations susceptible to landslides are distributed in every barangay of the Municipality. The result of the study reveals that areas with the most susceptible lands are found in the barangays of Sumadel, Batayan, Masla and Bantey. The susceptibility map also shows that the most susceptible to landslides in barangays Balaoa and Tue are those along the road.

CONCLUSIONS AND RECOMMENDATION

The landslide susceptibility map effectively identified areas with landslide risks within Tadian. Steep slopes, high precipitation, certain lithological units, and proximity to road and river networks predominantly characterize high-risk areas. These areas correspond closely with locations of historical landslide occurrences, validating the accuracy of the model.
The study confirmed that multiple factors significantly contribute to landslide susceptibility in Tadian. Among these, slope, precipitation, lithology, and land cover emerged as the most critical. Steep slopes and high rainfall greatly increase the likelihood of landslides, while certain rock types and soil textures also play crucial roles in slope stability.
Vegetation cover, as indicated by NDVI and land cover data, has a stabilizing effect on slopes. Areas with dense vegetation exhibit lower susceptibility to landslides, underscoring the importance of maintaining and enhancing forest cover in landslide-prone regions.

Human activities, such as road construction and urban development, contribute to increased landslide risk. Proximity to roads and rivers was found to correlate with higher susceptibility, highlighting the need for careful planning and infrastructure development to mitigate these risks.
The combination of Logistic Regression analysis and Geographic Information System (GIS) technology proved to be a robust approach for landslide susceptibility mapping. This methodology allows for the integration of various spatial data layers, providing a comprehensive assessment of landslide risk.
Based on the findings, several recommendations were proposed, including enhancing monitoring systems, implementing slope stabilization measures, promoting reforestation, educating communities, and regularly updating the susceptibility map with new data and improved techniques.

a. Enhanced Monitoring and Early Warning Systems:

Implement real-time monitoring of high-risk areas identified on the landslide susceptibility map using remote sensing and on-the-ground sensors to provide early warnings and reduce potential damages.
Develop a comprehensive early warning system that integrates weather forecasts, soil moisture levels, and other critical indicators to alert residents and authorities in advance of potential landslide events.

b. Land Use Planning and Zoning:

Restrict construction and development in high-risk zones identified by the susceptibility map. Implement strict zoning regulations to prevent new settlements and infrastructure in these areas.
Promote safer land use practices by encouraging the development of residential, commercial, and agricultural activities in low to moderate-risk areas.

c. Slope Stabilization and Infrastructure Improvement:

Stabilize vulnerable slopes using engineering solutions such as retaining walls, terracing, and slope vegetation to reduce the likelihood of landslides.
Improve drainage systems to prevent water accumulation and soil saturation, which are significant contributors to landslides. Regular maintenance of drainage channels and culverts is essential.

d. Vegetation and Reforestation Programs:

Initiate reforestation projects in areas with high landslide susceptibility. Planting deep- rooted vegetation can help stabilize slopes and reduce erosion.
Protect existing vegetation in landslide-prone areas to maintain natural slope stability.
Implement conservation practices that prevent deforestation and land degradation.

e. Community Education and Awareness:

Educate local communities about landslide risks and the importance of adhering to safety guidelines and land use regulations. Conduct workshops and disseminate information through various media channels.
Train residents and local officials in emergency response procedures, including evacuation routes and first aid, to enhance preparedness and resilience.

f. Regular Review and Update of the Susceptibility Map:

Continuously update the landslide susceptibility map with new data and improved modeling techniques. Regular updates ensure that the map remains accurate and reliable for decision-making.
Incorporate climate change projections into future susceptibility assessments to account for changing precipitation patterns and their impact on landslide risk.

g. Policy Development and Implementation:

Formulate and enforce policies that support sustainable land management and landslide risk reduction. Ensure that these policies are based on the latest scientific research and best practices.
Allocate resources and funding for landslide risk mitigation projects, including infrastructure improvements, monitoring systems, and community education programs.

h. Future researches

The high susceptibility zone beyond 2400 meters from rivers requires further investigation.

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