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South West Khasi hills district, Mawkyrwat, Meghalaya (India) landslides' 2022: Case studies, lesson learned and mitigation measures

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Abstract
In June of 2022, a series of landslides occurred in the South West Khasi Hills district of Meghalaya during the monsoon season. These events caused significant damage to roads, PHE pipelines, and agricultural areas, and resulted in the deaths of two people and nine animals. The primary cause of the landslides was the incessant rain; Meghalaya being the wettest place on Earth is particularly vulnerable to landslides due to heavy rainfall and extreme tectonic stress. In addition to these natural elements, the construction of roads and excavation activities would have increased the instability of the slopes and increased the risk of landslides. The paper aims to investigate the causes of landslides brought on by intense rains in different economic development, offer solutions to mitigate the effects of such occurrences, and highlight the valuable lessons that may be learned from this regrettable incident.
Keywords: economic development; incessant rain; mitigate; South West Khasi Hills Landslide

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1. Introduction

In June 2020, a large-scale landslip occurred in the Ranikor C&RD Block in the South West Khasi Hills district, causing significant damage to the surrounding community, including buildings, infrastructure, agricultural earth, and crops. Particularly on steep terrain, landslides represent a major threat to neighboring populations and ecological areas. Numerous homes, schools, and government facilities were destroyed by the landslip, which left many families without a place to live and interfered with daily operations in the community. People's ability to move about and obtain basic services was hampered by the significant damage done to the infrastructure, which included roads and bridges.

The agricultural land and crops were also impacted, with enormous portions of farmland buried, making it hard for farmers to cultivate their crops and resulting in severe economic losses and food shortages in the affected areas. Landslides also endanger the safety of local communities and biological habitats, as they can cause widespread displacement of people and animals, resulting in loss of life and injury, as well as the release of harmful pollutants with long-term health consequences for the community.

Precipitation-triggered landslides occur through a complicated and multidimensional mechanism, but it often involves soil and rock mass saturation, resulting in a loss of cohesiveness and stability (Hungr et al., 2013). When rainfall exceeds the soil's infiltration capacity, surplus water runs off the surface or seeps into the ground, resulting in increased pore water pressures and decreased shear strength (Cruden & Varnes, 1996). Depending on the site circumstances, this can lead to slope failures, debris flows, or other types of landslides.

When it comes to property damage and fatalities, the effects of precipitation-triggered landslides can be disastrous (Froude & Petley, 2018; Petley, 2012; Schuster et al., 2001). Homes, infrastructure, and agricultural land can all be destroyed by landslides, resulting in annual economic damages exceeding billions of dollars (Petley et al., 2005). Additionally, they have the potential to seriously harm the environment by causing things like soil erosion, stream sedimentation, and vegetation loss (Kirschbaum et al., 2015).

Because of its impact on precipitation patterns, climate change is expected to increase the frequency and severity of landslides. Because intense rainfall events saturate the soil surface and accelerate water runoff, they can result in shallow landslides, including mudslides and debris flows (Huggel et al., 2011). Rock collapses and other deep-seated landslides can be caused by prolonged, intense rainfall because the increased water content in the earth weakens and destabilises the bedrock (Crozier, 2010).

Furthermore, extreme precipitation events are predicted to become more intense and prolonged due to climate change. This could increase the risk of landslides and increase their likelihood, as well as their potential for damage and fatalities (Davenport et al., 2021; Singh et al., 2013; Handwerger et al., 2019, 2021, 2022). This emphasises the need of understanding the intricate interactions among precipitation, climate change, and landslide hazards and of creating practical plans for adaptation and mitigation of landslide risk.

Meghalaya's many rivers and other bodies of water raise the danger of flash floods, while the region's hilly topography and steep slopes make it vulnerable to landslides during periods of intense rainfall. During cyclones, the area is also susceptible to strong gusts that could destroy nearby vegetation and infrastructure. Because Meghalaya is situated in a seismic zone, there is a greater chance of earthquakes, which might worsen the region's vulnerability by causing landslides. Meghalaya is experiencing more frequent and intense natural catastrophes due to climate change. Rising temperatures and altered rainfall patterns are exacerbating the effects of cyclones, floods, and landslides.

Due to the force of gravity acting on unstable terrain brought on by mountainous topography, loose soil, and rock formations, heavy rainfall during the monsoon season made dirt heavier and more likely to slide down steep slopes. As a result, there were several landslides in the South West Khasi Hills District, which severely damaged the area's infrastructure and evicted a large number of residents.

In 2022, a period of intense rainfall in Meghalaya, India's South West Khasi Hills area led to landslides and the forced relocation of residents. The purpose of this study is to identify potential techniques for disaster mitigation in the future by analyzing the relationship between rainfall patterns and the occurrence of landslides during these intense downpours.

2. Methods

2.1. Study Area

The South West Khasi Hills district is situated in the northeastern state of Meghalaya, India. It covers an area of 1,341 square kilometers and is located at 25.3106° N, 91.2059° E. The district shares borders with the West Khasi Hills district to the north, Bangladesh to the south, the East Khasi Hills district to the east, and the West Khasi Hills district as well as the South Garo Hills district to the west. According to the 2011 Census, the total population of the district is approximately 1,10,152 people, with a literacy rate that stands at 76.84%. The district's elevation is around 1,524 meters, and it is situated around 75 kilometers away to the east-northeast direction relative to Shillong, the capital city in Meghalaya. The terrain in South West Khasi Hills is characterized by rolling hills that are interspersed with boulders, some of which are exceptionally large in size.

The study was divided into three parts: i. On June 23, 2022, a field investigation was carried out to record the landslides that took place. ii. Field research to ascertain how the socioeconomic circumstances in the study area are impacted by landslides. iii. To ascertain the relationship between the different contributing elements and the landslides that occurred in the research region. An event-based landslip inventory (April to July and September to October 2022) was created through participatory field mapping. To find out where field mapping will take place, we looked through newspaper articles and had conversations with representatives of the District Disaster Management Authority South West Khasi Hills District.

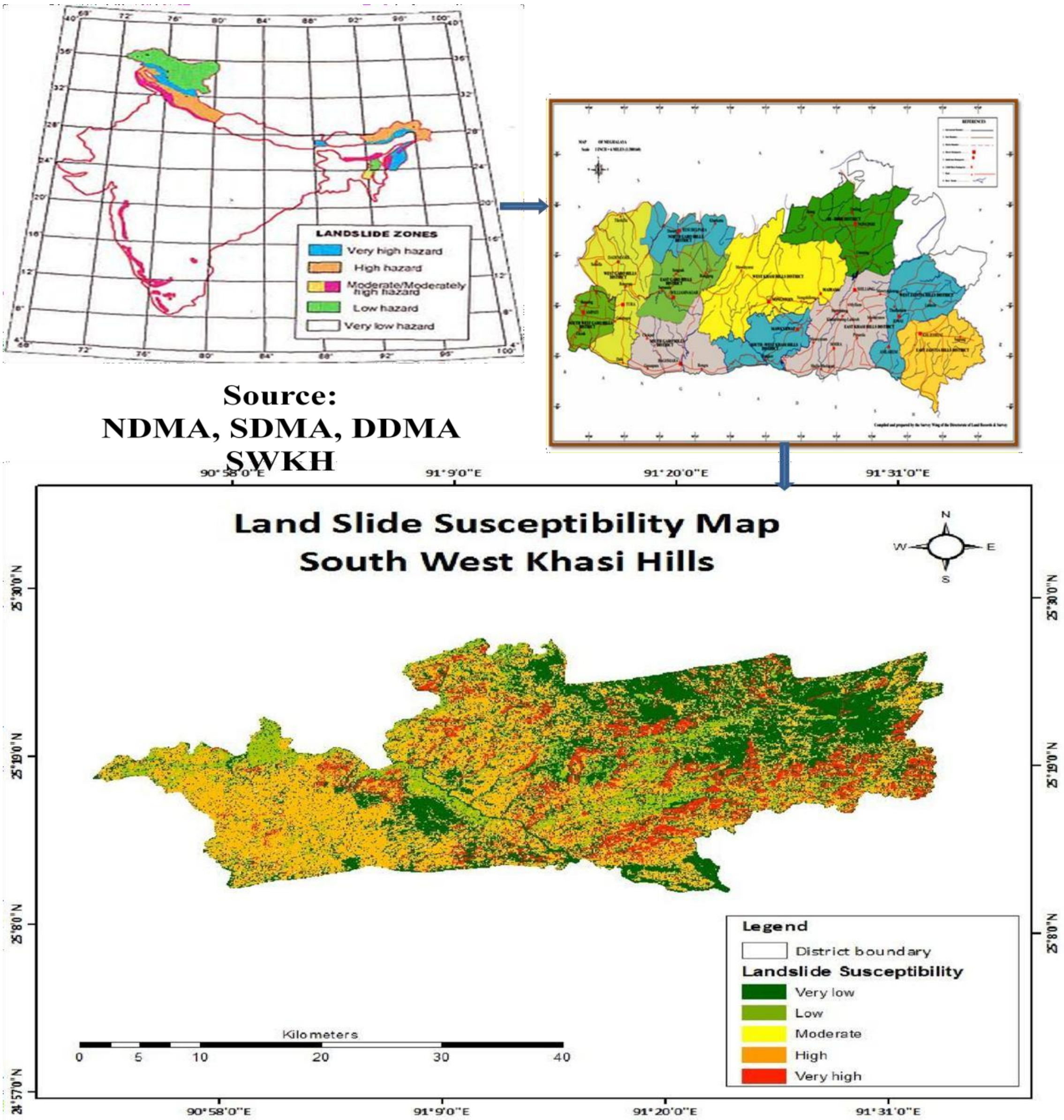

Figure 1. Study Map for South West Khasi Hills District, Meghalaya

2.2. Data Processing and Analysis

The data used in this study was maintained by the District Disaster Management Authority South West Khasi Hills District of Meghalaya.

The study utilized statistical methods such as t-tests, ANOVA, regression analysis to examine hypotheses, identify relationships between variables, draw conclusions, and make recommendations based on collected data. These inferential statistics were complemented with descriptive statistics, and the results were presented in tables and graphs for easy interpretation and understanding. Overall, a mix of descriptive and inferential statistics was employed to provide a thorough analysis of the data and draw significant insights.

3. Results and Discussion

According to the survey data supplied, the monsoon season in the South West Khasi Hills District (probably in the year of data collection) was marked by significant rainfall, with a total of 6509 millimeters (mm) falling between April and October. The rainfall was particularly heavy in June, with the most landslides (n=85) observed during this time. May also had a high number of landslides (n=34), whereas the lowest numbers were reported in April (n=10), September (n=7), October (n=4), and July (n=2). These results indicate that the monsoon season in this district was characterized by excessive rainfall and an increase in landslides between June and May (Table 1).

Table 1. Occurrence of landslides due to heavy rainfall in South West Khasi Hills, Meghalaya in 2022

Index	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Amount of rainfall (mm)	17	99	49	585	1566	2815	377	268	474	423	0	0
No. of landslides (times)	0	0	0	10	34	85	2	0	7	4	0	0

Recently, there was a terrible landslip in India's South West Khasi Hills District that seriously damaged both agricultural earth and public infrastructure and left two people dead. A total of 3887 persons, residing in about 630 dwellings, have been impacted by the tragedy; nine (9) livestock have also perished. In addition, the landslip has destroyed 52 gravity main lines, 101 hectares of agricultural earth, and 61 roadways. The impacted communities have been greatly impacted by this calamity, so it is crucial to offer those affected with relief and support right once (Table 2).

Table 2. Damages/loss due to Flash floods/Landslides in South West Khasi Hills District 2022

Sl.No	Block affected	No. of Househol daffected	No. of populatio naffected	No. of Person died	No. of Animal died	Roads (Nos)	Agricult ure(ha)	PHE (main line)
1	Ranikor C&RD Block	627	3758	1	1	39	13	33
2	Mawkyrw atC&RD Block	23	129	1	9	23	88	19
	Total	630	3887	2	9	61	101	52

The study observed that changes in vegetation patterns and landscape deterioration lead to decreased soil moisture retention, resulting in higher flow during rainstorm events, which can cause landslides. The study also emphasized the necessity of controlling land use in landslide-prone areas to reduce ground disturbance and erosion. To lessen the risk of landslides, it was advised that drainage systems be improved and soil saturation be reduced. The study emphasizes the importance of a comprehensive landslip risk management strategy that takes into account both natural and human-induced causes.

Additionally, the soil's ability to resist sliding is shown by a lower friction angle in moist soil. Accordingly, landslides in saturated soil conditions can be caused by minor changes in slope or disturbances like strong rains or earthquakes. Increased pore water pressure from saturated soil can further weaken the soil and enhance its susceptibility to landslides. Thus, in order to reduce the risk of landslides during periods of high precipitation, it is essential to monitor groundwater levels and soil moisture content. To lessen the chance of landslides in saturated soil conditions, strategies like drainage systems, land use planning, and slope stabilization measures can be used.

Based on the information provided in Figure 2, it can be observed that there is a correlation between average monthly rainfall and the number of landslides. Specifically, there were fewer landslides in April with an average monthly rainfall of around 100 mm compared to May with an average monthly rainfall of around 150 mm, which saw 34 landslides. This trend continued in June with an average monthly rainfall of around 200 mm and a significantly higher number of landslides at 85. This suggests that rainfall has a positive correlation with both the probability and the quantity of landslides; the quantity increases with increased rainfall. This information could be useful in developing strategies to mitigate the impact of landslides, such as implementing measures to manage water runoff during heavy rainfall and improving the resilience of infrastructure and communities in areas prone to landslides.

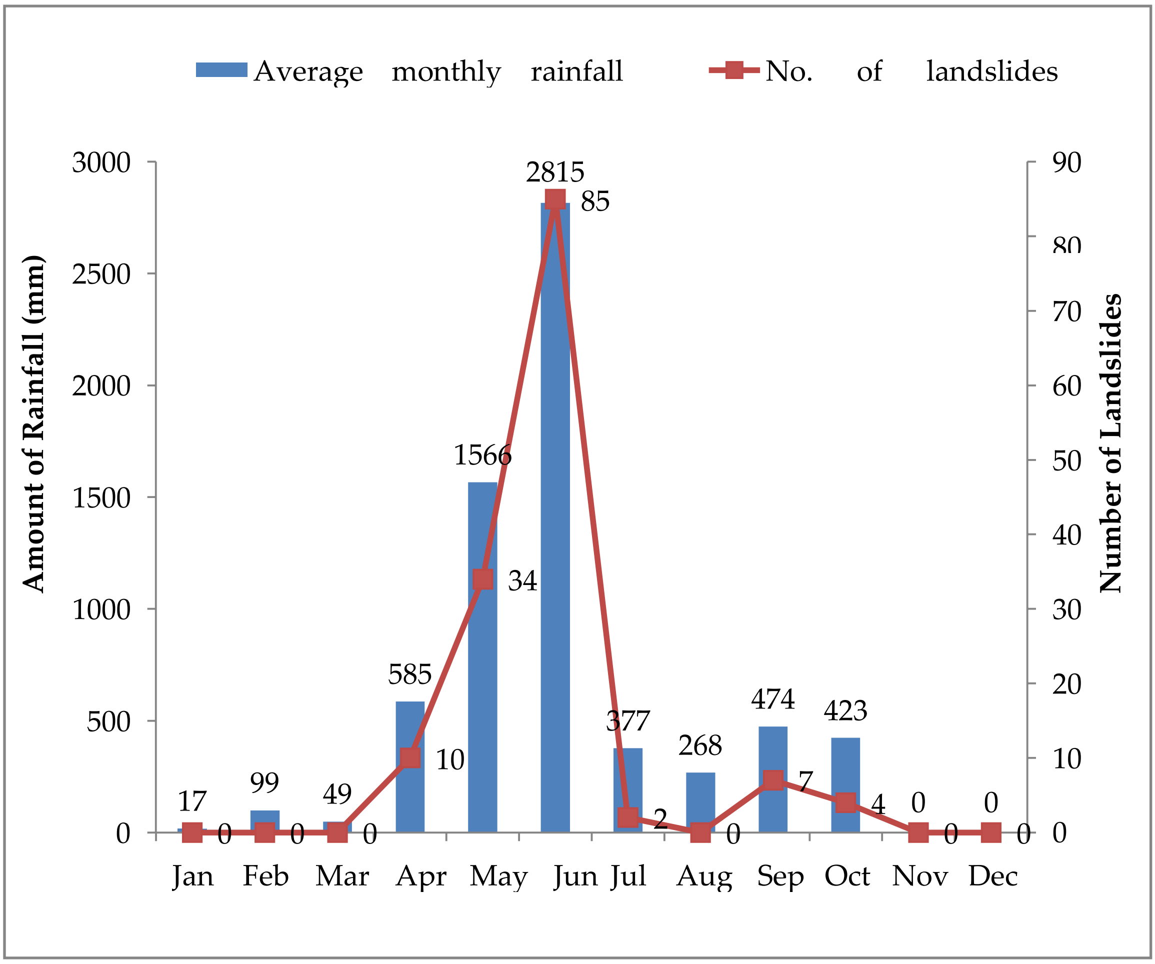

Figure 2. Occurrence of monthly rainfall and number of landslides in South West Khasi Hills, Meghalaya in 2022

Figure 3A. Specimen photographs capturing devastation caused by rain and landslides at the Maheskhola South West Khasi Hills, Meghalaya (Source: DDMA, SWKH)

Figure 3B. Specimen photographs of eroded section of roads and bridges (Sources: DDMA, SWKH)

Figure 3C. Specimen photographs of eroded section of Agricultural land (Sources: DDMA, SWKH)

Figure 3D. Specimen photographs of eroded section of gravity main pipe lines (Sources: DDMA, SWKH)

3.1. Lesson Learned

The region of South West Khasi Hills District in Meghalaya, India has witnessed several landslides in recent years. In particular, the year 2022 has seen some significant landslide events that have caused damage to infrastructure and loss of life.

It is crucial to keep a careful eye on precipitation patterns and groundwater levels in order to manage the risk of landslides. This can assist in alerting authorities to high-risk landslip locations so they can take preventative measures like drainage systems or slope stabilization before the disaster happens.

Assessing and reducing the danger of landslides also requires an awareness of the geological features and circumstances of the slope, including the kind of soil, the structure of the rocks, and the amount of vegetation cover. By adopting a comprehensive strategy for managing the risk of landslides, authorities can minimize the possibility of fatalities and property damage by effectively anticipating and responding to landslide incidents.

3.2. Mitigation Measures for Future Landslides

To mitigate future landslides in South West Khasi Hills district of Meghalaya, the following measures should be taken:

1. Implement comprehensive land use planning considering geological and hydrological conditions to identify landslide-prone areas and avoid construction in those areas.
2. Promote afforestation to stabilize soil, prevent landslides, and reduce soil erosion and runoff.
3. Encourage farmers to adopt terracing as a farming practice to prevent soil erosion and landslides.
4. Invest in building proper drainage systems to divert water during heavy rainfall, a major cause of landslides.
5. Install early warning systems to detect signs of landslides and alert residents for timely evacuation.
6. Establish a well-planned disaster management system to respond quickly and efficiently to landslide disasters and minimize loss of life and property.
7. Provide training and capacity building programs to help residents understand landslide risks and ways to mitigate them, fostering resilience and reducing impact.
8. Involve the local community in landslide mitigation efforts for ownership, responsibility, and long-term sustainability.
9. Invest in research and development to understand the causes of landslides and develop innovative solutions, facilitating a comprehensive strategy for landslide mitigation.

4. Conclusions

Following the landslide incidents in South West Khasi Hills District, Mawkyrwat, Meghalaya, India in 2022, it has become evident that comprehensive measures are required for mitigating landslide risks. Based on case studies, lessons learned and implemented mitigation measures, the following conclusions can be drawn:

1) Accurate landslide susceptibility mapping using remote sensing technologies, GIS and machine learning algorithms should guide land use planning as these maps can significantly enhance their accuracy and reliability. Regular updates should also be carried out considering changes like land use and climate.
2) Watershed management practices like afforestation, soil conservation, and drainage improvement should be implemented at the community level involving local communities.
3) Disaster risk reduction measures like early warning systems, evacuation plans and emergency response plans should be developed and implemented at both district and community levels. These measures should also undergo regular reviews and updates.
4) Capacity building programs should enhance the knowledge and skills required for landslide risk management among local communities and stakeholders. These programs should cover topics like landslide hazard assessment and response/recovery.
5) Collaboration and coordination among different stakeholders like government agencies, NGOs, and local communities should remain essential for effective landslide risk management. Regular meetings and workshops should facilitate communication and collaboration among these stakeholders.
6) Climate change adaptation measures like rainwater harvesting, water conservation, and flood management should be implemented to mitigate the impacts of climate change on landslide risks.

7) Regular monitoring and evaluation of landslide risk management strategies should be carried out to assess their effectiveness and identify areas for improvement. The results of these evaluations should be used to refine and update the strategies as necessary.

Therefore, the landslide incidents in South West Khasi Hills District, Mawkyrwat, Meghalaya, India in 2022 have highlighted the need for comprehensive measures to mitigate landslide risks. These conclusions offer guidance on developing effective landslide risk management strategies for this region as well as similar areas.

Furthermore, implementing early warning systems and conducting regular landslide hazard assessments can help communities prepare and respond to potential landslide events. The government can also explore alternative livelihood options for communities living in high-risk areas that rely heavily on agriculture for their livelihoods. By prioritizing damage mitigation and promoting community resilience, we can reduce the impact of landslides and promote sustainable development in landslide-prone areas.

The recent tragedy in the South West Khasi Hills serves as a stark reminder of the importance of assessing additional local parameters and developing site-specific scientific and engineering solutions in seismically active regions like the North East. It highlights the need for thorough safety and environmental reviews for all development projects in such areas.

The disaster has taught us that one size fits all solutions may not be effective in seismically active regions. The local geology, topography, soil conditions, water resources, and other factors must be taken into account while designing development projects. This will ensure that the projects are safe, sustainable, and environmentally friendly.

It is crucial that we learn from this tragedy and reverse the disastrous course as soon as possible. Failure to do so will result in similar disasters in the future. We must prioritize safety and environmental concerns over short-term gains.

The landslide events in South West Khasi Hills District in 2022 have highlighted the need for proper land use planning, improved drainage systems, and early warning systems to prevent landslides and reduce the risk of loss of life and damage to infrastructure. The government should consider implementing these measures to mitigate the impact of landslides in the region.

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Conflicts of Interest

The authors declare that they have no competing interests.

Data collected

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