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Integrating Infrastructure, Financial Preparedness, and Informational Resources for Effective Landslide Risk Management in the Langat Basin, Malaysia: A GIS-Based Analysis

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Abstract

Landslides present significant challenges to communities, particularly in regions where access to critical resources is uneven. This study examines the role of infrastructure, financial preparedness, and informational resources in managing landslide risks within the Langat Basin. Through GIS-based analysis, the research identifies substantial disparities in road accessibility, especially in rural and high-risk areas, underscoring the need for targeted infrastructure investments to enhance disaster response and resilience. Despite relatively high overall household income levels, financial inequalities persist, with marginalized communities facing heightened vulnerabilities due to rising living costs and limited access to disaster insurance. The study highlights the importance of inclusive financial strategies, such as subsidies, low-interest loans, and community-based disaster funds, to reduce these disparities. Informational resource gaps, including the lack of up-to-date hazard maps and underdeveloped early warning systems, further exacerbate risks. Addressing these deficiencies through real-time monitoring, comprehensive hazard mapping, and targeted public awareness campaigns is essential for empowering communities and improving preparedness. This research underscores the need for a multi-dimensional approach to landslide risk management, integrating advanced geospatial tools, equitable financial policies, and robust informational frameworks to build resilient and equitable communities. Future research should incorporate localized assessments and real-time data to refine these strategies and ensure equitable outcomes.

Keywords: Resource Access, Disaster Preparedness, Slope Failure Risk, Spatial Analysis, Geographic Information System (GIS)

Introduction

Landslides rank among the most destructive natural hazards, posing severe risks to human lives, infrastructure, and livelihoods. These disasters often occur without warning, triggered by factors such as heavy rainfall, earthquakes, or human-induced land use changes (Froude et al., 2018; Popescu, 2002). The Langat Basin, characterized by its geological composition, hilly terrain, and tropical climate, is highly susceptible to slope failures. The expansion of urban areas has altered natural slopes, increasing both the frequency and severity of such failures. Additionally, human activities such as land clearing and construction further destabilize the slopes, exacerbating the risk of slope failure (Froude et al., 2018; Mukherjee, 2022). Damaging landslides in Malaysia, as at Bukit Antarabangsa and Highland Towers, emphasize the urgent concern for appropriate management of slope stability within the urban environment. Landslides pose significant challenges in regions like Malaysia, where diverse land uses, steep terrains, and high rainfall contribute to their frequent occurrence. The Langat River Basin, a critical area for understanding landslide susceptibility, has been the focus of advanced predictive modeling techniques such as artificial neural networks (ANN) to assess risks more accurately (Selamat et al., 2022, 2023). Additionally, the spatial relationship between landslide events and human activities underlines the need for sustainable land-use planning to mitigate risks (Selamat et al., 2023). Studies exploring local variations in landslide factors, including in Pulau Pinang and Kuala Lumpur, have demonstrated how physical and demographic characteristics influence landslide risks (Zulkafli et al., 2023a, 2023b). These findings emphasize the importance of integrating geospatial analysis and interdisciplinary approaches to develop effective risk management and mitigation strategies, particularly in regions like the Langat Basin where resource access and infrastructure play a crucial role in disaster resilience.

In the Langat Basin, rapid urbanization and a notable rise in population over recent decades have fueled substantial economic growth and expanded human activities. However, this development has also increased the region's exposure to geohazards, particularly slope failures, creating a delicate balance between progress and risk. While the physical triggers of landslides in the area are well-documented, the socio-economic dimensions especially access to critical resources remain inadequately explored and analyzed. Understanding how resource accessibility intersects with vulnerability is essential to comprehensively addressing the challenges posed by these hazards (Kjekstad & Highland, 2009; Winter, 2014). Resource access is critical for mitigating the impacts of landslides. It includes infrastructure, financial resources, and informational resources that collectively determine a community's capacity to prepare for, respond to, and recover from such events. For instance, well-constructed roads and bridges enable timely evacuations, financial support facilitates recovery, and early warning systems reduce casualties. However, disparities in resource access often leave vulnerable communities disproportionately affected (Shakya et al., 2023). Despite advancements in understanding the physical triggers of landslides, the socio-economic dimensions of vulnerability remain underexplored, particularly in the context of resource accessibility. This gap in knowledge is critical, as resource access including infrastructure, financial resources, and information plays a pivotal and significant role in determining a community’s capacity to mitigate, respond to, and recover from landslide events. Addressing disparities in these areas is essential for reducing the disproportionate impact of landslides on vulnerable populations.

Moreover, resource access is a critical determinant of a community's ability to mitigate, respond to, and recover from landslides. Infrastructure, financial resources, and access to information collectively shape resilience against these natural disasters. For instance, well-designed and maintained roads and bridges facilitate timely evacuations and ensure aid delivery, reducing casualties and economic losses (Scaioni, 2013). Financial resources empower local authorities and individuals to invest in mitigation strategies and recovery efforts (Mertens et al., 2016). Furthermore, early warning systems and timely notification of disaster, when effectively implemented, significantly reduce casualties and damages (Larsen, 2008). However, disparities in resource distribution leave vulnerable and economically disadvantaged communities disproportionately affected by landslides (Turner, 2018). These disparities often result from inadequate infrastructure, insufficient financial aid, and limited access to critical information, exacerbating the impacts of landslide events.

This study focused on encompassing the three key dimensions: infrastructure, financial resources, and informational resources. Infrastructure, such as roads plays a pivotal role in landslide risk reduction. Well-maintained infrastructure facilitates timely evacuations, ensures accessibility for emergency responders, and reduces disruptions in critical services during disasters. Conversely, poorly designed or aging infrastructure can exacerbate vulnerabilities and hinder recovery efforts. Financial resources are equally essential for both individual and community resilience. Government funding for preventive measures, such as slope stabilization and hazard mitigation projects, is crucial. Additionally, personal financial resources, such as savings or insurance, support recovery efforts. However, communities with limited financial capacity often struggle to implement long-term solutions or respond effectively to disasters. Informational resources, including hazard maps, early warning systems, and educational campaigns about landslide risks, are vital for preparedness and response. Accurate and timely information empowers communities to take proactive measures, reducing casualties and economic losses. Unfortunately, the absence or underutilization of these resources often leaves communities unprepared and vulnerable during disasters. Despite their importance, disparities in resource access often leave vulnerable communities disproportionately affected. Remote and economically disadvantaged regions typically lack robust infrastructure, sufficient funding, and reliable informational systems, which amplifies their exposure to landslide risks and reduces their ability to recover effectively.

This study aims to further analyzed the effect of resource access by identifying gaps and provide actionable insights to enhance resource availability and utilization in landslide-prone areas. Such an assessment is vital for improving disaster preparedness and contributing to more equitable disaster risk reduction strategies. By integrating GIS-based spatial analysis with socio-economic assessments, the research provides actionable insights for policymakers, planners, and disaster management professionals. These findings align with global initiatives, such as SDG 11, by promoting inclusive and resilient disaster risk management strategies. Ultimately, the study aims to empower communities with improved resource access and practical solutions to mitigate landslide risks, contributing to a more equitable and sustainable future.

Study Area and Methodology

Study Area

The Langat Basin, situated in central Peninsular Malaysia, spans latitudes from approximately 2.500°N to 3.200°N and longitudes from 101.300°E to 102.000°E. Covering an area of around 2,350 km², the basin features so many diverse geographical characteristics. Its upstream regions are dominated by hilly terrains, making them highly prone to slope failures, whereas the downstream areas consist primarily of flatlands. The basin experiences a tropical climate, characterized by consistently high temperatures averaging 27°C and substantial rainfall throughout the year, with a mean annual rainfall of approximately 2,470 mm. The heaviest rainfall typically occurs in March and November. These climatic conditions, combined with the basin's geological features, contribute significantly to slope instability and increase the risk of landslides.

The Langat Basin also encompasses a mix of rural and urbanized areas, with significant development concentrated in its central region, particularly in Putrajaya, Sepang, and the lower part of Hulu Langat. According to the Department of Statistics Malaysia (DOSM, 2024), adding together all the district data, the basin has an estimated population of 3 million. This population reflects a diverse socio-economic composition, including civil servants, small to medium business operators, and job seekers engaged in multiple forms of employment. Access to resources within the Langat Basin varies significantly across its diverse regions and demographic groups, reflecting a complex interplay of geographical, socio-economic, and infrastructural factors.

Data Collection and Analysis

This study employs a secondary data analysis approach to assess resource access in the context of landslides, focusing on infrastructure, financial resources, and informational resources. Data collection and analysis were structured to leverage Geographic Information Systems (GIS) for spatial evaluation, ensuring a comprehensive understanding of resource distribution and its relationship with landslide risks. Data for the infrastructure assessment primarily relied on GIS datasets, particularly road network data obtained from OpenStreetMap (OSM). This included information about road accessibility and proximity to high-risk areas. The data underwent a cleaning process to ensure clarity and relevance, eliminating extraneous elements like human walkways and minor rural roads that could obscure analysis. Using ArcGIS, maps were created to visualize the road network's spatial distribution and highlight regions with inadequate infrastructure. These maps were integrated with population density data and hazard zones to identify areas with limited access to essential evacuation and response routes. Hillshade analysis was also conducted to provide a three-dimensional perspective of terrain features, aiding in identifying areas where infrastructure might be most vulnerable to slope failures. Financial resource analysis involved the transformation of income and financial data from census reports into clear tables and visualizations. Key metrics included household income levels, which were analyzed to understand the financial resilience of communities in the Langat Basin. This information was cross-referenced with GIS-based infrastructure assessments to explore the interplay between financial capacity and physical access to resources. Informational resources were evaluated by examining the availability of hazard maps, early warning systems, and public awareness programs. Data from governmental and NGO reports provided insights into the distribution

and effectiveness of these resources. Specific attention was given to identifying gaps in real-time warning systems and educational campaigns that affect community preparedness.

To analyze the hydrological and topographical influences on landslide risks, proximity to rivers and slope stability factors were incorporated. River networks and slope angle were analyzed to identify erosion-prone areas that contribute to slope instability. Proximity analysis using GIS tools allowed for an understanding of how road networks and essential infrastructure interact with high-risk zones, enabling the identification of critical nodes requiring fortification. A network analysis simulated potential transportation disruptions due to slope failures, offering a pathway to optimize alternative routes. Data synthesis integrated findings from all these assessments. Overlay analysis in GIS provided a multi-layered susceptibility model, pinpointing high-risk zones across the Langat Basin. This comprehensive approach allowed for the identification of areas most in need of infrastructure improvements, financial support, and enhanced informational resources. The output serves as a foundational tool for targeted risk mitigation and planning, contributing to a more resilient disaster management framework for the region.

Table 1
Demographic Data of Langat Basin

Regions	Population ('000)	Age ('000) (0 – 14)	Age ('000) (15 – 64)	Age ('000) (65+)	Household Income (RM)
Hulu Langat	1,508.1	314.2	1069.2	124.7	10 317.00
Sepang	346.9	79.3	242.3	25.1	11 724.00
Kuala Langat	326.3	77.5	225.4	22.3	8 717.00
Putrajaya	120.3	41.7	76.2	2.3	12 840.00
Seremban	712.7	166.2	497.1	49.5	7 601.00

(Department Of Statistics Malaysia 2024)

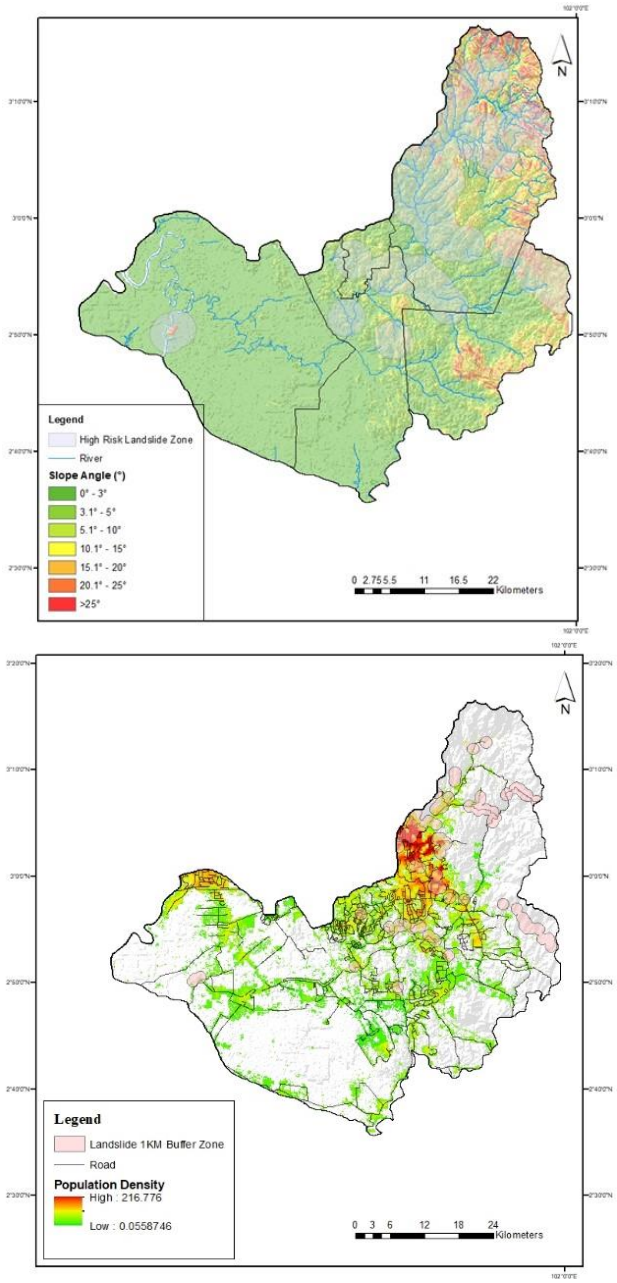

Figure 1 : Spatial Data of Langat Basin

Results and Discussion

The discussion evaluates the three main findings on infrastructure accessibility, financial preparedness, and informational resource gaps in addressing landslide risks in the Langat Basin. These insights, derived from GIS analysis and secondary data, offer a comprehensive understanding of vulnerabilities and actionable recommendations for enhancing resilience.

Infrastructure Accessibility

Through past studies, significant disparities in accessibility were revealed, especially in rural and high-risk areas. In some part of Langat Basin regions, poorly maintained or limited road infrastructure can severely hampers the ability to evacuate promptly or mobilize emergency response teams during landslide events. These limitations exacerbate the immediate risks posed by landslides, leading to delayed assistance and prolonged recovery periods. However,

the road network in Langat Basin was analyzed further to understand accessibility to critical infrastructure in the event of a landslide. Through a more detailed analysis of road accessibility, although there are no significant road quality problems, many parts of the road network are located near historical landslide events, increasing the risk of road disruption. In the upstream region, specific roads such as Jalan Hulu Langat, Jalan Ampang - Hulu Langat, Jalan Sungai Tekali, Jalan Sungai Lalang, and Jalan Sungai Lui are at higher risk of being affected if a landslide occurs in the rural areas of Hulu Langat. If a landslide event were to occur in the urban areas, the road network of the urban region in Langat Basin may still be affected which can cause a significant disruptions in access to infrastructure, mobility and services. However, there are backup roads that can be used in case of such events; although, if a high-magnitude landslide occurs, parts of the hilly region might be completely cut off, leading to isolation. It is noteworthy that the roads in the Langat Basin are generally in good condition and serve to effectively connect people throughout the region.

Addressing these issues requires targeted investments to improve road connectivity and reinforce vulnerable sections of the road network. For instance, rural areas with limited access to main roads should be prioritized for upgrades to ensure reliable connectivity during emergencies (Gangwal et al., 2023; Sim & Cho, 2023). Furthermore, disaster management plans must integrate infrastructure resilience as a core component, focusing on the construction of durable roads and bridges that can withstand extreme weather and geological disruptions. Strengthened infrastructure not only supports immediate disaster response but also facilitates long-term socio-economic development in high-risk regions (Scaioni, 2013). Secondly, areas with a dense population and well-developed road networks tend to achieve higher evacuation rates during simulated emergency scenarios (Alaeddine et al., 2015; Bretschneider & Kimms, 2012). A well-connected road network and an appropriate public transport system also favor faster economic recovery after the calamity because people can access places and get back to their daily activities fast. Resilient infrastructure cuts down the chances of secondary disasters, for example, landslides caused by heavy rainfall or other hazardous conditions, which in turn reduces overall effects of the landslide events.

The figures also highlighted that in high-risk zones, many areas in the population would have limited road access if there is landslide disaster, making evacuation during landslide events extremely challenging (Hou et al., 2017). Furthermore, the analysis of the figures 1 revealed that areas within 5km of historical landslide events still face a considerable risk due to high slope angle and proximity to the river, emphasizing the importance of preparedness and infrastructure improvements in these high-risk regions that can be properly addressed (Mandal & Mondal, 2019). In the event of a disaster, rural areas may face isolation due to limited infrastructure, while dense urban areas could experience significant challenges due to the high population concentration and potential infrastructure strain (Aksha et al., 2020; Serulle & Cirillo, 2014; Turner, 2018). While no specific populations were assessed in this study due to the lack of fieldwork and primary data collection, it is evident that both rural and urban populations are at risk albeit for multiple different reasons.

Financial Preparedness

Household income data revealed stark inequalities in financial resilience across the Langat Basin, with lower-income communities being the most vulnerable. These populations face significant barriers to adopting preventive measures, such as slope stabilization or emergency

preparedness kits, and experience prolonged recovery times after landslide events due to limited financial resources (Anderson et al., 2014). While the Langat Basin demonstrates relatively high overall household income levels, the findings reveal significant financial inequalities that exacerbate vulnerabilities to landslides. These inequalities are observed across different socio-economic groups and geographic areas, highlighting critical gaps in financial resilience.

Firstly, income distribution across the region is uneven, with rural and marginalized communities disproportionately affected. Despite high average incomes, these groups often lack the financial capacity to implement preventive measures such as slope stabilization or invest in disaster preparedness resources. This disparity underscores the need for targeted financial support mechanisms that specifically address the challenges faced by economically disadvantaged groups (Anderson & Holcombe, 2006; Vlaeminck et al., 2016). Secondly, high income does not always equate to financial resilience. Rising living costs, coupled with limited access to disaster insurance, leave many households economically vulnerable. Without adequate financial buffers, these households struggle to recover from landslide impacts, prolonging their recovery period and increasing long-term vulnerabilities (Antronico et al., 2020; Batista & Passini, 2023; Perera et al., 2019). Addressing these challenges requires innovative solutions, such as subsidized insurance schemes and government-backed low-interest loans, to enhance financial security in high-risk areas. Thirdly, financial vulnerabilities often intersect with other social factors, such as age, health, and disability, compounding the risks for certain population groups. For example, elderly residents or individuals with disabilities in affluent areas may still lack the means or support systems to effectively prepare for or recover from landslides (Fernandez et al., 2002; Lee et al., 2016; Meyer, 2017). This layered vulnerability highlights the importance of inclusive financial strategies that consider the diverse needs of all community members.

To mitigate these inequalities, it is essential to develop community-based disaster funds, promote localized economic resilience programs, and improve financial literacy through public awareness campaigns. These interventions can empower communities to adopt proactive measures and build a stronger foundation for disaster resilience. Enhancing financial preparedness requires implementing accessible support mechanisms. Government subsidies and low-interest loans can provide the necessary financial assistance to at-risk households, enabling them to invest in preventive measures and recover more effectively after disasters. Additionally, community-based disaster funds can act as a localized financial safety net, ensuring that even the most vulnerable populations have access to emergency resources. Bridging financial gaps is essential for reducing long-term vulnerabilities and ensuring equitable disaster resilience.

Informational Resource Gaps

Access to reliable and timely informational resources is critical in reducing the impacts of landslides. Hazard maps, early warning systems, and public awareness campaigns form the backbone of disaster preparedness and response, enabling communities to take proactive measures and avoid catastrophic losses (Wu et al., 2009; Xuan et al., 2007). However, significant gaps and lacks of action in these resources have been identified, particularly in landslide-prone areas like the Langat Basin.

Firstly, the lack of comprehensive and up-to-date hazard maps poses a significant challenge. These maps are essential for identifying high-risk zones and guiding land-use planning and evacuation strategies (Wadhawan, 2019). In many regions, hazard maps are either outdated or unavailable, leaving communities and local authorities with insufficient data to make informed decisions. Bridging this gap requires investments in geospatial data collection and analysis to develop accurate, user-friendly maps that are regularly updated and accessible to all stakeholders. Secondly, early warning systems are underdeveloped or non-existent in several parts of the Langat Basin. Timely alerts are crucial for preventing loss of life and minimizing damage during landslide events. The absence of these systems limits the ability of communities to respond promptly, often resulting in delayed evacuations and increased casualties. Implementing real-time monitoring systems that integrate weather data, soil moisture levels, and geotechnical parameters can significantly enhance preparedness and response capabilities (Greco & Pagano, 2017; Piciullo et al., 2018). Thirdly, public awareness about landslide risks and safety measures remains low due to the unavailable or lacks of infoormation in many communities in Langat Basin. Informational campaigns tailored to local contexts are either insufficient or not conducted consistently. This lack of awareness exacerbates vulnerabilities, as communities may not recognize early warning signs or understand how to respond effectively during emergencies (Fathani et al., 2016; Piciullo et al., 2018). Expanding education and outreach programs through schools, community centers, and digital platforms can address this gap and empower individuals with the knowledge needed to mitigate risks (Boon et al., 2012; Fernandez et al., 2002). Technology plays a pivotal role in addressing informational resource gaps. Mobile applications and online platforms can be utilized to disseminate hazard information and real-time alerts effectively. Collaborations between government agencies, NGOs, and technology providers can ensure the creation of accessible and reliable tools that meet the needs of diverse communities.

Finally, closing these informational gaps requires a coordinated effort to prioritize investments in data infrastructure, capacity building, and community engagement. By integrating advanced monitoring systems, comprehensive mapping, and robust public education programs, landslide-prone regions like the Langat Basin can significantly improve their disaster preparedness and resilience. By focusing on these three key areas, the discussion highlights critical priorities for enhancing disaster resilience in the Langat Basin. Strengthening infrastructure, addressing financial vulnerabilities, and closing informational gaps collectively provide a robust framework for reducing landslide impacts and supporting sustainable regional development.

Conclusion

This study highlights the critical role of resource access in managing landslide risks in the Langat Basin. By focusing on infrastructure, financial preparedness, and informational resources, the research provides valuable insights into existing vulnerabilities and outlines actionable strategies to enhance resilience. The GIS analysis of road networks revealed significant disparities in accessibility, particularly in rural and high-risk areas. Poor infrastructure can limit the effectiveness of evacuation and emergency response efforts, underscoring the need for targeted investments to improve road connectivity and resilience. Such improvements are not only essential for disaster management but also for supporting long-term socio-economic development in vulnerable regions.

Financial preparedness findings highlighted stark inequalities within the Langat Basin. Despite relatively high overall household income levels, significant disparities persist, particularly among rural and marginalized communities. Rising living costs and the absence of adequate insurance coverage exacerbate these vulnerabilities. Implementing financial mechanisms such as subsidies, low-interest loans, and community-based disaster funds can empower communities to adopt preventive measures and recover effectively from landslide impacts. Additionally, inclusive financial strategies must address the needs of socially vulnerable groups, such as the elderly and disabled, ensuring equitable access to resources.

Informational resource gaps emerged as a critical barrier to effective disaster management. The lack of up-to-date hazard maps, underdeveloped early warning systems, and inconsistent public awareness campaigns hinder community preparedness. Investing in real-time monitoring systems and comprehensive hazard mapping, alongside targeted education and outreach programs, can significantly enhance community understanding and response capabilities. Leveraging technology through mobile apps and online platforms can further improve the accessibility and dissemination of vital information. In conclusion, improving access to infrastructure, financial resources, and informational tools is imperative for mitigating landslide risks and building a resilient future for the Langat Basin. The findings serve as a foundation for targeted risk reduction efforts, emphasizing the need for a multi-dimensional approach to disaster management. Future studies should build upon this work by incorporating real-time data and localized assessments to further refine strategies and ensure equitable outcomes for all communities.

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