Demographic factors of social vulnerability in slope failure: Case studies of Langat Basin, Malaysia

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Abstract

Slope failures pose a significant threat to communities within the Langat Basin, Malaysia, where rapid urbanization and environmental degradation have heightened the risk of disaster. This study investigates how demographic factors, specifically age, income levels and resource accessibility, influence social vulnerability to slope failures. Using Geographic Information Systems (GIS), demographic indicators were integrated with historical landslide records and one one-kilometre buffer analysis was conducted to assess the exposure of important facilities to hazards and critical services. The results reveal that elderly populations, low-income households and communities with limited access to healthcare and educational facilities are disproportionately concentrated in high-risk zones, particularly in Hulu Langat and Seremban. These findings underscore the need for targeted disaster risk reduction strategies, including improved infrastructure, enhanced education and awareness programs and community-based resilience initiatives. By emphasizing the role of demographic vulnerability and spatial risk assessment, this study offers valuable insights for building adaptive capacity and promoting safer, more resilient communities in slope failure-prone regions.

Keywords: Demographic factors, disaster management, GIS, slope failure, social vulnerability

Introduction

Slope failures represent a significant risk globally, causing substantial human, economic and infrastructural losses annually. According to data recorded by the International Disaster Database EM-DAT (2023), there were over 3,800 recorded natural disaster incidents in Asia from 2000 to 2024, with 231 of these incidents caused by slope failures. These figures highlight the urgent need for comprehensive strategies to manage and mitigate such hazards. In response to these disaster challenges, the United Nations Office for Disaster Risk Reduction (UNDRR) introduced the Sendai Framework for Disaster Risk Reduction 2015–2030. Adopted by the United Nations (UN), the framework established four key priorities for disaster risk reduction: (i) understanding disaster risk, (ii) strengthening disaster risk governance, (iii) investing in disaster risk reduction for resilience and (iv) enhancing disaster preparedness for effective response and improved recovery. This framework emphasizes the necessity for an inclusive and data-driven approach in identifying the most vulnerable communities. Such an approach requires consideration not only of the physical

factors of slope instability but also the social vulnerability of local populations, which influences their level of preparedness, capacity for response and resilience in post-disaster recovery. Therefore, developing an assessment model grounded in social vulnerability is essential to support the aspirations of the Sendai Framework in reducing disaster losses and enhancing the resilience of at-risk communities.

Before delving deeper into the concept of social vulnerability, it is important to first understand the phenomenon of slope failure itself. Slope failure is defined as the movement of rock masses, debris, or soil down a slope influenced by various factors affecting slope stability (Mandal & Mondal, 2019; Turner, 2018). Additionally, slope failure is described as the loss of slope support, potentially leading to a sudden collapse (Rusydy et al., 2016). These geological phenomena often result from a combination of natural triggers such as intense rainfall, earthquakes and volcanic activity, along with human-induced factors including deforestation, urban expansion, and inadequate land management practices (Larsen, 2008; Liu et al., 2021; Nazrien Ng et al., 2022; Zhang et al., 2021; Li et al., 2020). The impacts of slope failures arising from both physical and anthropogenic factors not only involve the destruction of property but also pose substantial threats to the safety and well-being of communities, particularly those that are socially vulnerable (Guillard-Gonçalves & Zêzere, 2018; Mendonca & Silva, 2020; Ram & Gupta, 2022). These socially vulnerable populations often face additional challenges during disaster events due to pre-existing socio-economic disparities.

Vulnerability, in general, refers to the susceptibility of individuals, communities, or systems to the adverse effects of hazardous events. It encompasses not only physical exposure to hazards but also the inherent and adaptive capacities of affected populations to cope and recover (Ajtai et al., 2023; Faas, 2016; Pollock & Wartman, 2020). In this paper, particular emphasis is placed on social vulnerability, which highlights how demographic and socio-economic characteristics such as age, income and access to resources shape a community's ability to anticipate, respond to and recover from disasters (Cutter et al., 2003; Cutter, 2024; Derakhshan et al., 2022; Guillard-Gonçalves et al., 2015). Key factors contributing to social vulnerability typically include age distributions, economic disparities, educational attainment, accessibility to healthcare, availability of emergency services and the level of community awareness or disaster preparedness measures (Cumberbatch et al., 2020; Cutter, 2024).

Although GIS-based approaches have been widely adopted to assess social vulnerability and hazard exposure, the application specifically focusing on slope failure contexts and social vulnerability within Malaysian regions remains limited (Frigerio & De Amicis, 2016; Guillard-Gonçalves & Zêzere, 2018; Meng et al., 2016; Nelson et al., 2015; Strode et al. 2020). Based on Cutter (2024), GIS and spatial modeling can work together effectively to identify and visualize patterns of social vulnerability across hazard-prone areas. Particularly within rapidly urbanizing and environmentally sensitive areas such as the Langat Basin, limited studies have comprehensively integrated demographic factors and resource access with spatial hazard analysis using Geographic Information Systems (GIS). This gap highlights the need for localized, spatially explicit assessments to support disaster risk reduction strategies tailored to the socio-economic dynamics of the region.

Therefore, the primary aim of this study is to investigate how demographic factors, including age, income levels and resource accessibility, influence social vulnerability to slope failures in the Langat Basin, Malaysia. By employing GIS-based spatial analysis techniques, this study seeks to map and monitor the intersection of social vulnerability and slope failure risks,

ultimately providing critical insights to inform more effective disaster preparedness, mitigation, and resilience-building initiatives in the region.

Study area

The Langat Basin, situated in the central region of Peninsular Malaysia, spans approximately 2,350 km², extending from latitudes 2.5°N to 3.2°N and longitudes 101.3°E to 102.0°E. Encompassing a diverse landscape of urban centers, agricultural zones and forested areas, the basin serves as a critical water catchment, supplying fresh water resources to surrounding cities, including Kuala Lumpur, the nation's capital (Muhamad et al., 2015). Topographically, the basin transitions from hilly and mountainous regions upstream to flatter agricultural plains downstream. This variation in terrain profoundly influences the environmental risks faced by communities, particularly the incidence of slope failures. The Langat Basin experiences a tropical climate characterized by frequent and intense rainfall throughout the year, with heavy precipitation identified as a major trigger for landslides and slope instability (Selamat et al., 2023; Zhang et al., 2021). These natural vulnerabilities are further compounded by anthropogenic activities such as rapid urbanization, deforestation and land use changes, which have significantly altered the natural stability of slopes, especially in the upper catchment areas.
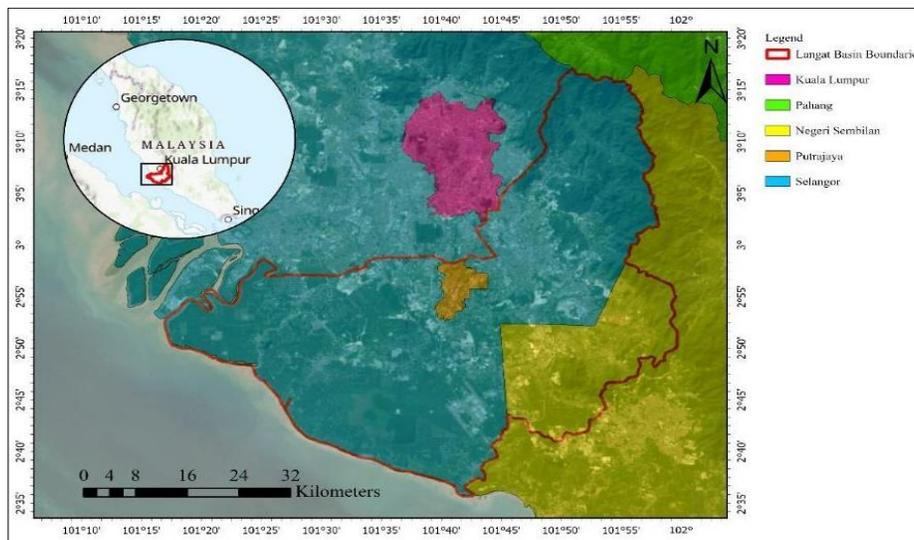

Figure 1. The location of Langat Basin in Malaysia

As shown in Figure 1, the Langat Basin is located in the central region of Peninsular Malaysia and spans across multiple administrative areas, including the states of Selangor, Putrajaya and Negeri Sembilan. The basin is strategically situated and shares borders with Wilayah Persekutuan Kuala Lumpur to the northwest and the state of Pahang to the east. This geographic positioning places the basin at the intersection of urban, suburban and rural development zones, making it highly relevant for assessing varying levels of social vulnerability, infrastructure access and environmental exposure related to slope failure risks.

Environmental hazards in the basin are unevenly distributed, with areas of steep gradients and human encroachment exhibiting a higher propensity for slope failures (Pollock & Wartman,

2020; Selamat et al., 2024). Such hazards pose direct threats to both critical infrastructure and human settlements (Popescu, 2002; Taghizadeh-Hesary et al., 2021), amplifying the risk for populations residing in proximity to unstable slopes (Subasinghe & Kawasaki, 2021; Thanapackiam et al., 2012). The increasing frequency of slope-related disasters underscores the urgent need for integrated risk management strategies within the basin. Social complexity further accentuates the vulnerability landscape of the Langat Basin (Aldrich & Meyer, 2015; Mioc et al., 2015; Reid, 2013). The population is socio-economically diverse, encompassing affluent urban communities, rural agricultural households and indigenous groups inhabiting remote regions. These demographic variations result in differential exposure to hazards, preparedness levels and recovery capacities. Socio-economic disparities, educational attainment gaps, and unequal access to healthcare and infrastructure create distinct patterns of social vulnerability across the basin. Given the Langat Basin's physical diversity, environmental risks and socio-economic complexities, it offers a compelling case study for examining the demographic determinants of social vulnerability to slope failures. The unique characteristics of the basin align directly with the objectives of this research, which seeks to spatially assess and map vulnerability through the integration of demographic indicators and Geographic Information Systems (GIS)-based analysis.

Methodology

This study adopts an integrative approach combining demographic analysis with spatial assessment of slope failure risks within the Langat Basin. The methodology is structured into three key stages: data collection, data preparation and spatial analysis using Geographic Information Systems (GIS).

Data collection

Secondary data were utilized to ensure comprehensive coverage of both demographic and environmental variables relevant to social vulnerability. The primary sources of demographic data included the Population and Housing Census of Malaysia, supplemented by localized socio-economic reports on the Langat Basin. The demographic indicators selected, which are age distribution, income levels and resource accessibility, were based on their established relevance to disaster vulnerability as highlighted in previous studies (Cutter, 2024; Cutter et al., 2003; Derakhshan et al., 2022). These indicators capture critical aspects of a community's capacity to anticipate, respond to and recover from slope failure events. Slope failure records were sourced from geological surveys, technical reports and landslide inventory datasets maintained by local authorities and academic institutions. These records provided essential information on the frequency, location and severity of slope failures within the Langat Basin, facilitating a comprehensive understanding of physical hazard exposure. The term "slope failure records" is consistently used throughout this study to refer to documented instances of slope instability events.

Data preparation

All collected datasets were harmonized to a common geographic coordinate system to enable integrated spatial analysis. Demographic data were aggregated at appropriate administrative levels to ensure sufficient spatial resolution for analysis, while slope failure records were digitized into

georeferenced point or polygon data layers, depending on the available detail. Essential service facilities, including healthcare centers and educational institutions, were also mapped to assess resource accessibility as a component of social vulnerability.

In addition, demographic data were aggregated and summarized by administrative boundaries within the Langat Basin, including districts such as Hulu Langat, Sepang, Kuala Langat, Putrajaya and Seremban. Key attributes such as total population, age group distribution (0–14 years, 15–64 years, 65 years and above) and average income levels were compiled to facilitate comparative analysis across different localities. This aggregation allowed for a clearer spatial representation of social vulnerability factors linked to demographic characteristics, as presented later in the results section. Moreover, according to the Department of Statistics Malaysia (DOSM, 2023), the school completion rate within the study area approaches almost 100%, indicating widespread access to basic education. Therefore, the mapping of educational facilities in this study primarily serves to assess physical accessibility to critical services during disaster events, rather than measuring educational attainment as a social vulnerability indicator.

Spatial analysis

GIS-based spatial analysis was employed to conduct a buffer analysis around historical landslide inventory points within the Langat Basin. Buffer zones were generated to delineate the areas potentially impacted by slope failures. A buffer zone of one kilometre was generated around each slope failure location inventory in Figure 2, that has been sourced by the author from records to capture nearby communities and essential services that could be potentially affected by slope failure events. Within these buffer zones, the locations of healthcare facilities and educational institutions were overlaid to assess the proximity and accessibility of critical services for affected communities in Figure 4. This spatial layering provided insights into the preparedness and resilience capacity of communities residing near high-risk slopes. The integration of slope failure hazard zones with critical infrastructure mapping allowed for a focused evaluation of service accessibility in disaster-prone areas. The findings support targeted disaster risk reduction planning by identifying gaps in infrastructure coverage within vulnerable zones.
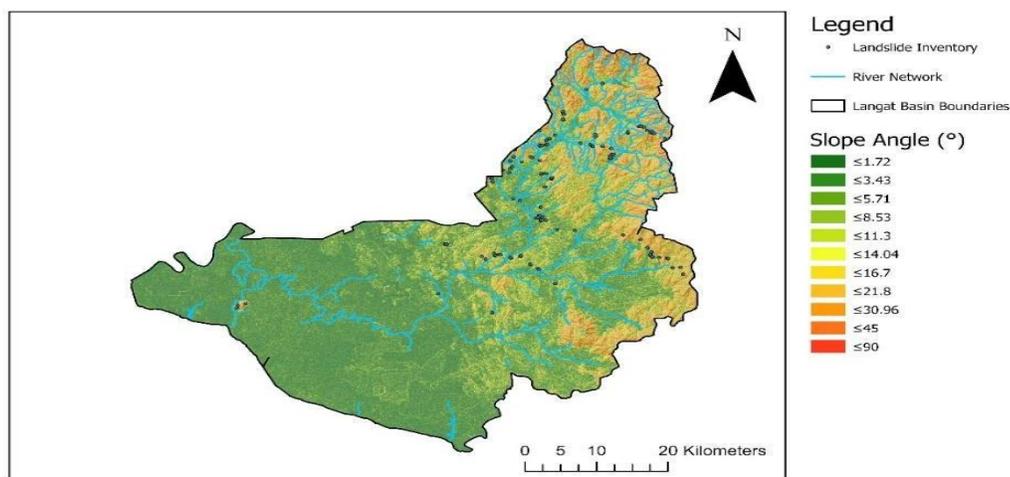

Figure 2. The landslide inventory of Langat Basin

Methodology workflow

To provide a clear overview of the research process, a methodology workflow diagram is illustrated in Figure 3. Figure 3 presents the overall methodology workflow adopted in this study, outlining the key stages involved in assessing social vulnerability to slope failures in the Langat Basin. The process begins with the collection of secondary data, including demographic indicators and slope failure records. This is followed by data preparation, which involves the harmonization of datasets, georeferencing of landslide locations and aggregation of demographic data at the administrative level. The third stage involves spatial analysis using Geographic Information Systems (GIS), where buffer zones are created around historical landslide points and overlaid with critical infrastructure such as healthcare and educational facilities. This structured approach in Figure 3 ensures that both the physical and social dimensions of vulnerability are comprehensively captured, aligning with the study's objectives to provide a spatially explicit understanding of demographic factors influencing social vulnerability to slope failures. The workflow diagram comprises the following sequential steps:
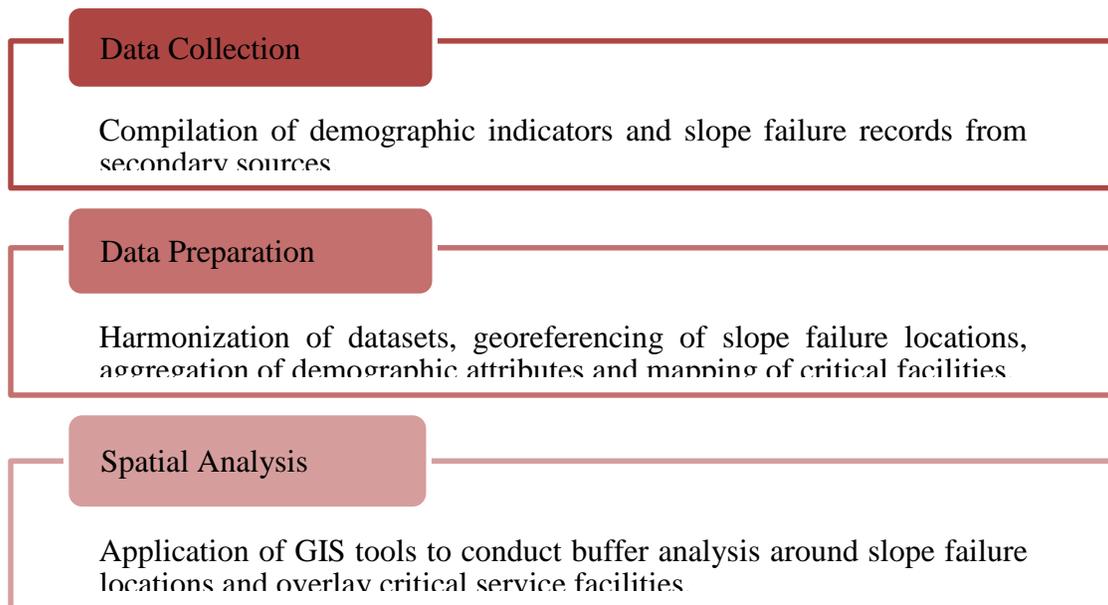

Figure 3. Workflow diagram for methodologies

Results and discussion

The disaster of slope failures or landslides has been influencing the social vulnerabilities through multiple factors such as age, education, income and access to resources (Antronico et al., 2020; Diana et al., 2021; Pollock & Wartman, 2020). In Langat Basin, Malaysia, the steep terrain and rapid growing urbanization bring a significant risk of landslide and slope failure to the population. The disaster is also prone to happen, particularly during heavy rainfall ,which happens more in the urban areas and the cleared forest (Nazrien Ng et al., 2022; Zhang et al., 2021). Various demographic groups experience different levels of exposure and susceptibility to slope failure. For

example, some communities like the indigenous communities may lack the necessary knowledge of landslide risk, or live in the area where infrastructure is insufficient to mitigate the disaster hazards (Miska Rahmah et al., 2023; Pandey et al., 2018). By analyzing factors such as age, resource access and income, we can identify the population at risk and design the intervention that can enhance the resilience.

Table 1. Demographic data of Langat Basin

Regions	Population ('000)	Age ('000) (0 – 14)	Age ('000) (15 – 64)	Age ('000) (65+)	Income (RM)
Hulu Langat	1,508.1	314.2	1,069.2	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

Source: OpenDOSM Malaysia, 2024

Table 1 presents the aggregated demographic characteristics for selected districts within the Langat Basin, focusing on total population, age group distributions and average income levels. The data highlights significant variation across the districts in terms of demographic composition and socio-economic status. Hulu Langat records the highest population, exceeding 1.5 million residents, while Putrajaya has the lowest population size. Age distribution analysis reveals that the majority of the population falls within the 15–64 age group, but notable proportions of vulnerable age groups, which consist of children (0–14 years) and the elderly (65 years and above), are also present, particularly in Hulu Langat and Seremban. Income levels vary across districts, with Putrajaya recording the highest average income and Seremban the lowest, indicating disparities in economic resilience within the basin.

Age factors and vulnerabilities

Age distribution plays a crucial role in influencing social vulnerability to slope failures. Both the elderly and younger populations are recognized as high-risk groups during disaster events due to their physical, cognitive and social limitations (Fernandez et al., 2002; Peek & Stough, 2010). In the Langat Basin, analysis of Table 1 reveals that Hulu Langat and part of Seremban districts have higher concentrations of elderly residents, many of whom are located within the 1-kilometer buffer zones around historical slope failure locations. Elderly individuals face heightened risks during slope failure events, primarily due to mobility impairments, health complications and the possibility of living alone with limited social support (Meyer, 2017). Past studies also stated that the lack of accessible evacuation routes and emergency facilities in rural and hilly areas can further compound these vulnerabilities, potentially delaying timely evacuation and emergency response (Augustine & Schoettmer, 2005; Shahabi & Wilson, 2018). Moreover, a lack of awareness about disaster preparedness plans among the elderly population can also hinder effective evacuation and increase their susceptibility to disaster impacts (Asharose et al., 2015; Musacchio et al., 2014).

Similarly, indigenous communities residing in remote parts of the Langat Basin also face significant challenges. While traditional knowledge systems provide some resilience, modern disaster preparedness strategies often overlook their specific needs, exacerbating their

vulnerability during slope failure events (Hilhorst et al., 2015; Mosurska et al., 2023). Limited access to emergency infrastructure and services remains a critical issue for these groups, necessitating a more inclusive disaster planning and incorporating indigenous knowledge while addressing modern infrastructural gaps.

Younger populations, particularly children living within high-risk zones, also experience unique vulnerabilities. Many schools located in upstream or hilly regions of the Langat Basin fall within identified high-risk buffer zones in Figure 2 and Figure 4. However, not all educational institutions have robust disaster preparedness plans in place, leaving students unprotected during emergencies (Ruiz-Cortes & Alcantara-Ayala, 2020; Safriani et al., 2022). Children, especially those with disabilities, rely heavily on adults for evacuation and response guidance, increasing the complexity of emergency management (Peek & Stough, 2010). The emotional and cognitive impacts of disaster stress further impair children's ability to respond quickly and effectively during slope failure incidents (Foltin & Cooper, 2009).

Addressing these vulnerabilities requires targeted interventions, including the enhancement of evacuation routes, the development of dynamic emergency response mapping and the implementation of comprehensive disaster education programs in schools located within hazard-prone areas (Boon et al., 2012; Feng et al., 2015). By strengthening the preparedness capacity of elderly residents, indigenous communities and children, disaster resilience across the Langat Basin can be significantly improved.

Income factors and social vulnerabilities

Income level is a significant determinant of social vulnerability in the Langat Basin. Based on Table 1, several parts of the basin, particularly Seremban, are home to low-income families, often residing in rural areas near unstable slopes. These households, constrained by financial limitations, frequently lack the resources to improve housing structures, implement preventive measures, or relocate to safer areas. Previous research highlights how income disparities critically influence community resilience, especially in rural regions exposed to natural hazards (Subasinghe & Kawasaki, 2021). In contrast, Hulu Langat shows a relatively higher average income, reflective of greater urbanization and diversified employment opportunities. However, even within urbanized areas, small pockets of vulnerable, lower-income groups may exist. Communities located downstream, where agricultural activities dominate, generally experience fewer slope failures; yet, limited economic capacity still hampers their ability to effectively prepare for or recover from disasters.

Wealthier households are typically better equipped to invest in structural reinforcements, insurance coverage and rapid recovery measures. In contrast, lower-income groups, regardless of their geographical position upstream or downstream, often face longer recovery periods and greater exposure to secondary hazards such as soil erosion or localized flooding (Smyth & Royle, 2000; Zúñiga et al., 2014). This persistent income-based disparity highlights the urgent need for equitable risk reduction initiatives that prioritize economically disadvantaged communities, particularly those situated near high-risk slope areas within the Langat Basin.

Access to healthcare and education facilities

Access to healthcare and educational facilities is crucial to analyze further regarding social vulnerability in the Langat Basin, especially during the slope failure incidents. The resource access

to these essential services directly affects the resilience of communities when facing disaster scenarios (Kapucu et al., 2013; Paturas et al., 2010; Sanuki et al., 2013). In the Langat Basin, based on Figure 4, the distribution of health and education services and facilities is uneven with rural and economically disadvantaged areas typically experiencing more limited access compared to urbanized regions on the Langat Basin. This inequality implies that resource-constrained communities are often less prepared to manage, respond to and recover from landslides (Serulle & Cirillo, 2014).

Through the use of Geographic Information Systems (GIS), a spatial analysis of health and education infrastructure across the Langat Basin was conducted to identify areas with limited access and to assess how these align with regions prone to landslides. The analysis revealed that several of the most vulnerable communities are situated in areas with poor access to essential facilities. Figure 4 also shows that the rural populations and communities lack nearby healthcare facilities, which reduces the ability of the population to get immediate help during an emergency and disaster, especially in the northeast part of the Langat Basin.

In particular, based on Figure 4, rural sections of Hulu Langat and Sepang exhibit considerable gaps in access to healthcare facilities, reducing the ability of residents to obtain immediate medical assistance during emergencies. Furthermore, although educational institutions are widely distributed, schools located within high-risk buffer zones may face difficulties in serving as emergency shelters or evacuation centers if physical access routes are compromised. These disparities highlight the need for more focused interventions to improve critical infrastructure in high-risk zones. By enhancing access roads, establishing alternative evacuation routes and reinforcing the capacity of local health centers and schools to function as disaster response hubs, the resilience of vulnerable communities can be significantly strengthened (Gangwal et al., 2023; Sanuki et al., 2013; Saurman, 2016; Serulle & Cirillo, 2014). Improving accessibility to healthcare and educational facilities not only reduces vulnerability but also plays a vital role in ensuring that essential services remain operational during disaster events, ultimately safeguarding lives and supporting more effective disaster management strategies within the Langat Basin.
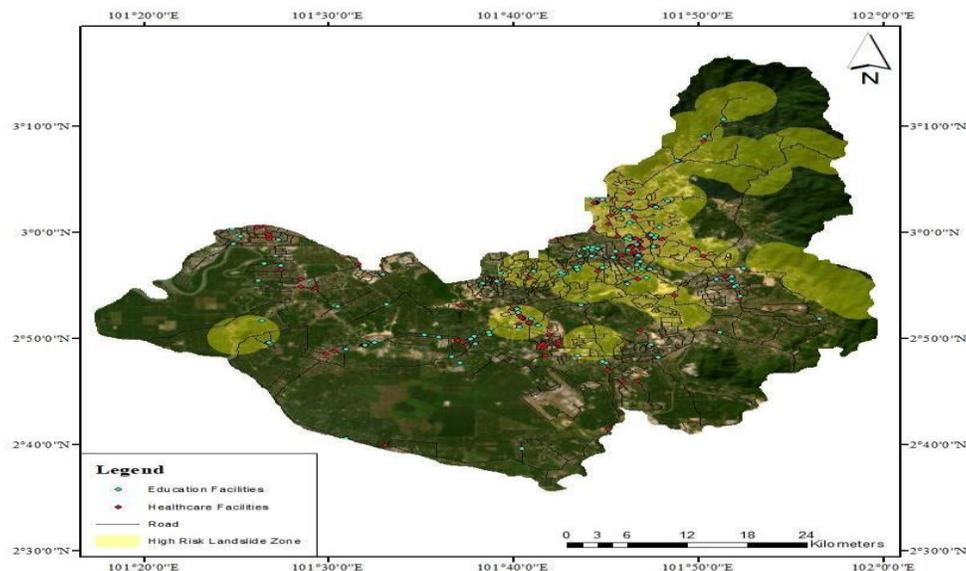

Figure 4. Crucial facilities in Langat Basin

Discussion

The findings collectively demonstrate that social vulnerability to slope failures in the Langat Basin is shaped by the intersection of age demographics, income disparities and resource accessibility. Areas with high concentrations of elderly residents, low-income populations and limited access to healthcare facilities exhibit heightened vulnerability. The spatial distribution of critical services and the proximity of vulnerable groups to landslide-prone zones further emphasize the layered risks faced by these communities. This study underscores the necessity of adopting an integrative and spatially informed approach in disaster risk reduction strategies. Enhancing healthcare accessibility in rural and high-risk zones is crucial to ensure timely emergency response and improve overall community health resilience. Similarly, strengthening the physical infrastructure of schools and ensuring their capacity to serve as effective evacuation centers that can provide essential protection during slope failure events.

Addressing socio-economic disparities, particularly in income levels, remains central to building resilience. Targeted financial support programs, coupled with community-based education and training initiatives, can empower low-income and marginalized groups to better prepare for and respond to disasters. Moreover, the incorporation of spatial analysis into risk assessments enables the identification of specific localities where interventions are most urgently needed. Policymakers and planners should prioritize high-risk buffer zones identified through GIS analysis to optimize resource allocation and disaster preparedness efforts. To truly strengthen social resilience against slope failures, a multi-pronged approach is needed. Education and awareness initiatives, particularly for young people and less formally educated populations, should be expanded through workshops, community seminars and school programs that build a culture of preparedness from an early age (Asharose et al., 2015; Ruiz-Cortes & Alcantara-Ayala, 2020). Infrastructure improvements, such as enhanced drainage systems, reinforced roads, and sustainable land management practices, are vital for stabilizing slopes and ensuring safer evacuation routes (Tanavud et al., 2000; Ullah, 2024). Existing infrastructure must also be evaluated and upgraded to withstand increasingly severe weather patterns associated with climate change (Syafiq & Azri, 2023).

Support for vulnerable groups, including the elderly, low-income households and indigenous communitie,s must be prioritized through the establishment of local community networks, emergency response teams and the integration of indigenous knowledge systems into disaster planning (Alfarizi et al., 2023; Ingham & Redshaw, 2017). Furthermore, fostering collaboration among local authorities, NGOs and community groups is essential for developing inclusive, community-driven disaster response frameworks. Ultimately, a holistic disaster risk management framework that integrates demographic vulnerability analysis, socio-economic factors, community participation and spatial risk modeling can significantly enhance the adaptive capacity and safety of communities within the Langat Basin. Such a framework not only supports immediate risk reduction efforts but also contributes to building long-term resilience against future slope failure events.

Conclusion

This study assessed the demographic factors influencing social vulnerability to slope failures within the Langat Basin by integrating demographic data and spatial analysis techniques. The

findings demonstrate that vulnerability is not distributed evenly across the basin but is concentrated in areas characterized by a higher proportion of elderly populations, lower-income households, and limited access to critical services such as healthcare and education. Age, income and resource access emerged as significant indicators of vulnerability, particularly in districts such as Hulu Langat, Seremban and Sepang. The application of Geographic Information Systems (GIS) in this study successfully highlighted spatial disparities in exposure and access to essential services, providing a clear visual understanding of community risks.

This study further highlights that demographic factors such as age, education, and income play a critical role in shaping the level of risk communities face in landslide-prone areas like the Langat Basin. Understanding these connections enables the development of better-targeted strategies to reduce social vulnerability and enhance community preparedness. Improving access to education can raise awareness about disaster risks and enhance individual readiness. Strengthening infrastructure, particularly in high-risk and rural areas, can significantly stabilize slopes and ensure the availability of safe evacuation routes. Additionally, offering social support programs, developing accessible maps and providing targeted education to vulnerable groups such as the elderly and low-income families can further reduce disaster risks.

Strengthening disaster resilience in the Langat Basin requires a multi-faceted approach that incorporates improving access to healthcare, enhancing educational preparedness, upgrading infrastructure and providing targeted support to vulnerable groups. Community-based initiatives, integration of indigenous knowledge and inclusive planning processes are essential to ensuring that resilience-building efforts are equitable and effective. By emphasizing the role of demographic and spatial factors, this study contributes valuable insights into disaster risk management strategies, offering a model that can be applied to other regions facing similar slope failure hazards. Ultimately, proactive planning, informed by spatial and demographic analyses, can significantly reduce disaster impacts and enhance the long-term resilience of at-risk communities.

Acknowledgement

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