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Evacuation Route Planning at Batu Dam, Selangor

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Abstract

This research analyzes evacuation planning around the Batu Dam in Malaysia, focusing on the risks from dam overtopping due to heavy rainfall and climate change. It emphasizes understanding population density in the Gombak District using a city population web application for effective disaster risk management and urban planning. The study details specific evacuation routes, distances, travel times, flood arrival estimates, and populations served in the Batu Caves area, which are crucial for ensuring safe resident movement to designated safe zones during emergencies. Factors such as proximity to urban areas, economic opportunities and land use influence population density, making it a key consideration in developing these plans. The research categorizes population density based on Malaysian statistics, highlighting its importance in identifying high-risk areas and ensuring resident safety and well-being.

1. Introduction

Flood disasters resulting from dam overtopping present considerable dangers to communities residing in adjacent areas. When the water level in a dam surpasses its maximum capacity, overtopping occurs, causing water to overflow the dam's crest [1]. Heavy rainfall, fast-rapid snowmelt or a mix-combination of these factors can lead to this, resulting in an inflow of water that exceeds the dam's discharge capability [2]. The effects of dam overtopping can be catastrophic, including environmental degradation, property damage, and potential loss of life. The population density surrounding Malaysia's Batu Dam is a crucial factor that needs to be carefully considered due to its ramifications for urban planning and disaster risk management. Situated upstream of Kuala Lumpur in the metropolitan area, the dam is susceptible to flooding and poses a threat to the densely populated downstream areas due to challenges brought on by heavy rainfall and climate change. Evaluating the potential effects of flooding on people and infrastructure requires an understanding of the population density near Batu Dam.

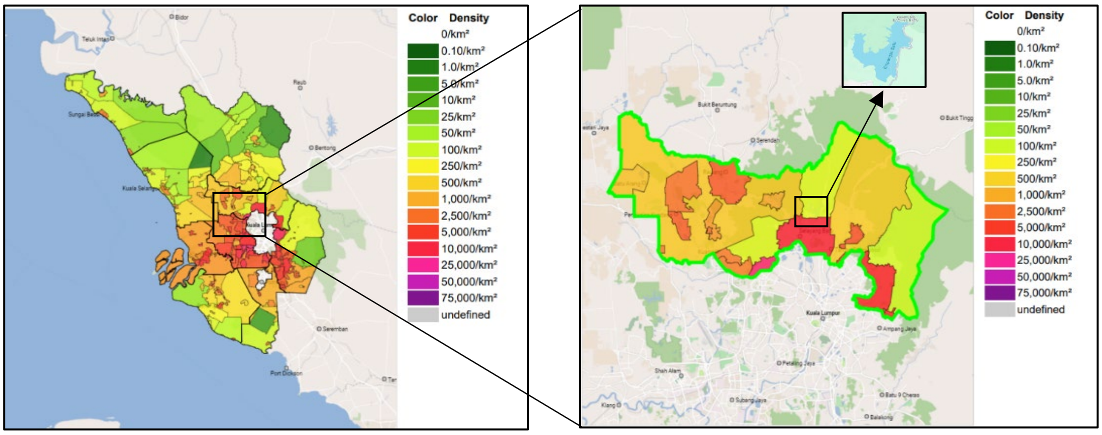
2. Total Population in Gombak District

In 2020, Malaysia's Gombak District had a population of 942,400 people living in a 653.0 km^2 area, which equates to a population density of 1,443 people per square kilometer. The data presented, which ranges from 0/km^2 to 75,000/km^2 with various color gradations, indicates substantial variance in the population density of the Gombak District in Malaysia. The district's high population density has consequences for infrastructure development, resource management, and urban planning [3]. The population increased at a moderate rate between 2010 and 2020, with a 3.5% annual growth rate, which may have an impact on housing, transportation, and public services.

The importance of understanding population distribution in the area is highlighted by Batu Dam's proximity to Gombak Selangor and its location just upstream of Kuala Lumpur. The potential effects of flooding and the necessity for efficient flood mitigation measures are heightened by the dense population downstream of the dam

[4]. Authorities responsible for disaster management and policymaker can create targeted strategies to improve resilience, protect public safety, and lessen the effects of floods on surrounding communities by combining population density data with hydrological assessments.

Analyzing the population density near Batu Dam is essential for risk assessment, disaster preparedness, and sustainable urban development. Fig. 1 below provides an overview of the population density map and location of Selangor and the Gombak district in Malaysia using city population application. The population density of Gombak District in Malaysia varies significantly, with data provided in the attached file ranging from 0/km^2 to 75,000/km^2 with different color gradations. This wide range of population densities suggests that there are areas within the district with very low population density (green), as well as areas with extremely high population density (yellow to red).



(a) **(b)**

Fig. 1 *An overview of the population statistics map and location of (a) Selangor; and (b) Gombak district in Malaysia by using city population*

A city population web application provides essential demographic information and data related to a city's population, including age distribution, gender ratio, population density, and trends over time [5]. Users can interact with the application to explore these various statistics, which are valuable for understanding the demographic composition and growth patterns within a specific district or region.

In the context of disaster response, such an application can play a crucial role by providing real-time demographic data to enhance preparedness and response strategies [6]. It helps identify high-density areas and population centers, which is vital for developing effective evacuation plans and routes to ensure the safe and efficient of residents during a disaster. Additionally, the application can support risk assessments by identifying vulnerable populations or densely populated areas that may be more susceptible to certain types of disasters [7]. This allows for targeted mitigation efforts, ensuring that resources and aid are distributed where they are most needed.

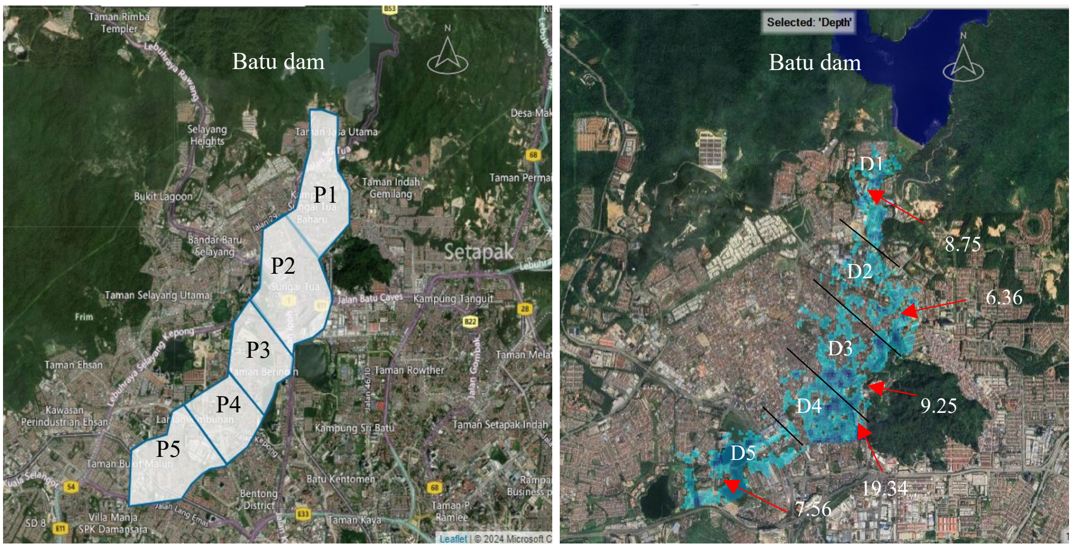
2.1 Population Density at Batu Dam

The Department of Statistics Malaysia classifies population density based on the number of individuals per square kilometer. This classification is essential for understanding how population distribution across different regions plays a crucial role in urban planning, resource management, and socio-economic development. By identifying areas that may require additional infrastructure, services, or resource allocation, this data supports more effective planning and decision-making. Table 1 presents the population density categories in Malaysia.

Table 1 *Population density categories in Malaysia*

Population density	Range (People per km^2)	Description	Characteristics
Low	< 50	Rural or less-developed areas	Low urbanization, mostly agricultural or forested regions
Moderate	50 - 150	Semi-urban or suburban areas	Moderate infrastructure, mix of residential and agricultural
High	150 - 500	Urbanized regions with significant development	High infrastructure, economic activity, mixed-use areas
Very high	> 500	Highly urbanized and densely populated areas	Dense infrastructure, commercial, residential, and industrial

Batu Dam is classified as a high-risk dam due to the dense downstream population which increases the potential for loss of life and property damage in the event of a dam-related disaster. Population mapping data indicates that a significant number of individuals reside in areas susceptible to severe flooding during dam overtopping. The data highlights the need for effective flood mitigation strategies and emergency preparedness measures to protect the vulnerable population. Fig. 2 and table 2 illustrate the population and flood depth at the downstream of Batu dam highlighting the areas exposed to major flooding in the event of overtopping.



(a) **(b)**

Fig. 2 *(a) Population mapping (P1-P5) in Batu dam; and (b) Flooding (depth) (D1-D5)*

Table 2 *Number of population and maximum flood depth at downstream of Batu dam*

	Number of population (P)	Maximum depth (m) (D)	Total area (km^2)	Population density level
1	21662	8.75	3.0	High
2	21506	6.36	3.8	Moderate
3	12670	9.25	2.4	High
4	12353	19.34	2.2	Very high
5	40156	7.56	3.1	Moderate

Table 2 presents data on the population and maximum flood depth at various locations downstream of Batu Dam. It highlights the correlation between population density and flood depth, which significantly impacts local ecosystems and livelihoods.

The first entry reports 21,662 people experiencing a flood depth of 8.75 meters over an area of 3.0 square kilometers. The second entry has a slightly smaller population (21,506) and a lower flood depth of 6.36 meters, but it covers a larger area. The third entry, with 12,670 people, faces a higher flood depth of 9.25 meters in a smaller area, which may contribute to a richer aquatic ecosystem. The fourth entry, with 12,353 people, experiences a significant flood depth of 19.34 meters over 2.2 square kilometers, suggesting the presence of a large body of water. Finally, the fifth entry records the largest population (40,156 people) with a flood depth of 7.56 meters across 3.1 square kilometers.

Overall, the table highlights how variations in flood depths and population sizes impact local communities, influencing resource management and ecological sustainability.

3. Digital Evacuation Planning

Digital Evacuation Planning is an advanced approach to managing evacuations during emergencies, leveraging real-time data and technologies such as GIS, predictive analytics, and mobile applications [8]. Unlike traditional methods that rely on fixed routes, this system dynamically adjusts evacuation plans based on changing conditions, optimizing routes, and guiding evacuees through the safest paths. By prioritizing vulnerable populations, reduces congestion and etching response efficiency. Digital Evacuation Planning represents a significant advancement in crisis management and community safety in today's rapidly evolving environment.

3.1 Data Collection

Digital evacuation planning aims to create efficient, safe, and effective evacuation routes while minimizing risks such as traffic congestion and delays, key aspects include [8]:

i. ArcGIS enables planners to map evacuation routes, infrastructure, population density, and hazard zones, helping to avoid avoidance of disaster-prone areas such as flood zones or fire-risk regions.
ii. Real-Time Mapping Tools (Google Maps, OpenStreetMap): These tools provide visualizations of evacuation routes, monitor real-time conditions (e.g., road closures, traffic, and weather), and enable dynamic adjustments based on current situations.
iii. Traffic Analysis and Routing: Digital mapping platforms optimize evacuation routes by analyzing real-time traffic data. For example, Google Maps provides live traffic updates and suggests alternate routes to reduce congestion, ensuring the fastest and safest evacuation paths.
iv. Evacuation Simulation: Digital tools simulate various evacuation scenarios, to assess the effectiveness of plans. By factoring in traffic conditions, road capacities and population density, help predict and mitigate.

These technologies work together to create a comprehensive and adaptable evacuation plan, maximizing safety and efficiency during emergencies. By utilizing digital evacuation planning tools, evacuation efficiency, safety and resource management can be significantly improved. Table 3 shows the differences between the traditional method and digital evacuation planning.

Table 3 *Key differences of traditional and digital evacuation method*

Aspect	Traditional Methods	Digital Evacuation Planning
Data source	Static, infrequent	Real-time, interactive
Route adaptability	Fixed, hard to change	Dynamic, responsive
Simulation and prediction	Limited, manual	Automated, data-driven
Resource allocation	Broad estimates	Targeted, data-informed
Public communication	Slow, one-way	Fast, interactive, multi-channel
Plan updating	Infrequent	Continuous, seamless

Digital evacuation planning distinguishes itself from traditional methods through its use of real-time, interactive data and advanced technologies. Traditional approaches typically rely on static, paper-based maps and pre-established routes, with evacuation plans often based on infrequent census data and generalized hazard maps. This can result in outdated or inflexible strategies that may not reflect current population distributions, infrastructure changes, or evolving hazards. In contrast, digital evacuation planning leverages Geographic Information Systems (GIS), real-time mapping tools, and live demographic data, enabling planners to visualize population density, infrastructure, and hazard zones with much greater accuracy and immediacy.

Int. J. Sustain. Constr. Eng. Technol. Vol. 17 No. 1 (2026) p. 169-178

Another key difference lies in route adaptability. Traditional evacuation routes are usually fixed and difficult to adjust during an emergency, making it challenging to respond to unexpected obstacles such as road blockages or sudden changes in flood patterns. Digital systems, however, allow for dynamic adjustment of evacuation routes based on live traffic, weather, and hazard data, optimizing paths in real time to ensure the fastest and safest evacuation for residents. Simulation and predictive analytics also set digital planning apart. While traditional methods might depend on manual drills or basic scenario planning, digital platforms can simulate multiple evacuation scenarios, considering factors like traffic flow, road capacity, and flood progression. This enables authorities to anticipate congestion points, test alternative routes, and refine plans before an actual disaster occurs.

Resource allocation is more precise in digital planning. Instead of relying on broad estimates, digital tools enable targeted deployment of emergency personnel, vehicles, and supplies by identifying vulnerable populations and high-density zones. This ensures that assistance reaches those who need it most, improving both efficiency and equity in emergency response. Communication with the public is also enhanced in digital evacuation planning. Traditional methods often depend on mass media, sirens, or door-to-door notifications, which can be slow and may not reach everyone. Digital approaches use mobile apps, SMS alerts, and social media to deliver real-time updates and route guidance directly to residents, while also allowing for two-way communication and feedback.

Finally, digital evacuation plans are designed for continuous improvement. Unlike traditional plans, which are updated infrequently and may quickly become obsolete, digital plans can be revised regularly as new data becomes available and as urban environments change. This ensures that evacuation strategies remain relevant and effective, supporting resilient urban planning and disaster management in rapidly evolving settings.

4. Evacuation Route Planning

Population density directly affects evacuation efficiency during floods by influencing congestion, transportation accessibility and route organization. Understanding population density is essential for designing effective evacuation plans tailored to communities of varying sizes.

Separating the flood risk into different locations, such as P1-P5 is important for several reasons, as it allows for a more detailed and effective approach to flood management and response. Each location represents a distinct scenario in terms of how quickly the flood will arrive, how severe the flooding will be and what level of preparedness is required. The primary reason for separating locations into categories is the variation in their proximity to the dam. The closer a location is to the dam, the faster the flood will arrive and the more immediate the threat. By separating the locations into individual categories (P1-P5), it is easier to identify which locations will be hit hardest and need more urgent attention.

The flood arrival times for population points P1-P5 in the Batu Dam evacuation planning were obtained using HEC-RAS software by extracting the time when the simulated flood wave first reached each location. These times were then used to estimate how much warning and evacuation time residents at each point would have before being impacted by flood waters. Safe evacuation buildings in the Batu Dam evacuation route planning were selected based on the building heights. Only condominiums, apartments, flats, and schools with more than three floors were chosen as designated safe evacuation sites. This criterion ensures that evacuation shelters are elevated above the maximum expected flood depths, which can reach up to 19.34 meters in some downstream areas. By selecting buildings with more than three floors, planners aimed to provide vertical refuge that remains accessible and safe even in severe flood scenarios. Additionally, the selected buildings are required to be located outside the expected flood zones, further reducing the risk to evacuees. Fig. 3, Fig. 4 and table 4 outline evacuation routes, including start and end points, distances, travel times, flood arrival estimates and nearby population data from P1-P5.

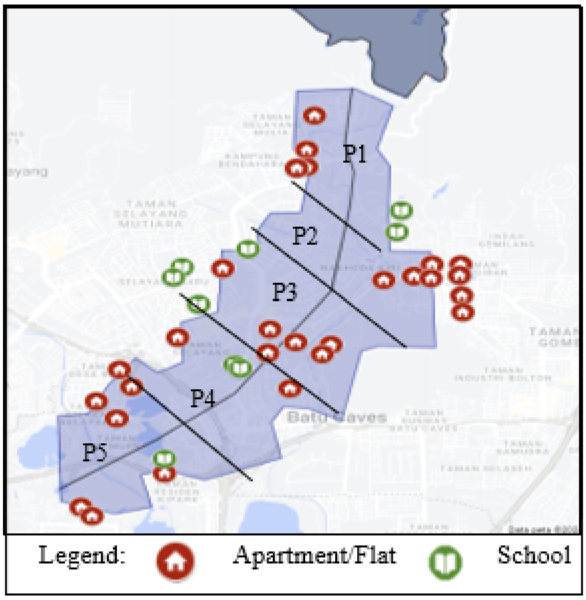
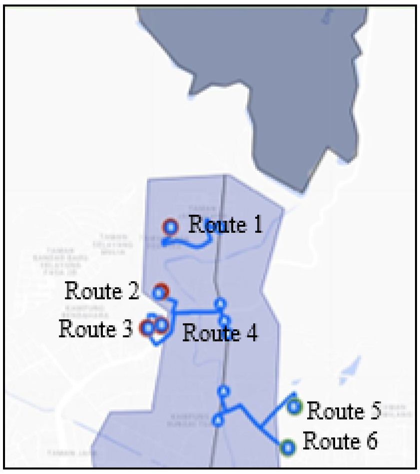


Fig. 3 *Evacuation route at Batu dam during dam break event*



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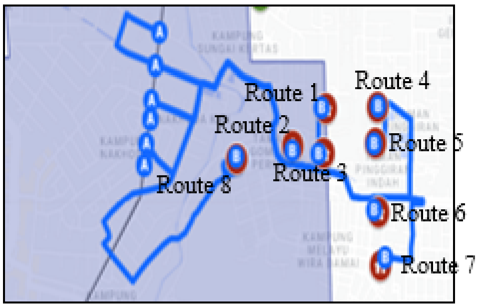

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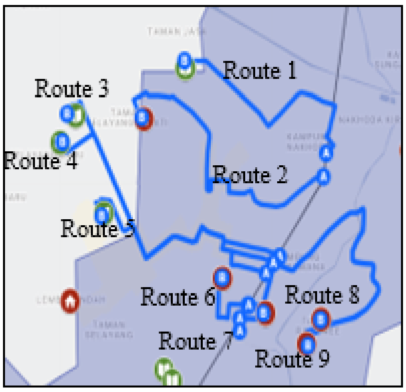

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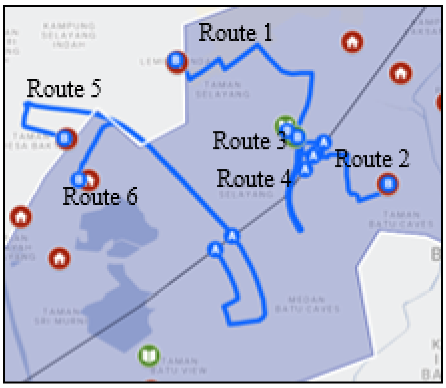

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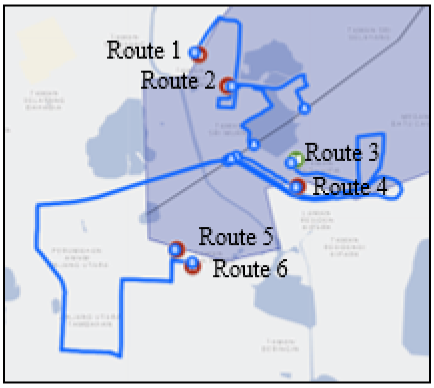
Int. J. Sustain. Constr. Eng. Technol. Vol. 17 No. 1 (2026) p. 169-178



(e)

Fig. 4 *Evacuation route at (a) P1, (b) P2, (c) P3, (d) P4 and (e) P5 during evacuation process*

Table 4 *Details on evacuation routes from P1 to P5*

Population	Route	Total distance (km)	Walking time (minute)	Driving time (minute)	Estimated flood time arrival
P1	1	0.75	11	2	15
	2	0.60	9	2	15
	3	1.00	15	3	15
	4	0.75	11	2	15
	5	0.90	15	3	15
	6	1.60	24	4	15
P2	1	2.10	30	6	17
	2	1.50	21	4	17
	3	2.10	29	7	17
	4	1.10	15	5	17
	5	1.20	17	5	17
	6	1.30	18	4	17
	7	1.80	25	7	17
	8	2.00	28	7	17
P3	1	1.30	17	5	19
	2	1.70	23	5	19
	3	1.30	19	5	19
	4	1.80	25	7	19
	5	1.50	21	5	19
	6	0.40	5	2	19
	7	0.15	2	1	19
	8	0.80	11	6	19
	9	0.60	9	6	19
P4	1	0.45	7	3	20
	2	0.35	6	2	20
	3	1.50	21	6	20
	4	0.60	8	2	20
	5	1.60	22	8	20
	6	1.20	17	4	20

Population	Route	Total distance (km)	Walking time (minute)	Driving time (minute)	Estimated flood time arrival
P5	1	1.70	23	7	22
	2	1.10	15	4	22
	3	1.40	19	12	22
	4	0.60	9	9	22
	5	2.90	39	7	22
	6	3.10	42	9	22

Table 4 outlines evacuation data for different population groups (P1 to P5) during a flood scenario includes route distances, walking and driving times, and estimated flood arrival times.

For P1, six evacuation routes range from 0.60 km to 1.60 km. Walking times vary between 9 to 24 minutes, while driving times range from 2 to 4 minutes. Notably, the flood arrival time is consistent at 15 minutes across all routes. For P2, eight routes span 1.10 km and 2.10 km. Walking times are longer, from 15 to 30 minutes, and driving times range from 4 to 7 minutes. The flood arrival time is 17 minutes, slightly later than P1. The longer distances and travel times indicate a more challenging evacuation scenario. For P3, nine routes range from 0.15 km to 1.80 km. Walking times vary significantly, from 2 minutes for the shortest route to 25 minutes for the longest. Driving times range from 1 to 7 minutes. The flood arrival time is 19 minutes later than both P1 and P2. The presence of very short routes could facilitate quicker evacuations for some individuals. For P4, six routes range from 0.35 km to 1.60 km. Walking times span 6 and 22 minutes, while driving times range from 2 to 8 minutes. The flood arrival time is 20 minutes, slightly later than P3. Although distances are shorter than in P2 some routes have longer driving times. For P5, six routes span 0.60 km to 3.10 km, making it the longest evacuation route. Walking times range from 9 and 42 minutes, and driving times vary between 7 to 12 minutes. The flood arrival time is the latest at 22 minutes. The population faces the most varied and potentially difficult evacuation conditions due to longer distances and extended travel times.

Overall, the data underscores the importance of tailoring the evacuation plan to the specific needs of each population. Key factors such as route distance, travel speed, and flood arrival time play a critical role in optimizing evacuation strategies and ensuring public safety during emergencies. By analyzing these elements, emergency responders can prioritize routes, allocate resources effectively and minimize risk to facilitate timely evacuations.

5. Discussion

The population density around Batu Dam, Malaysia, is shaped by multiple factors, particularly its proximity to urban hubs like Selayang and Kuala Lumpur. As these cities expand, residential developments such as Taman Jasa Utama, Taman Selayang Mulia, and Taman Bukit Permata, along with commercial establishments and infrastructure projects, continue to attract more residents. This increasing density adds complexity to managing evacuation routes, particularly in flood events.

Population density directly affects evacuation efficiency during floods by influencing congestion, transportation accessibility and route organization. Understanding population density is essential for designing effective evacuation plans tailored to communities of varying sizes. By analysing these elements, emergency responders can prioritize routes, allocate resources effectively and minimize risk to facilitate timely evacuations [9].

To ensure the organization of evacuation efforts, the estimated population for each evacuation route is calculated by considering the number of blocks and units, assuming an average of 5 persons per unit. The assumption of 5 persons per unit in the Batu Dam evacuation route planning is a standard demographic estimation technique commonly used in Malaysian urban planning and disaster management studies. This approach is designed to provide a practical and consistent method for estimating the number of people who may need to be evacuated from residential buildings during an emergency [10]. This estimation helps determine the number of individuals requiring evacuation and assists in prioritizing and coordinating evacuation strategies effectively. Additionally, the varying distances and travel time across different routes reflect the region's diverse layout, indicating that some areas may require more time for evacuation than others.

The uniform estimated flood arrival time across the region ensures synchronized evacuation efforts, allowing all routes to efficiently accommodates the population in a timely and orderly manner. Ultimately, understanding the relationship between population density and evacuation strategies is crucial for risk mitigation during flood ensuring residents receive the necessary support particularly in densely populated areas near critical infrastructure like Batu Dam.

6. Conclusion

The population density surrounding Batu Dam, shaped by ongoing urban expansion and proximity to metropolitan centres like Selayang and Kuala Lumpur, presents complex challenges for flood evacuation planning. Our methodology integrated digital mapping, hydraulic modeling, and demographic analysis to design evacuation routes tailored to the specific needs of each population cluster. The assumption of 5 persons per unit, while practical for planning, may not capture the full diversity of household sizes, and both flood and population data are based on the most recent available datasets, which may not reflect real-time changes or temporary population fluctuations.

Limitations of this approach include the use of static flood and population data, simplified assumptions in hydraulic modelling, and the lack of real-time adaptation during an actual emergency. The flood simulations were based on modelled breach scenarios and available topographic data, which may not account for unexpected factors such as infrastructure blockages or rapid demographic shifts. Similarly, population estimates relied on census data and web applications, which, while robust, may not fully capture transient or vulnerable populations.

Future work should focus on incorporating real-time simulation tools and stakeholder-driven evacuation drills to validate and refine the evacuation plans. The use of live data feeds, mobile applications, and participatory testing with local communities and emergency responders will enhance the flexibility and effectiveness of evacuation strategies.

Implications for urban planning and policy are significant: integrating dynamic population and hazard data into city planning processes can improve disaster resilience, inform zoning and infrastructure development, and ensure that emergency response plans remain relevant as urban landscapes evolve. Policymakers should prioritize investments in digital infrastructure, real-time monitoring, and community engagement to build adaptive and inclusive disaster management systems.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design****: S. I. N. S Hashim, S. H. A. Talib, M. S. Abustan;* ***data collection****: S. I. N. S Hashim, S. H. A. Talib, M. S. Abustan;* ***analysis and interpretation of results****: S. I. N. S Hashim, S. H. A. Talib, M. S. Abustan;* ***draft manuscript preparation****: S. I. N. S Hashim. All authors reviewed the results and approved the final version of the manuscripts.*

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