

Catastrophic Flood Mapping: A Geospatial Analysis for Strategic Urban Planning

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Abstract

In Malaysia, Floods frequently occur, particularly during the monsoon season when heavy rainfall overwhelms drainage systems, resulting in flash floods. Rapid urbanisation, inadequate drainage, and limited flood management infrastructure exacerbate the situation, and Kuala Lumpur frequently experiencing flash floods that cause significant property damage and economic losses. Despite these challenges, the lack of detailed flood susceptibility maps hinders sustainable urban planning and proactive flood management. This study developed a flood vulnerability map for Kuala Lumpur to address this gap. Thematic maps were used to categorise the area into five susceptibility zones: very low, low, moderate, high, and very high. The map, created using a weighted overlay method, was integrated into GIS technology. Four primary flood risk factors were analysed: river proximity, rainfall distribution, slope, and elevation. The results classified 29.26% of the area in the moderate susceptibility, while 24.98% and 23.64% in the high and very high zones, respectively. The remaining areas are classified as low (16.25%) and very low (5.78%) susceptibility. These flood susceptibility maps provide essential insights for targeted flood mitigation and improved urban planning in Kuala Lumpur. These maps support targeted measures to mitigate flood impacts, helping to strengthen the city's resilience and ensure more sustainable urban development.

1.0 INTRODUCTION

In Malaysia, floods present an enormous environmental and socio-economic problem, especially in the city of Kuala Lumpur, where the risks of flooding are enhanced by rapid urbanisation, cutting down trees, and climate fluctuations (Wu et al., 2023; Wen et al., 2023). There are also severe flash floods, caused by excessive monsoon rain and lack of proper drainage channels, causing a significant loss of economic resources as well as the destruction of infrastructure (Huey, 2022; D'Ayala, 2020; Hasan, 2019). As urban development continues, although mitigation procedures have been put in place, flood susceptibility mapping is not conducted in high resolution, which negatively affects effective urban planning (Zhou et al., 2019; Vazhuthi & Kumar, 2020).

In order to overcome this constraint, GIS based Weighted Overlay analysis was used to determine the flood susceptibility zones in Kuala Lumpur by evaluating and mapping it. The technology measures main contributors of floods which include river presence, rainfall pattern, the slop, and topography to ascertain their impacts on the flood risk. The approach helps urban planners and disaster management authorities to take informed decisions by elaborating a spatially explicit flood susceptibility map. Moreover, it affirms the significance of incorporating flood risk analyses into sustainability urban planning in order to boost measures of mitigating (Ramanathan et al., 2021). This study is pegged on the initial hypothesis that topographical and hydrological variables especially the closeness to rivers contribute greatly to the flood susceptibility. It also supposes that Weighted Overlay Analysis made by GIS is quite a feasible system of flood risk assessment. Finally, the study suggests that it will enhance mitigation and will assist in limiting economic losses once flood susceptibility maps are integrated into urban planning policy. In Kuala Lumpur, several critical flood catchment areas fall under the supervision of DBKL, including Bukit Tunku, Tasik Danau Kota, and the Universiti Malaya (UM) football field catchment. These localized hotspots highlight how specific urban catchments frequently experience flash floods, reinforcing the urgency of integrating flood susceptibility mapping into strategic urban planning.

Based on the study of geospatial analysis, the research is evidenced by the already published literature that has prioritized the relationship between urbanization and flood specifically in its susceptibility. Past research findings have revealed that the GIS-based models, specifically the Weighted Overlay Analysis and the Analytical Hierarchy Process (AHP) are effective in flood-prone area identification (Romali et al., 2021; Yaseen et al., 2024). An example given is, studies conducted in Malaysia emphasize the need to merge the hydrological and topographical data whereas the international case studies also support the significance of GIS in the establishment of mitigation measures on flood. Based on these findings, this research uses GIS and Weighted Overlay Analysis to produce high-resolution of floods susceptibility maps with focus dwelling solely on Kuala Lumpur. The maps are localized in nature and hence beneficial to the urban planning, disaster preparedness, flood resilience, and ultimately to improve mitigation thus minimizing economic losses.

2.0 LITERATURE REVIEW

The increased rate of occurrence of floods and in this case, flash floods around the world has highly been supported by the development of intensive floods vulnerability maps (Subraelu et al., 2024). The Malaysian situation is no exception and urban flood vulnerability mapping has become the issue of paramount importance in managing the frequent flash floods that have devastating effect on infrastructure and activities in the economy. What can be dangerous and highly risky to human life, property, and even the safety of people is these floods, which can appear in several hours and very frequently preconditioned by several hours and yet significant rainfall (Buslima, 2018). Such socio-economic impacts of flooding as the damaged property, population displacement, and increased vulnerability of the affected groups are obvious. The colossal extent of disruption caused can be illustrated by the past instances of floods experienced in Malaysia in 2000, 2006 and 2017. Remarkably, the eruption of the floods in 2006 led to substantial losses of properties and lives in areas like Bintulu, revealing the high sensitivity of the areas to disaster (Yusoff et al., 2021; Abdullah et al., 2022; Hamel et al., 2022). In the meantime, the flooding of 2017 was estimated at RM 100 million, most of which was used to cover the emergency response, such as evacuation efforts and the supply of basic needs to homeless people, including food and clothing (Rosmadi et al., 2023; Fulazzaky et al., 2023).

A study by Romali et al. (2021) approximated that in the Province of Pekan Segamat, Johor, Malaysia, a total annual Expected Annual Damage (EAD) in the commercial zones are RM 2.96 million and it affects the 9,318 premises. In the meantime, the residential sector had an EAD of RM 12.59 million and 50,112 housing units. In the same light, Wu et al. (2023) indicated that the flood disaster that occurred in the Henan Province of China had a CNY 110.20 billion economic loss. Yaseen et al. (2024) are in agreement with such observations, as they stressed that flood prediction allows limiting the extent of both human lives loss and financial losses by constructing proactive mitigation measures. Against this backdrop, the current research is an attempt to conduct a flood vulnerability assessment of Kuala Lumpur, a fast urbanising city region in Malaysia through Weighted Overlay Method coupled with Geographic Information System (GIS) analysis. It is a methodological approach that has been sufficiently popular because it can incorporate several flood-causing parameters in a single vulnerability map.

The technique has been widely defined, confirmed and used in flood mapping in towns and cities because it has the potential to combine various physical and environmental variables. WSA has been found effective in characterizing flood prone regions in the Malaysian context, thus, aiding in the deployment of focused mitigation measures against floods and an informed structuring of urban planning. It is especially useful in an urban setting where not only a structural risk due to flooding is problematic but also has serious social and economic impacts. In addition, research highlights that inadequate drainage networks, reduction of green areas, and the expansion of impervious surfaces significantly amplify flood risks in Kuala Lumpur. As paved areas increase, soil infiltration declines, leading to greater surface runoff and heightened flash flood susceptibility.

3.0 METHODOLOGY

This paper is written using systematic and orderly approach to create flood susceptibility map of Kuala Lumpur using Geographic Information System (GIS) technology and Weighted Overlay Analysis method. The study design has four major stages that include preliminary assessment, data acquisition, data processing and analysis of results (Figure 1). A detail-oriented tier-based process guarantees soundness and credibility of the assessment of flood risks by following sequence and cross-combining a variety of geospatial data and techniques. Parameters relating to floods are measured in terms of their proportionate effect on floods susceptibility and the score is given in a range of 2 (Having little effect) to 10 (Having significant effect).

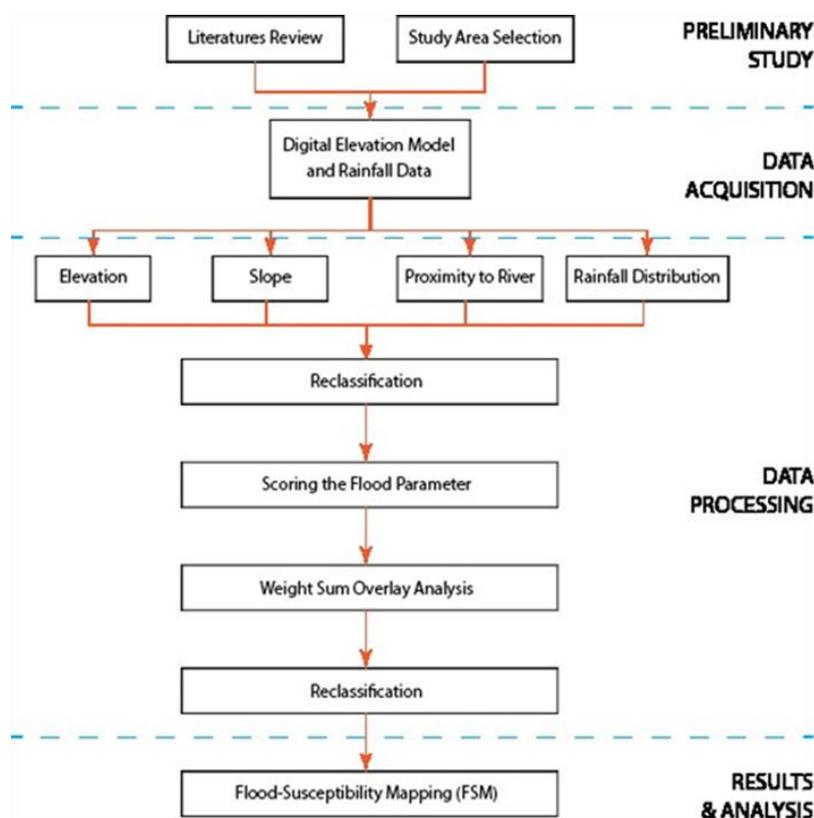


Figure 1. Weighted Sum Approach for Flood Susceptibility Analysis

3.1 Preliminary Assessment

The literature review forms the beginning of the research to create a firm theoretical base. The review of the study is critical of previous research related to flood susceptibility mapping, the use of Geographic Information Systems (GIS) and relevant hydrological models. Using it, such main flood-inducing variables as the proximity of rivers, their slope, elevation, and even precipitation distribution are determined (Hammood et al., 2021; Deur et al., 2020; Nai et al., 2022). This step guarantees the use of the best methodological practices and at the same time fill the gaps that have been left in the literature.

After undertaking the literature review, they have identified the study area according to special criteria, such as flood vulnerability, geographical features and possible accessibility to data. The city of Kuala Lumpur was selected based on the high frequency of floods that mainly attributable to high rate of urbanisation, high intensity rainfall and complex topography. Within the city, DBKL has identified key flood-prone catchment zones such as Bukit Tunku, Tasik Danau Kota, and the UM football field catchment, which are recurrently affected during extreme rainfall. Including these localized sites helps illustrate the distribution of flood risk across urban sub-catchments. Another aspect to consider is that the city is geographically strategic since it sits on confluence of Klang River and Gombak River. At the beginning of 2023, Kuala Lumpur accommodated over 33 percent of the total Malaysian population, and this is considered the density that will rise in the near future (Deur et al., 2020). Figure 2 shows the study area. Selection is based on the fact that the analysis is carried out on the territory where susceptibility mapping to floods is especially important to plan cities strategically and successfully respond to disasters (Subraelu et al., 2024).

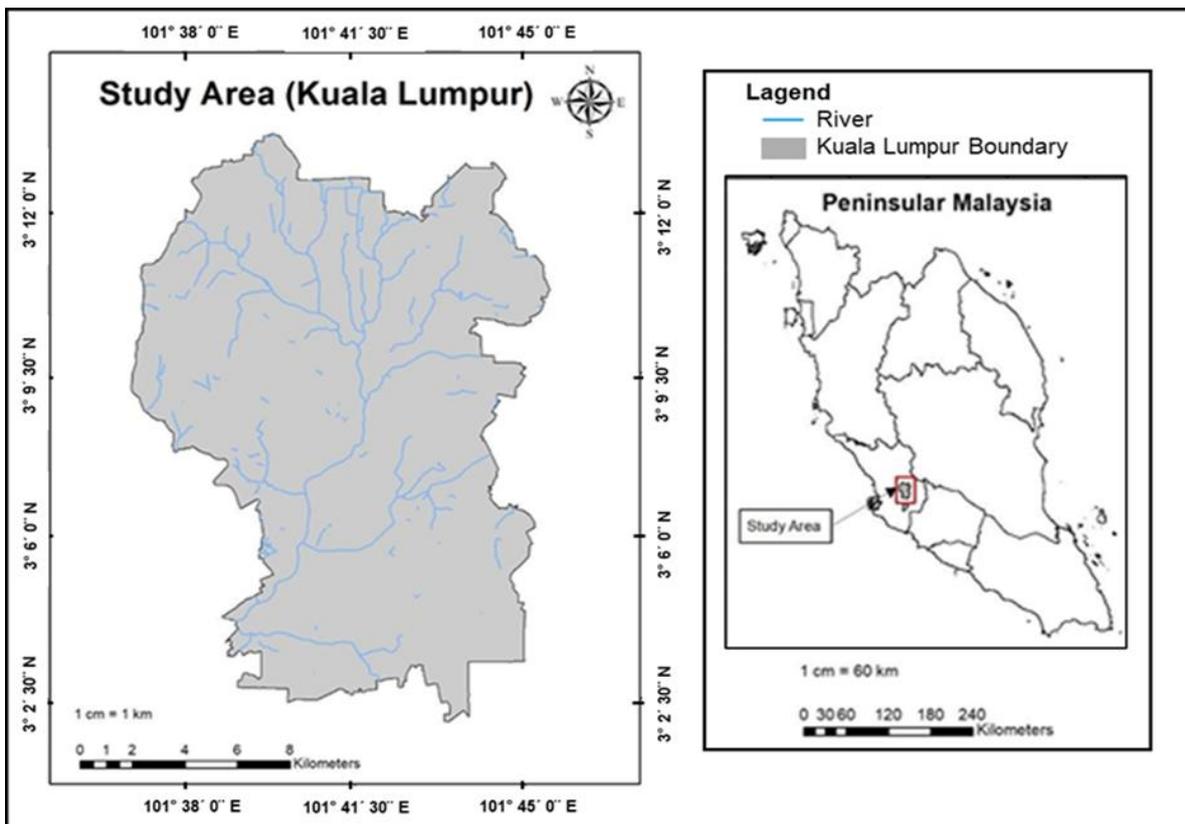


Figure 2. Location of the study area.

3.2 Data Acquisition

The research paper uses geospatial mode of analysis within the study where spatial information was used to determine flood prone areas. The study area of Kuala Lumpur is a fast urban sprawling metropolitan area that is prone to occurrence of flash floods commonly caused by torrential downpour and lack of drainage system. To come up with a good flood susceptibility mapping, the study combines various geospatial data, which include:

- i. **Digital Elevation Model (DEM) Data:** Digital terrain obtained at 30 metres resolution, were obtained courtesy of the United States Geological Survey (USGS). These data were analysed and used to examine the changes in elevation and slope over the Kuala Lumpur. They were essential and helpful in determining the role played by topography in determining the direction of water flow and its deposit in flood susceptible regions.
- ii. **Digital Elevation Model (DEM) Data:** Digital terrain obtained at 30 metres resolution, were obtained courtesy of the United States Geological Survey (USGS). These data were analysed and used to examine the changes in elevation and slope over the Kuala Lumpur. They were essential and helpful in determining the role played by topography in determining the direction of water flow and its deposit in flood susceptible regions.
- iii. **Rainfall data:** The rainfall data were downloaded in WorldClim.org and this source provides the past history of the rain pattern since 1970-2000. The dataset provides important evidence on the seasonal pattern of rainfall intensity and variability, and the relation of flood occurrence to past floods.
- iv. **River Proximity Data:** There are hydrological data on river networks and the spatial closeness to urban structures which were extracted on official hydrological maps. This happened to be useful in the location of the high risk flood areas especially those, which are in close proximity to significant water bodies hence helping to identify the area under greater flood susceptibility.
- v. **Building Footprint Data:** This paper has also used building footprint data (extract.bbbike.org) which were downloaded through geospatial websites with open access in order to assess the level of exposure of the urban infrastructure system to any possible disturbances of floods.

A process of data acquisition involved the combination of several sets of data into a Geographic Information System (GIS) structure so as to be spatially consistent and reliable. Table 1 highlights the origins of these datasets and provides a critical intelligence on the topographical and climate characteristics that are valid in a consideration of flood susceptibility assessment.

Table 1. Spatial data layers used in this study, along with their respective formats and origins.

Data/Information Extracted	Format	Source
Digital Elevation Model	Raster	USGS
Amount of rainfall	Raster	worldclim.org
Buildings polygon	Vector	extract.bbbike.org/

3.3 Data Processing

Data processing involved standardisation and merging of all the data in a Geographic Information System (GIS) platform. Step by step approach was also implemented to verify the processing and analysis of the spatial data collected in a systematic way.

The first step of data processing was reclassification of readings on all the four flood-related factors namely elevation, slope, proximity to river and the distribution of rainfall and giving them standard susceptibility categories. Such standardisation allowed comparing the variables directly and hence, made a successful Weighted Overlay Analysis possible. After reclassifying, every parameter was given a susceptibility score depending on the relative contribution to levels of flood risk. The areas were attributed higher scores depending on four important features including low altitude, steep slopes, closeness to rivers and intense rainfall. One has to note that these factors were regarded as the most important factors that led to flood risk. The framework of scoring was based on the systematic survey of literature as well as on the professional opinion; thus, the weights were reasonable in the context of current flood risk situation.

Prior to that, the weighting of each parameter was first derived in the consent between the experts and assessed by the consultations with other professionals in the hydrology and urban planning field including the representatives of the Malaysian Space Agency (MYSA). Such a deliberative procedure resulted in the weights being locally rooted and scientifically rigorous in the risk perception. In addition, the Analytical Hierarchy

Process (AHP) is used to organize the expert opinion and come up with consistent and defensible weightings to each of the factors. A sensitivity analysis was conducted to determine the strength of the weighting scheme where the weight of individual weights was altered between +10-10 percent. The derived flood susceptibility maps were found to be having little spatial differences and thus confirming the reliability and stability of the weighting model. All the flood-inducing parameters were finally rated on a 2-10-points scale, with the highest value of 10 indicating the strong influence on the flood vulnerability of the study area and the lowest value of 2 was taken as having a weak impact on the flood vulnerability of the study area.

The weighted sum overlay analysis was then done with the Geographic Information System tools (GIS) to combine and analyse the parameters of flood. The thematic layers reclassified and weighted are synthesised using this method to produce a composite flood susceptibility index. Every parameter will be given a weight depending on how influential it will be in causing flooding, so that a spatial model can be defined that will define where in the study region flood prone areas are. The result is the flood susceptibility map that graphically represents the spatial pattern of flood vulnerable areas in Kuala Lumpur. Second reclassification was done on the composite output to improve and group flood susceptibility levels. The step will make sure that the final map correctly classifies areas into five susceptibility levels namely very low, low, moderate, high, and very high (as shown in Table2). The score was established based on the contribution of each parameter to flood risk providing a more specific and feasible decision-making process to authorities and urban planners dealing with flood mitigation.

Table 2. Spatial The parameters used to define the flood susceptibility in this study.

Flood Parameter	Characteristic	Description	Score	Total Weight (%)
Rainfall (mm/month)	282 - 289	Very Low	2	35
	290 - 296	Low	4	
	297 - 303	Moderate	6	
	304 - 309	High	8	
	310 - 316	Very High	10	
Proximity to River (m)	0 - 232	Very High	10	30
	233 - 497	High	8	
	498 - 778	Moderate	6	
	779 - 1147	Low	4	
	1147 - 2046	Very Low	2	
Slope (°)	0 -5	Very High	10	20
	>5 - 15	High	8	
	>15 - 25	Moderate	6	
	>25 - 35	Low	4	
	>35 - 63	Very Low	2	
Elevation (m)	-115 - 53	Very High	10	15
	54 - 79	High	8	
	80 - 120	Moderate	6	
	121 - 184	Low	4	
	185 - 325	Very Low	2	

The table, Table 2, is structured into five columns namely, Flood Parameter, Characteristic, Description; Score, and Total Weight (%).

- i. In the **Flood Parameter** column, the most important variables affecting the susceptibility to floods have been listed such as proximity to rivers, the distribution of rainfall, slope gradient, and elevation. These parameters are very vital inputs to the flood risk assessment model
- ii. The **Characteristic** column connotes the particular nature or character of every flood related parameter. An example is where in the case of the parameter proximity to a river, the value associated will be the distance measured off a river channel.
- iii. The **Description** column also gives a description of each parameter showing its role and importance in causing flood risk

- iv. The column **Score** reflects the numerical mark of each parameter, starting at 1 and going up to 10, depending on its relative importance in producing a flood risk. The higher the score of the parameters the more the susceptibility to the floods and thus the more of a role they play in identifying those regions at risk.
- v. The **Total Weight (%)** column corresponds to the overall impact of any parameter as a predictor of the flood susceptibility. It is obtained after combining the equivalent given to every parameter and its comparative relevance in causing the total flooding risk.

3.4 Result & Analysis

The last step is Results and Analysis that concerns the generation of the Flood Susceptibility Map (FSM) the main output of the current study. The FSM provides the spatially explicit representation of the different flood risk levels, and such information may be used to detect the areas under high risk of floods where prioritised mitigation measures should be taken. In order to determine that it is reliable, the FSM is tested against the past records of flood occurrences in a comparative manner. Where I find different results, some changes are made on the weighting scheme so as to ensure that the model is more accurate.

The analysis of this research provided important conclusions concerning the patterns and trends of the distributions of flood susceptibility throughout Kuala Lumpur. The region where risk to floods was the highest was subjected to detailed analysis and specific suggestions regarding the mitigation measures were offered regarding the results of spatial analysis. The resultant Flood Susceptibility Map (FSM) becomes an important decision-aid to urban planners, Disaster Risk Management & policymakers, to make evidence-based decisions to design more resilient cities. These conclusions confirm earlier local research, including that by Romali and Yusop (2021) who used GIS-based flood mapping in Johor, Malaysia, and discovered that the proximity of the river and topographical attributes were important predictors in the occurrence of floods. Correspondingly, the study by Laka (2023) in Nigeria and Ramesh and Iqbal (2022) in India were conducted internationally using the methods of multi-criteria decision analysis, thus confirming the rationale of combining floatation water and topographic information in the flood hazard evaluation.

Such an approach, though, builds on current methods relating to 3D flood simulation visualisations, which, in theory, offer a more holistic, spatially explicit picture of the vulnerability to urban flooding. The GIS-Weighted Overlay analysis was the most effective tool on flood susceptibility assessment among the methods that were used in the analysis. The given approaches are especially beneficial, as they allow considering and weighing several spatial parameters, e.g., elevation, slope, rainfall distribution, proximity to rivers, leading to a descriptive and practical flood susceptibility map.

The This analysis study proposes using the Weighted Overlay Analysis method provided in Geographic Information Systems (GIS) since such an approach proved to be successful when using it to combine and analyse several spatial datasets, such as Digital Elevation Models (DEM), distribution of rainfall, slope, and proximity to a river. In this way, flood susceptibility may be assessed quantitatively with scores given to each factor in a weighted manner so that a systematic, objective layout of the flood-prone regions can be achieved. The approach is used in a systematic manner to integrate topographical, hydrological and climatic factors in order to increase flooding risks resilience. To make it consistent and less subjective Multi-Criteria Decision Analysis (MCDA) was used to standardise weighting process thereby making the model more predictable. The resulting flood susceptibility map was then validated using geostatistical analysis by comparing the resulting map with historical data depicting flood, which further proves the accuracy and credibility of the model. GIS platform also improves spatial perception, which allows the specific demarcation of high-risk areas of floods. In particular, a Spatial Analyst tool available in ArcMap 10.8 was used to reclassify the datasets, which is accurate, replicable, and easily fit in the GIS setting. This leads to the map that divides the land into five different groups of flood susceptibility, these are, very low flood susceptibility, low flood susceptibility, moderate flood susceptibility, high flood susceptibility and very high flood susceptibility, which provides a clear data based framework that could be used to guide urban planning and disaster risk management.

The given study relies on an integration of analytical tools, such as Weighted Overlay Analysis, Multi-Criteria Decision Analysis (MCDA), Geostatistical Analysis, and the GIS-based spatial processing to design a powerful and data-oriented model of flood susceptibility mapping. The introduction of these approaches will make the approach methodologically rigorous and applied. The outputs thus have valuable implications on the

provision of effective strategies to be implemented by stakeholders in disaster management, urban planners and policy makers in alleviating flood risks in Kuala Lumpur.

4.0 RESULT AND DISCUSSION

The research uses statistical tools and geospatial data analysis methods to provide unambiguous, trustworthy, and analysable answers to the area of flood susceptibility in Kuala Lumpur. The application of the Weighted Overlay Analysis under a Geographic Information System (GIS) model can guarantee a statistically based evaluation of flood peril without biases of any sort. The methodology followed is organized and concise with a minimal level of complexity but maintaining a degree of strictness in the analysis. To enable easy interpretation and effective implementation in the course of urban planning and disaster management, flood susceptibility is systematically grouped into five different levels: namely, very low, low, moderate, high and very high.

4.1 Flood Parameter: Thematic Maps

The development of thematic maps on all parameters of flood causing processes was utilized to determine the susceptibility of flood in Kuala Lumpur. In order to enhance readability and interest in the findings, the study has provided its results in a formatted presentation combining visual continuity. The thematic maps and classification tables are also used so that the information could be available and easily to understand. The maps are produced based on ArcGIS and demonstrate spatial differences in terms of rainfall distribution, a distance to the river, slope and altitude. Such visualisations offer the complete outlook of the spatial distribution of flooding danger in the study region. The overall scores are rated as very low through to very high (scores 2-10) to determine the flood susceptibility as given in Table 2. All the parameters which were pertinent were reclassified using the ArcGIS platform on basis of this scoring scheme, and this gave a composite flood hazard map. Figure 3 to 7 depicts the results of such classification process. Every next subsection includes empirical examination of individual parameters and their contribution to the general vulnerability of floods. Moreover, 3D flood simulations are incorporated to foster visualisation of flood effects to urban infrastructure, which is why mitigation strategies are highly instrumental, and they have to be very precise.

In the Results and Discussion section the overall flood susceptibility of Kuala Lumpur is evaluated based on various factors, which are rainfall distribution, river vicinity, elevation, slope variation and flood simulations in 3D. Parameters have been categorised systematically into the number of risk exposure as to the aspect of the flood risk with a titled numeric scoring mechanism that has been used to indicate a scale of susceptibility.

4.1.1 Rainfall Density

The rainfall intensity map categorizes regions according to their average monthly precipitation levels. Areas experiencing more than 310 mm of rainfall per month are classified as high-risk zones due to their elevated potential for generating substantial surface runoff. These findings underscore the necessity of prioritizing flood mitigation interventions in such areas, including the implementation of enhanced drainage infrastructure and flood retention systems. Figure 3 illustrates the spatial distribution of rainfall intensity, demonstrating a clear correlation between precipitation levels and the susceptibility scores assigned within the study.

In the rainfall distribution analysis, the levels of precipitation are put in five different classes such as very low till very high and recorded as a flood susceptibility score of 2-10. The maximum score indicating the increased susceptibility to excessive surface runoff is attributed to those areas that get 310 mm to 316 mm of rainfall per month. At that, the lowest scores denote, on the contrary, a low possibility of flooding in regions with less than 289 mm of rainfall monthly. This classification system clearly and methodically reveals the logical relationship between the falls of rain and the vulnerability to floods, hence underlines the fact that precipitation is a key aspect that is one of the main causes of flood risks.

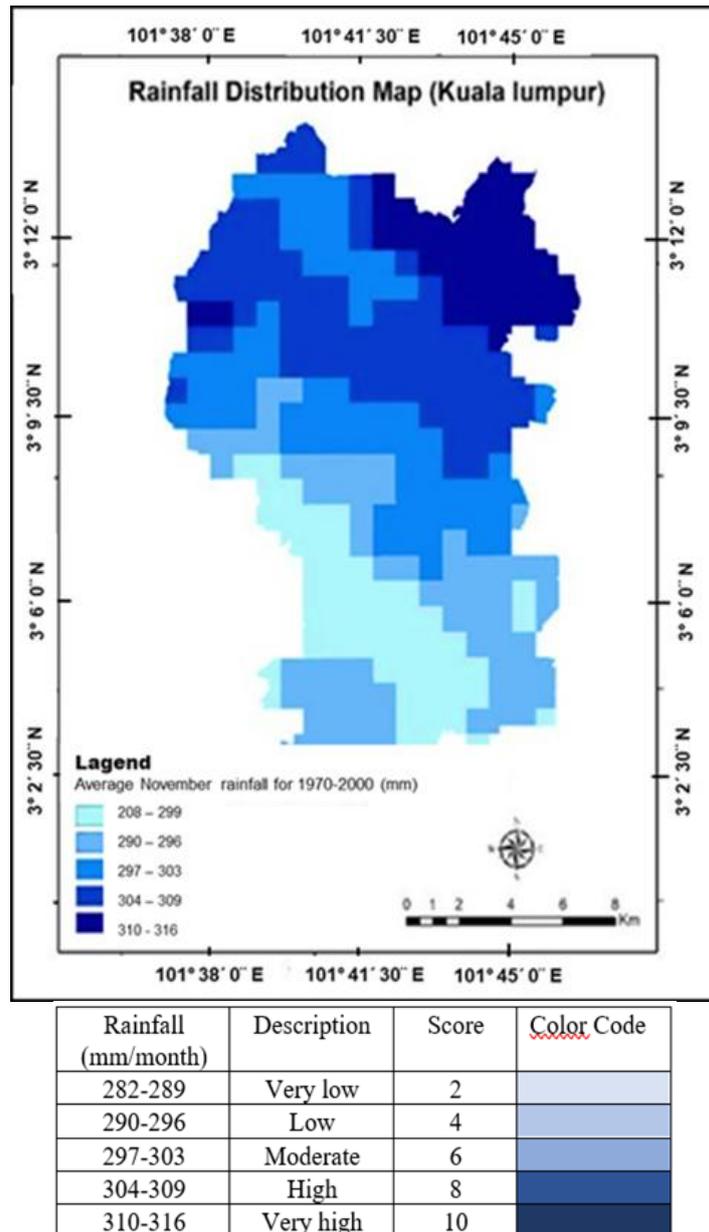


Figure 3: Rainfall map and Classification of Rainfall Distribution (mm/month)

4.1.2 Proximity to River

The proximity of the river analysis shows that the river overflow is of great importance in the occurrence of flood lands especially those found within 500 meters of large water bodies. The flood risk map (Figure 4) indicates that settlements in the urban area near the riverbanks have the greatest risk to floods. The main reason why it has become so vulnerable is that, first, there is more surface runoff coming out of the impervious urban areas, there is less infiltration capacity, and there are repetitive flood moving historical patterns. The results show that there is an acute necessity to introduce strengthened flood defense systems, improved drainages, and a better system of drainages in such areas, as only in this way, the effects of future flood could be limited.

The areas have been categorized in the table based on distance to any major water bodies whereby a zone within 232m to a river has the maximum score of flood susceptibility of 10. The susceptibility score that is assigned drastically goes down as the distance to the river went up whereby locations past 1, 147 meters have the lowest score 2. This categorization was systematic, because of the huge impact of the nearness to rivers in flood risk levels and assessment, as grounds nearest to rivers have high chances of inundation due to water surfaces and water spillage of rivers (Laka, 2023). The tabulated table supports the data brought out in the flood susceptible map, which reveals settlements in the city near rivers as risky sites.

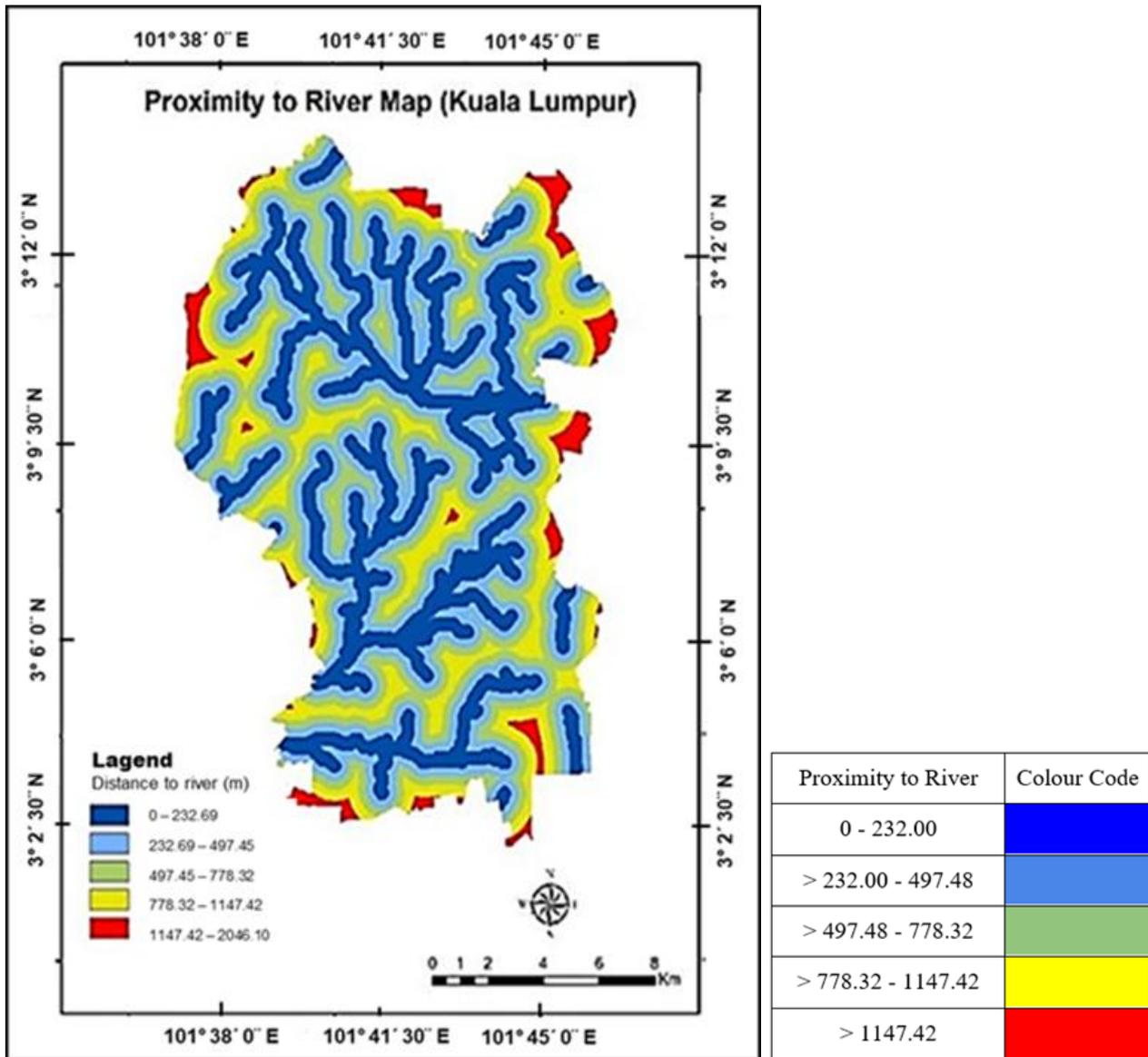


Figure 4. Proximity of River Map and Proximity distance.

4.1.3 Elevation

The elevation map (Figure 5) ranks the areas basing on the land height, points out the low lying areas to be the most prone to floods, mostly below 63 meters. These facts support the claim that such areas are regularly flooded, mostly because of presence near floodplains, and natural drainage lines. The elevation data and historic flood events can also be compared to highlight further the importance of topography to modify the vulnerability of the flood. These findings indicate that there is a need to prioritise flood control measures in the low-altitude regions to eliminate a potential future flooding problem.

The elevation parameter indicated in the table shows the high importance of the land height so far as impacting the flood susceptibility is concerned. Even areas that are lower and have less than 63 meters been given the maximum flood risk scores which means that the area is more prone to water accumulation and inadequate drainage capabilities. On the other hand, areas located above 185 meters are said to be those with very low susceptibility area and they are scored of 2 due to topographical advantage of this area in reduction of flood risk. This division correlates with the results depicted on the elevation map that clearly indicates concentration of flood prone areas in areas of lower altitudes (Ariyani et al., 2023; Deur et al., 2020).

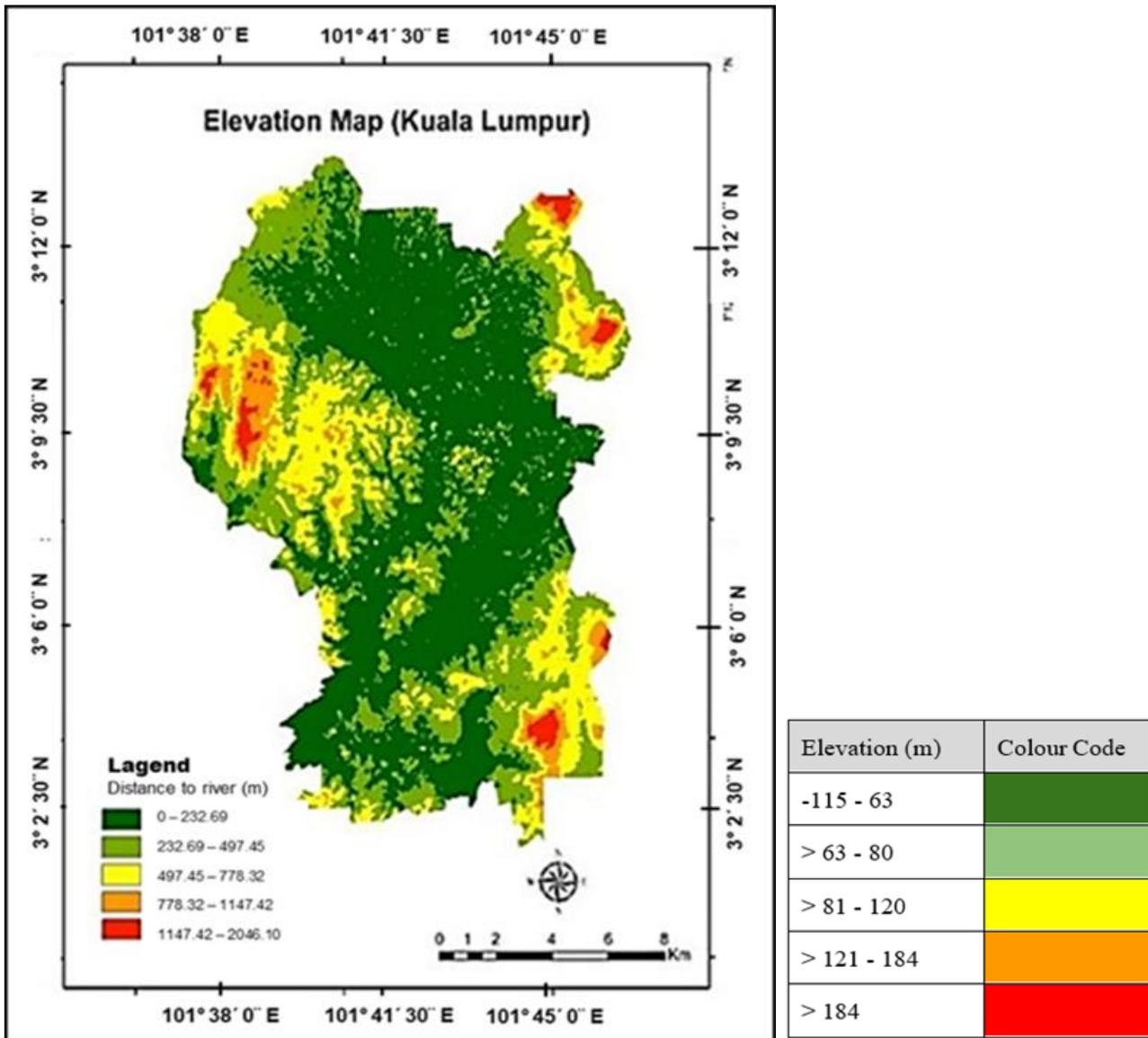


Figure 5. Elevation Map and Classification of the topographical elevation.

4.1.4 Slope

Slope is an important factor that determines the form water accumulation and run off behaviour. Flatter terrains especially in a gradient ranging between 0 and 5 are more likely to hold on to surface water thus making it more susceptible to floods. On the contrary, a steeper slope encourages the acceleration of runoff, which could activate the occurrence of localized flooding and lead to an augmented risk of floods down the river. The given spatial relationship is presented in the thematic map (Figure 6) that shows the clusters of flood-prone areas located in the low-slope areas, particularly, in the city where the drainage facilities can be lacking.

The trend of slope variations is well tabulated; flatter lands with a score of 10 are ranked as most versatile to floods because of their higher water retention capabilities further increasing flood susceptibility. On the other hand, the steeper the slope is, the lower the susceptibility score will be and the slope that has a greater angle than 35 is marked with the lowest one-2. This classification shows evidence in the research study that shallow slopes have additional opportunities of surface water collection whereas steep slopes cause augmented runoff, and this minimizes the chances of a localized flooding.

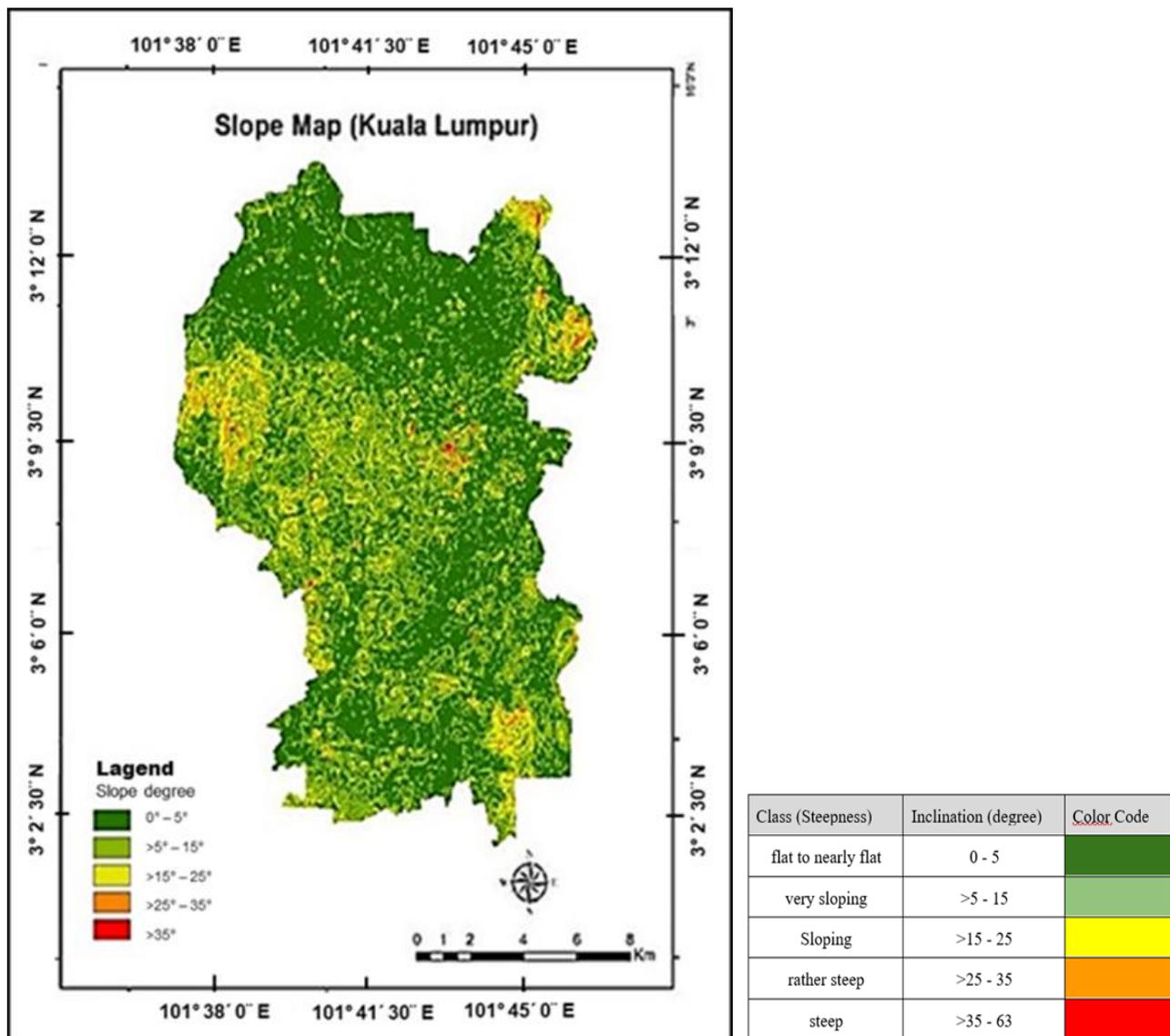


Figure 6. Slope Map and Category of slope steepness.

The results are well-expressed, and they constitute a clear and straightforward explanation of data. The analysis indicates that the northeast precinct of the Kuala Lumpur is the most prone to flood in Kuala Lumpur since it has a low altitude, low slopes, high precipitations level and is very near to river systems.

4.2 Final Output: Flood Susceptibility Mapping

The weighted overlay analysis combines various parameters related to flood that result in an overall flood susceptibility map (Figure 7), which divides the study area into five different classes of risks. The analysis shows that about 23.64 per cent of Kuala Lumpur lies in the zone of flood susceptibility consisting of the very high category and another 24.98 per cent under the high category of the country. These are spatial patterns that match well with previous and past flood records hence increasing the predictive reliability of the model. The evidence suggests that disaster preparedness is an urgent problem that urban resilience should be highly reinforced through targeted flood mitigation measures in high-risk regions.

The table is an important analytical instrument through which the raw geospatial data is transformed into a clear and practical model of the flood susceptibility based on the systemised classification of the essential parameters. The formal scoring model provides a quantitative representation of the strength of such factors as the rainfall level, distance to the river, altitude, and slope in terms of flooding risks. The method boosts evidence-based decision-making and underpins policymakers in coming up with accurate and efficient measures in reducing floods.

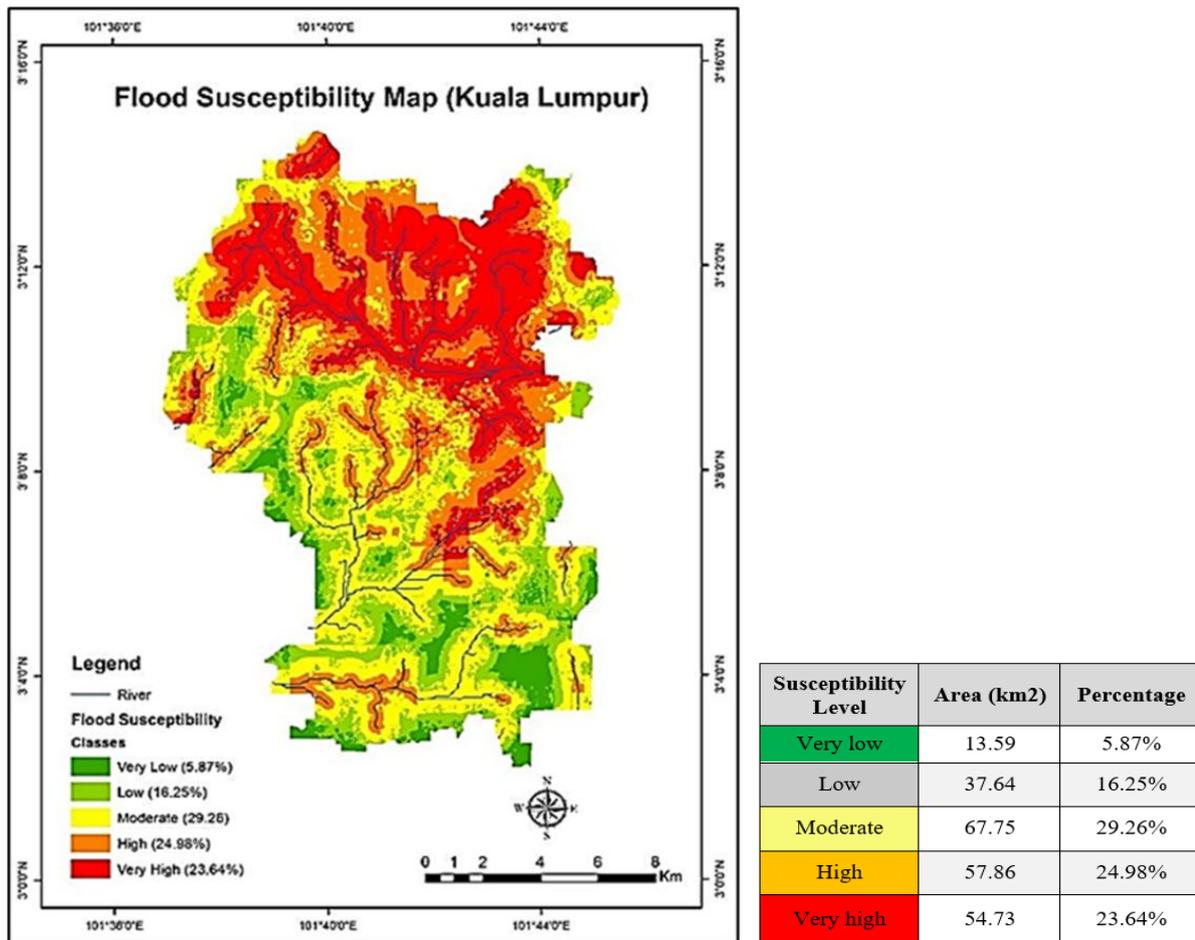


Figure 7. Flood-Susceptibility Map of Kuala Lumpur using Weighted Overlay Analysis method and Percentage area following levels of flood susceptibility.

The research makes data visualisation report be well-done including figures and tables. The tables have been grouped so as to better understand which of the parameters contribute to the risk of a flood. The 3D simulations of flood (Figure 8) offer sophisticated graphic display of the characteristics of the flood and give very good demonstration of where water will be accumulated in the areas that are at risk. The comparative approach which is carried out between the pre-flood and during-flood situations shows that there was considerable flooding of the ground surfaces and city infrastructure as well. There is evidence with these simulations that show that flooding may be something to reckon with especially as far as economic and property damage is concerned in the course of high precipitation. Besides, this research also determines that regions, which lie at a lower altitude compared to the other rivers or oceans, are particularly prone to flooding, because the power of gravity-supported water course aggravates the destructive effect of inundation.

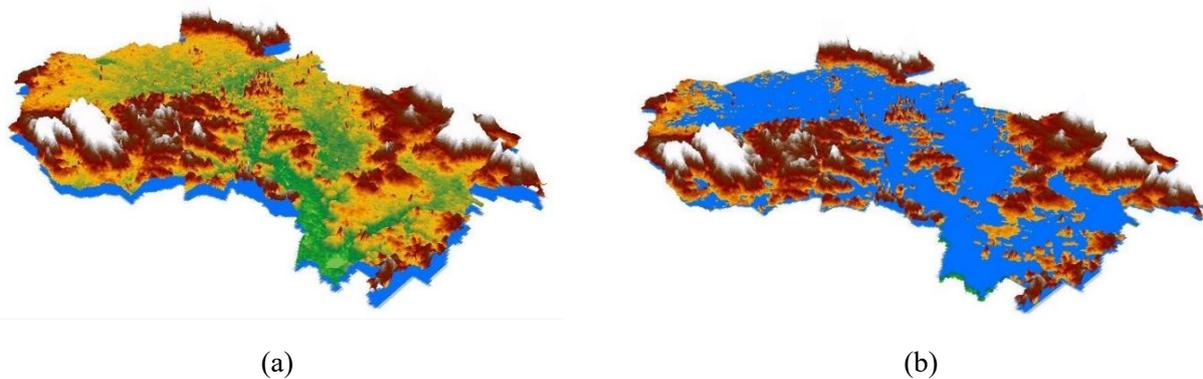


Figure 8. Showing the comparison of 3D Flood-Simulations of study case, Kuala Lumpur; (a) ground surfaces before floods; (b) ground surfaces during floods.

The paper also makes a use of three-dimensional (3D) flood simulations which succeed in dynamically mapping the spatial effects of floods within different types of terrain. Although the results of the simulation process are not presented in the table of data, there is a close relationship between the simulation data and the tabulated levels of flood susceptibility identified during the analysis. It is noteworthy that the hierarchical rating system is consistent with what has been visualized since higher-susceptibility score areas present very large water puddles in the region in the simulation. Comparative 3D visualisation of the pre-flood and flood scenario highlight the intensity of the inundation, especially in the vulnerable locations. These results prompt an utmost demand of location-specific and purposeful flood defense measures in high-risk cities.

Severity of floods is more likely increased with lower ground compared to adjoining seas or rivers. Under these circumstances, the flow of water streams is disturbed by experiencing the surface irregularities thus making it more susceptible to flooding as a result of heavy rain or increased water volume in the other nearby water bodies (Wang et al., 2018). The given observations are also supported by more recent studies that have more sophisticated and detailed analysis of the issue, such as the ones by Yaseen et al. (2024), Syakira et al. (2023), Ramesh et al. (2022), Tehrani et al. (2018), and Laka (2023).

5.0 CONCLUSION

The research bears immense implications on flood risk management, city planning and climate adaptation in KL. It also stresses the importance to have better drainage systems as well as implement sustainable development plans considering the fact that around 48.62 percent of the study site is categorized to be a high flood prone area. The combination of Geographic Information Systems (GIS) and the Weighted Overlay Approach can be efficient regarding the analysis of flood risk, as similar studies have already documented the importance of using topographical and hydrological data (Yaseen, 2024; Alharbi, 2024; Basri et al., 2022; Kassaye et al., 2024). Based on the significance of the main variables river proximity, rainfall intensity, slope, and elevation this research provides the repetitious model of analysis that can be applied to other urban settings. On the policy level, the results suggest that stricter zoning policies be enacted, that urban development should be reconsidered to take place in flood-resistant areas, and that nature-based solutions towards surface runoff mitigation should be incorporated (Hamel & Tan, 2022). Despite the main parameters based on which the analysis is made, diverse elements including land use patterns, drainage capacity, and density of the population are also important determinants of flood vulnerability. They were omitted because of the limited data yet have to be considered similarly in future studies to increase the completeness and the accuracy of future flood susceptibility models. Specifically, quantifying the extent of green space reduction and calculating the proportion of permeable versus impermeable surfaces would provide valuable insights into runoff dynamics. Integrating drainage infrastructure data and urban catchment characteristics would also enable a more robust representation of flood risk in Kuala Lumpur.

Although this research work has provided insights that can be used, it also has limitations. It concentrates more on four causes of floods without giving emphasis to other factors of critical reasoning including type of soil, land cover dynamics, and urbanisation patterns, which, to be precise, would boost predictive performance (Fulazzaky et al., 2023). The weighted overlay methodology which is applied in the analysis is itself subjective since manual selection of the parameter weights is done. This weakness signifies the interests in integrating the tools of machine learning or multi-criteria decision-making (MCDM) to increase objectivity and the analysis resilience (Karger et al., 2021; Lohani et al., 2020). Besides, the geographical scope of the study that confines to the Kuala Lumpur tends to reduce the generalisability of the results which may require calibration locally during application of the model to areas with contrasting climates and socio-economic scenarios. The future studies must include the additional set of parameters related to flooding, adopt new modelling methods, and use real-time monitoring technologies based on remote sensing and the Internet of Things (IoT). Cross-Southeast Asia comparative analyses and analyses of long-term mitigation measures against floods, including the use of retention basins and permeable pavement installations, may also bring additional contributions to sustainable urban flood management (Ahmad & Ayob, 2023).

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