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Flood susceptibility assessment using multi-criteria analysis: Case Study in Selangor, Putrajaya, and Kuala Lumpur

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Abstract. This study discusses flood assessment that makes use of the geographic information system (GIS) technology to provide a thorough identification of flood susceptibility zones in Selangor, Kuala Lumpur, and Putrajaya. Using MCA-GIS, flood susceptibility zones were delineated based on environmental factors such as precipitation, TWI, distance from the river, elevation, slope, land cover, and flow accumulation. To verify the framework's accuracy and dependability, comparisons with historical flood events were used to validate the flood susceptibility zones. The findings indicate that almost 13.9% of the study area is extremely susceptible to flooding, with the highest risk concentrated in the upstream and downstream regions of the Selangor River. Only 0.1% of the region was deemed to be at very low risk, indicating widespread flood susceptibility. As over 46% (very high susceptibility and high susceptibility) of the study areas are classified as flood-prone areas, stakeholders must prioritise appropriate precautions to lessen the impact of catastrophic flood events. The generated flood susceptibility zone maps can be used by urban planners and risk management professionals as a crucial source of information.

1. Introduction

One of the key components of the strategic activities promoted by Agenda 2030, as mentioned in SDG 11 (*Make cities and human settlements inclusive, safe, resilient, and sustainable*), is protecting metropolitan areas against natural disasters such floods, cyclones, storms, landslides, droughts, and heat waves. This focus evolved through a series of agreements, beginning with Yokohama Strategy and Plan of Action for a Safer World [1]. It then continued to Millenium Development Goals 2000– 2015 [2], the Johannesburg Plan of Implementation [3], the "Hyogo Framework for Action (2005-2015) [4]", the "The Future We Want" [5], the Sendai Framework for Disaster Risk Reduction 2015–2030 [6] and the 2030 Agenda for Sustainable Development [7].

The 2030 Agenda's Goal 15 (*Protect, restore, and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and biodiversity loss*) specifically addresses flood-related issues is target 15.3, aiming to combat desertification; restore degraded land and soil, including land affected by desertification, drought and floods; and strive to achieve a land-degradation-neutral world by 2030. The long-listed assemblies have shown consistency in commitments from each country to address natural disasters and environmental degradation. Each agreement was built on the previous commitments and lessons learned, demonstrating a persistent effort to strengthen international cooperation and responses to environmental issues.

Cities face significant challenges due to current unsustainable urbanisation patterns, including rapid growth, poor planning, urban sprawl, resource management issues, and pressure on infrastructure to improve resilience to slow-onset disasters [8]. Referring to the report 'The human cost of disaster: an overview of the last 20 year (2000-2019)' [9]. Over the last 20 years (between 1980 and 1999), there were 4,212 natural disasters that affected 3.25 billion people, causing an estimated 1.19 million fatalities and US$1.63 trillion in economic damage.

GIS serves as the backbone for spatial analysis and data integration, enabling the creation of comprehensive risk maps and decision support systems that provide actionable insights for effective flood risk management strategies. The integration process involves utilising spatial data encompassing various flood-related parameters, including rainfall patterns, terrain characteristics, land use, and soil type, alongside socio-economic indicators to create flood hazard maps, aiding in the identification of high-risk areas vulnerable to flooding [10]. Complementing GIS, remote sensing technologies offer timely and high-resolution imagery, facilitating tasks such as flood extent mapping, change detection, and continuous monitoring, thereby enhancing the accuracy and reliability of flood risk assessments.

Susceptibility typically refers to an area's flooding probability due to its physical attributes to flood events [11]. This involves assessing the factors that contribute to the likelihood and severity of flooding impacts. The integration of remote sensing data with GIS tools has become crucial strategy for analysing flood disasters, identifying flood-prone areas, and supporting decision-making processes [12] Flood susceptibility analysis using multi-criteria analysis (MCA) has been shown to be effective in informing flood risk management decisions in Selangor, Putrajaya, and Kuala Lumpur. Additionally, the use of GIS and MCA in flood susceptibility mapping has been recognised as a valuable tool for assessing hazards, vulnerability, and risk due to flooding, which can aid in community-based assessments and decision-making [13][14]. By integrating remote sensing data with GIS techniques, researchers can identify high-susceptibility zones, map flood hazards, and prioritise adaptation strategies [15]. Sophisticated spatial analysis techniques, such as overlay analysis, proximity analysis, and suitability mapping are essential for guiding flood mitigation strategies and optimising land-use planning efforts to enhance resilience against future flood events [16].

Flood-prone areas in Selangor, Putrajaya, and Kuala Lumpur have been the focus of numerous studies on flood event assessment [17], coastal inundation simulation[18] and spatial prediction of floods[19]. The Drainage and Irrigation Department identified 52 hotspots and 307 at-risk areas in Selangor [20]. These studies utilised geospatial technology, remote sensing, GIS, and advanced modelling techniques to identify and predict areas susceptible to flooding [18], [19]. Intensification of rainfall and urbanisation have been identified as factors contributing to the susceptibility of these regions to flooding [21], [22]. Furthermore, attention has been drawn to the effects of sea level rise on low-lying coastal areas such as Kuala Selangor, emphasising the need for early warning systems and flood management strategies [18][23].

Efforts to map flood-prone areas and predict flood susceptibility involve the application of machine learning models, statistical methods, and flood inventory data [24][25]. These studies aimed to provide accurate flood susceptibility maps for effective flood risk management and the identification of vulnerable zones [26]. Furthermore, the influence of land-use patterns on traffic congestion in Kuala Lumpur has been studied, indicating a dispersed land use that contributes to congestion issues [27]. The challenges posed by urbanisation and growth in Greater Kuala Lumpur have also been addressed, emphasising the need for effective urban growth management strategies [28].

Studies of natural flood studies including risk analysis [29], [30], flood susceptibility [31], [32], flood vulnerability and flood assessment [33], [34]. Several flood analysis studies have been conducted in the study area. Researchers have utilised historical flood data [17] analysed the hazard map in Sungai Besi

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Camp, Kuala Lumpur [35], studied disaster-resilient communities [36] and assessed the flood risk in the Langat River [37]. This study demonstrates the use of satellite-based flood susceptibility mapping using MCA-GIS. The specific aims were to develop flood susceptibility maps and analyse flood mitigation from an urban planning perspective.

2. Study Area

The study area encompasses Selangor, Kuala Lumpur and Putrajaya on the West Coast of Peninsular Malaysia, bordered by Perak, Pahang, Melaka and Negeri Sembilan. It covers 796,029 ha square (Figure 1) and is characterised by a hot, humid tropical weather with average mean maximum temperatures ranging from 22.8 to 33.4 °C. Situated between 300 and 570 meters above sea level, the region experiences two monsoon seasons: northeast (November to March) and southwest (May to September). Monthly rainfall averages between 80 mm and 242 mm. In most cases, floods in smaller rivers are caused by heavy short-term rainfall (flash floods) and develop rapidly. This study covers both seasonal flash floods and pluvial flooding. The former mainly affects small watersheds or urban areas, whereas the latter may occur at any location in the study area. The Sembah, Kanching, Kerling, Rawang, and Tinggi Rivers are the main tributaries of the river basin. Ten sub-basins make up the river basin: those located in Tanjung Karang, Rawang, Kuala Selangor, Sg. Tinggi, Rantau Panjang, Hulu Rening, Sg. Batang Kali, Kuala Kubu, and Kerling [38].

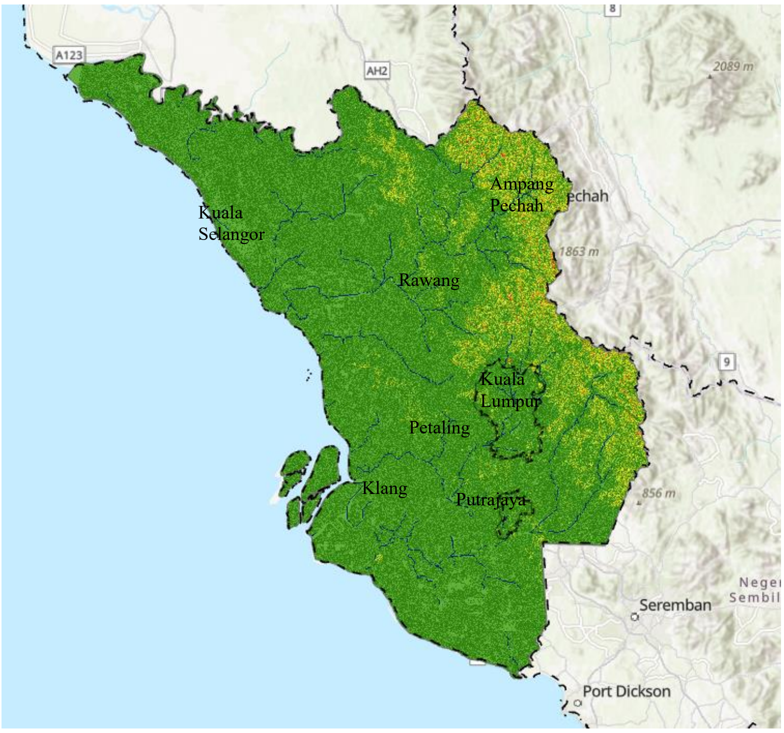

Figure 1. The study area: Selangor, Kuala Lumpur and Putrajaya.

3. Methodology

3.1 Material and Method.

The river dataset, flow accumulation, elevation, and slope were gathered from the Shuttle Radar Topography Mission (SRTM). Precipitation data were retrieved from the Climatic Research Unit gridded time series data from the University of East Anglia and land use/land cover from Living Atlas ArcGIS. Historical floods were retrieved from the Department of Irrigation and Drainage in Malaysia (DID). Detailed information is presented in Table 1.

Table 1. Variables along with classes, flood susceptibility categories, rating and weight

Parameters	Types of data	Data Sources
Flow Accumulation, Elevation, Slope, TWI, Distance from river	Raster data	STRM data https://dwtkns.com/srtm30m/
Precipitation	Raster data	Climatic Research Unit gridded Time Series https://crudata.uea.ac.uk/cru/data/hrg/
Land Cover	Raster data	Living Atlas ArcGIS https://livingatlas.arcgis.com/landcover/
Historical Flood Data from 2017 to 2022	Point data	Department of Irrigation and Drainage, Malaysia (DID)

3.2. Flood Susceptibility Mapping

Flood susceptibility mapping is a tool used to identify flood-prone areas, land use planning, emergency preparedness, and disaster risk reduction [39]. The integration of GIS-based MCA was used to identify susceptible areas to flood in the study area. Spatial data layers affect the occurrence of floods, such as elevation, slope, flow accumulation, distance to rivers, precipitation, topographic wetness index (TWI), and land use. All these parameters were prepared in a raster data format using GIS and remote sensing data and retrieved from different sources. An analytical framework (Fig. 2) was prepared for a detailed understanding of the study. All spatial layers were converted into grid databases with 30-30 m pixels.

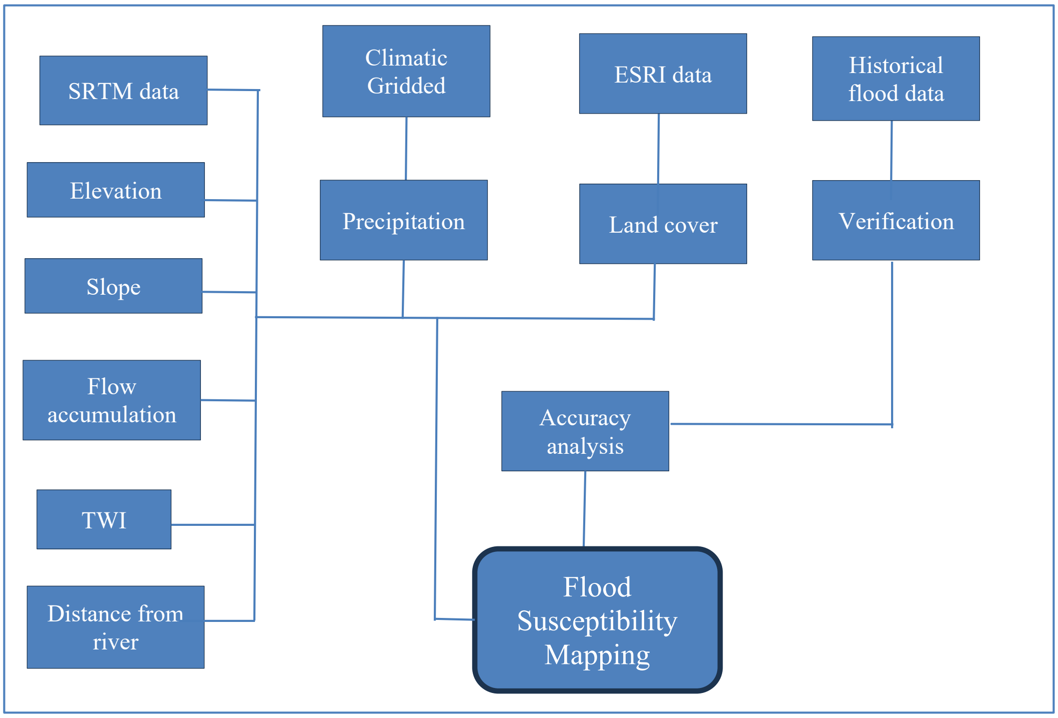

Figure 2. The methodology of the study.

3.3 Parameters for Flood Susceptibility Mapping

Precipitation: The CRU TS (Climatic Research Unit gridded Time Series) data, an established climate dataset covering all land domains of the world except Antarctica on a 0.5° latitude by 0.5° longitude grid, is where the precipitation data were downloaded. Monthly climatic anomalies from large networks of weather station readings are interpolated to derive it. Data on precipitation are derived from annual data.

Land cover: Sentinel-2 10m land use/cover in 2022 was used to download land cover using ESRI. In 2017, seven land use and land cover types were identified within the watershed. The following land use/cover types have been identified in the study area: forests, built-up areas, green land areas, and waterbodies. For this reason, the water body received a score of five because of how vulnerable it is to flooding. Built-up regions' land use/cover type was ranked 4th because of its high vulnerability to flooding. The expert [40] confirms that changes in land use and cover are a major cause of flooding, with increased urbanization, increased impermeable cover, and decreased forest cover in metropolitan areas all increasing runoff.

Elevation: The elevation raster layer was created using DEM data from the Shuttle Radar Topographic Mission (STRM) data. Using the reclassification tool in ArcGIS environment, the elevation data are classified into five groups: extremely high (less than 123 m), high (123–344 m), moderate (344–636 m), low (636–983 m) and very low (983 m and above). Each class covers approximately 88.6%, 5.7%, 4%, 1%, and 0.1% of the total watershed area, respectively. Lower elevated areas and lowlands are more easily flooded, whereas higher elevated areas experience inundation during flood events.

Flow accumulation: The flow accumulation was computed using the flow direction raster. Every cell in the flow accumulation raster functions as a discharge profile since it contains information about the number of cells that flow into it. Therefore, a rise in flow accumulation ought to result in a rise in the vulnerability to flooding. To create the hydrologically acceptable DEM, the flow accumulation raster classes were constructed at a scale of 1:50,000, which best fit the vector layer of a river network.

Distance from the river: Areas that are vulnerable to flooding are defined in large part by the distance to the river. Floods most commonly damage the areas closest to rivers. River datasets were found through the use of ArcGIS for hydrological analysis. The manual interval method was used to modify the classes for the raster of distance from rivers. Given that rivers and the areas around them serve as the primary conduits for flooding, proximity to rivers is another crucial conditioning factor. In this work, the stream was created by varying the maximum pixel value to build the river from the DEM using flow accumulation data.

Slope: In the study region, the slope percentages varied from 0 to 60 m. In contrast, lower slope values indicated topography that was very flat and prone to flooding, while higher slope values indicated topography that was steeper and less likely to flood. The slope layer was derived from the DEM, with a resolution of 30 x 30 meter, using the Slope tool in ArcGIS. Five tiers of slope were identified based on their vulnerability to flooding. Based on how the slope affected the likelihood of flooding, the research area's slope was categorized into five groups: very high (0–15°), high (15.1–25°), moderate (25.1–35°), low (35–45°), and very low (45.1 above°). About 85, 11, 4, 1, and 0.01% of the entire watershed area, respectively, are represented by each slope class. The slope category was designated by referring to the Highlands and Hillslopes Development Planning Guideline.

Topographic Wetness Index (TWI): Topography's degree of wetness is shown by TWI. It is the topography's distribution of flow accumulation, soil moisture, saturation zone, and wetness [41]. Compared to traditional hydrodynamic models, TWI offers a more economical method for determining flood levels [42]. The five ranks of TWI were categorised into five groups: very high rank 1 [10.1 above], high rank 2 [5.1 to 10], moderate rank 3[3 to 5], low rank 4[-5.1 to 3], and very low rank 5 [-10 to (-5)].

The raster data were classified from 1 (*high risk*) to 5 (*low risk*), and the weighted sum was identified based on the literature review. Factor weight was applied to each reclassified factor map by the aggregation approach (weighting sum) (Table 2). The results are summarised as follows. Figures 3 to 6 showing the maps for each parameter according to the analysis.

Table 2. Variables along with classes, flood susceptibility categories, rating and weight.

Flood	Class	Flood susceptibility	Rating	Weight
TWI	10.1 above	Very high	1	0.17
	5.1 – 10	High	2	
	3 – 5	Moderate	3	
	-5.1 – 3	Low	4	
	(-10) – (-5)	Very Low	5	
Flow Accumulation	50001 - 650000	Very high	1	0.12
	2501 – 50000	High	2	
	501 – 2500	Moderate	3	
	251 – 500	Low	4	
	0-250	Very Low	5	
Elevation	300 below	Very high	1	0.15
	301 – 600	High	2	
	601 – 1000	Moderate	3	
	1001 – 1500	Low	4	
	1501 above	Very Low	5	
Precipitation	331 – 352	Very high	1	0.17
	311 – 330	High	2	
	291 - 310	Moderate	3	
	281 - 290	Low	4	
	Below 280	Very Low	5	
Land Cover	Waterbody	Very high	1	0.10
	Built-up area	High	2	
	Cultivated Land	Moderate	3	
	Grassland	Low	4	
	Forest	Very Low	5	
Distance from waterbodies	<200	Very high	1	0.17
	201-400	High	2	
	400-1000	Moderate	3	
	1001 – 5000	Low	4	
	More than 5001	Very Low	5	
Slope	0 – 15	Very high	1	0.13
	15.1 – 25	High	2	
	25.1 – 35	Moderate	3	
	35.1 – 60	Low	4	
	60 above	Very Low	5	

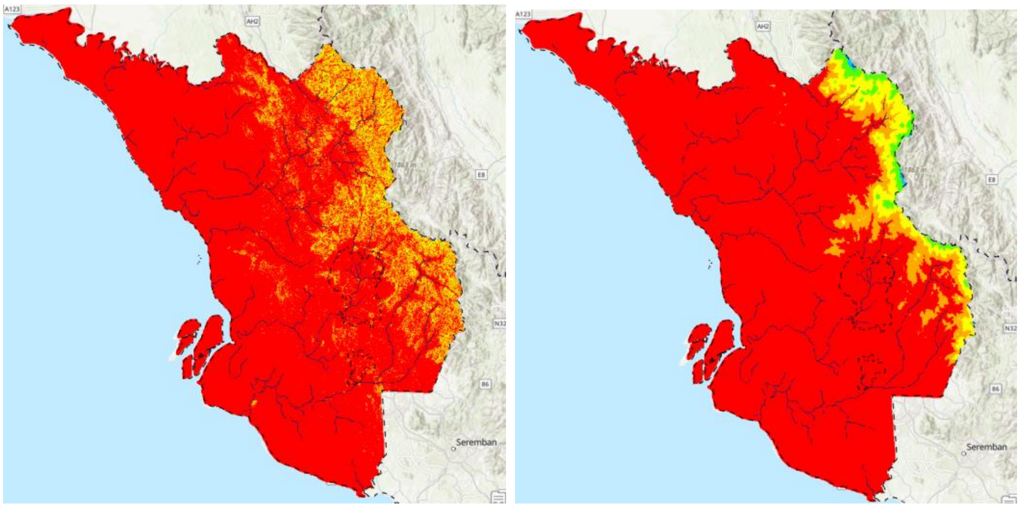

Figure 3. Flood parameter: Slope (left), Elevation (right).

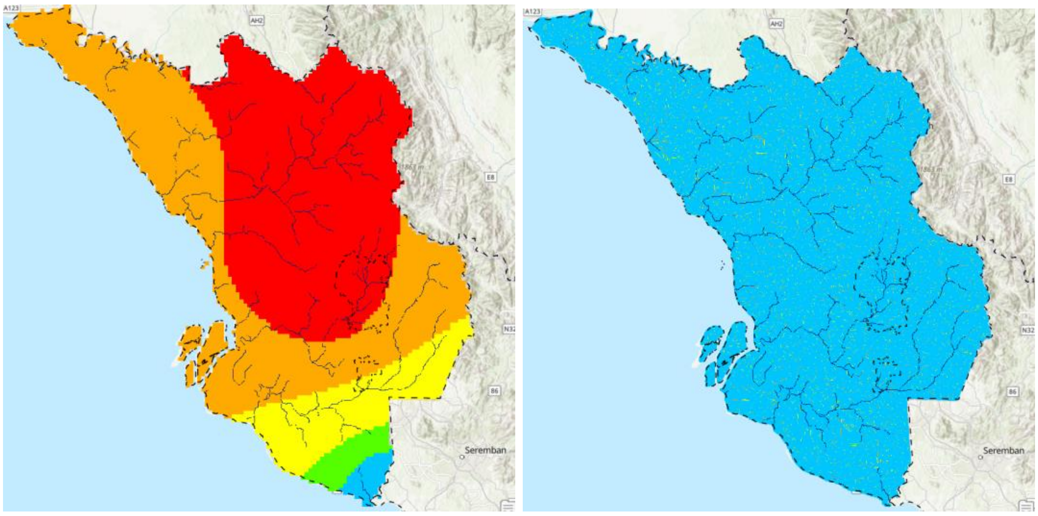

Figure 4. Flood parameter: Precipitation (left) and Flow accumulation (right).

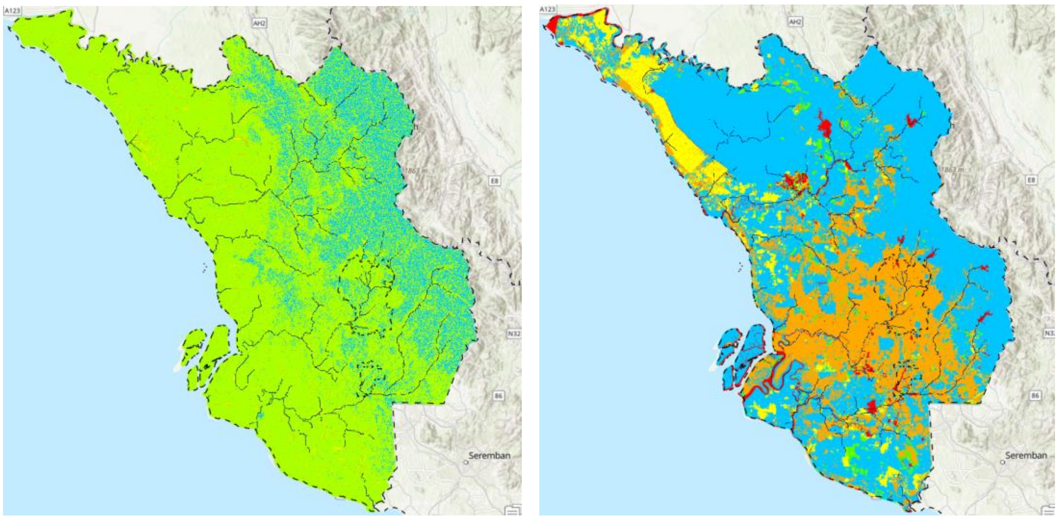

Figure 5. Flood parameter: TWI (left) and Landcover (right).

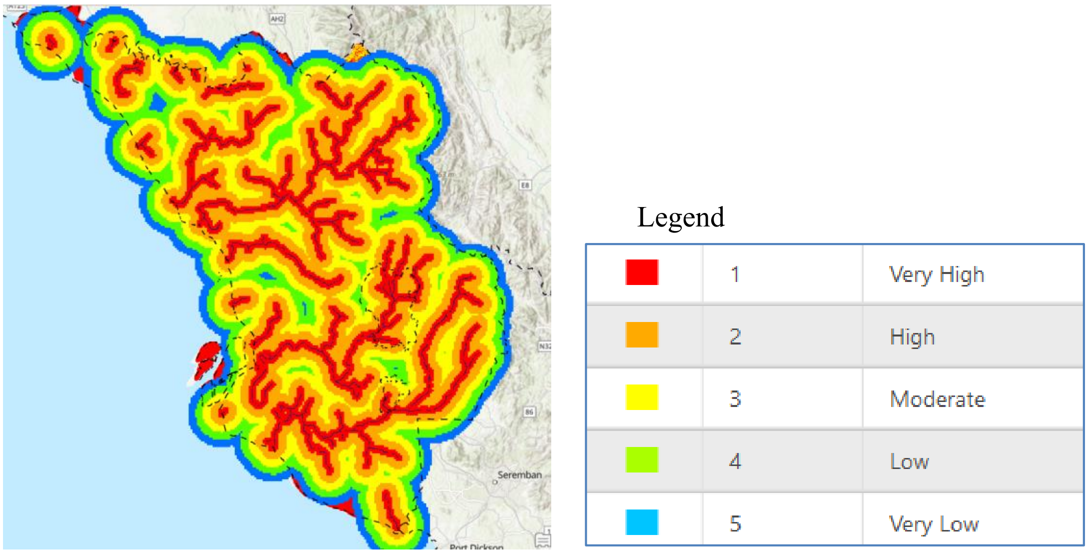

Figure 6. Flood parameter: Distance from river.

3.4. Validation of the flood susceptibility zonation map

Validation is a crucial step in assessing the accuracy and reliability of flood susceptibility maps. To validate the prepared flood susceptibility mapping, historical data for the flood inventory of the study area were overlaid. Datasets from the DID were gathered and transferred to GIS, using the address and location in the form of points. Data were retrieved from the 2017 to 2022 datasets. To validate the flood hazard map results, the locations of the historical flood events were generated based on the datasets provided by the DID. The department supplied relevant information for 1347 flooding sites. These historical flood points were then overlaid on the modelled output. Figure 6 illustrates examples of these historical flood points in the modelled flood susceptibility zones.

The locations of past floods from the historical data were then overlaid onto the susceptibility zones on the prepared flood map. The data were then analysed to identify whether the areas with past floods corresponded to the predicted high or very high susceptibility zones on the map. The results confirm the validity and application of the suggested methodology, as they are in line with historical data of the distribution of flood disasters.

4. Result

The map (Figure 7) also shows that the flooded area mostly located along to the river including upstream and downstream regions, showing that it held the greatest concentration of risk. The forested areas in the hilly area at the northeast are delineated as regions that exhibit relatively low flood risk. The central part of the study area is classified as a high flood susceptibility zone. The map was overlaid with historical flood data from 2017 to 2022. The results (Table 3) indicate that 13.9% of the study area is in very high susceptibility zones for flood analysis, and 32.4 per cent of the study area exhibit relatively high susceptibility to flood occurrence. The Gombak and Klang rivers are close to several areas with a high hazard of flooding. Flood hazard are not as likely to occur in the east, north, or west hills as they are in lower lying areas.

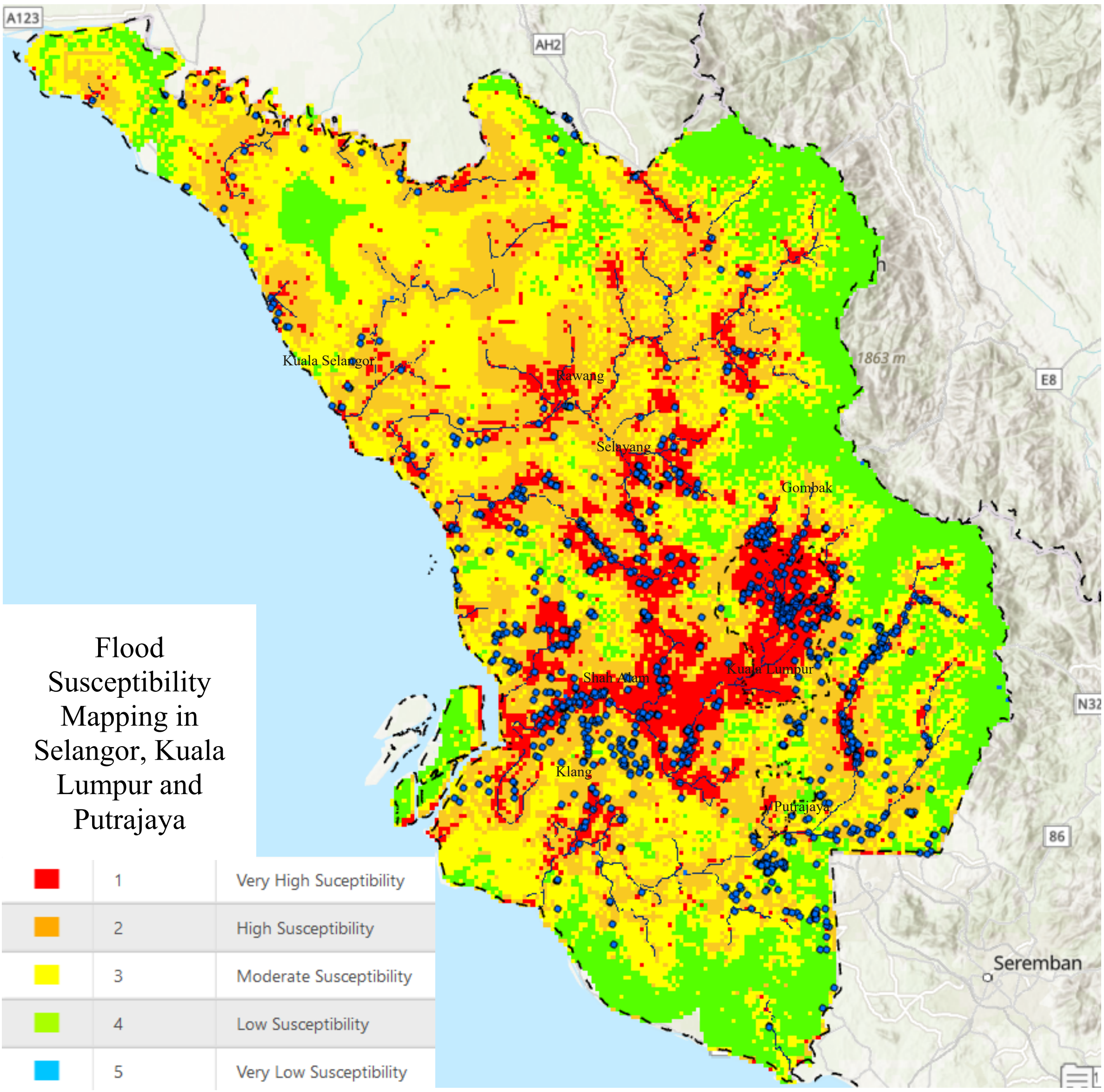

Figure 7. Final map for flood susceptibility mapping.

Table 3. Area for susceptibility mapping.

Susceptibility	Area	Percentage (%)
Very High	110586.2	13.9
High	257596	32.4
Moderate	257157.5	32.3
Low	170113.7	21.4
Very low	575.5417	0.1
Total	796,029	100

From a planning perspective, the findings are very useful, as they relate to the arrangement of land uses, considering the susceptibility of the area to flood incidents. The results demonstrate that the concentration of very highly susceptible flood areas is located mostly in densely built-up areas within the stretch of the District of Gombak, Kuala Lumpur, District of Petaling, and District of Klang. Historical data show that these areas have been affected by a series of floods. Meanwhile, the areas found to have very low susceptibility are generally located in the eastern part of Selangor, bordering Pahang. These areas are mainly covered by forestry, such as the Hulu Selangor Permanent Forest Reserve (PFR), the Gading PFR, the Hulu Gombak PFR, and the Hulu Langat PFR. In relation to the factors influencing flooding, the results reflect that the highest weight for this study is the distance from the river. This calls for the holistic implementation of river reserves by DID, as not all river reserves are gazetted. This situation allows development to encroach on the river reserve, and the present occurrence of floods may worsen. Thus, more practical mitigation measures are required to manage flood incidents in these areas. With the current movement of integrating the importance of Disaster Risk Reduction (DRR) in managing the land uses arrangement, the future planning will need to consider the investigation of flood susceptibility assessment in its scope. Therefore, it is hoped that a more holistic approach that includes DRR will strengthen the delivery system for planning in Malaysia.

5. Conclusion

This study demonstrated the use of key factors for satellite-based flood susceptibility mapping in Selangor, Kuala Lumpur, and Putrajaya. Comparison with historical flood events revealed consistent distribution patterns. The main findings showed that over 46 % of the study area is flood-prone area. As DRR becomes increasingly integrated into land use management, future planning must consider flood susceptibility assessment. Incorporating a comprehensive DRR strategy can improve Malaysia's planning delivery system.

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