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Flood Risk Mapping in Batu Pahat Using GIS and Analytic Hierarchy Process

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Abstract

Flooding represents an ongoing natural disaster which creates major hazards that endanger human life and destroy buildings and vital systems. This research project develops a flood risk map for Batu Pahat Malaysia by combining Geographic Information Systems (GIS) with Python-based Analytic Hierarchy Process (AHP) technology. The flood-prone area identification process needs to evaluate high-risk zones and study spatial analysis methods which predict flood risks. Researchers studied three key elements which included land cover and slope and Digital Elevation Model (DEM) based elevation data to determine their impact on flood vulnerability. The AHP process became more efficient and reproducible through Python automation which executed the AHP process for the analysis. The AHP results showed that elevation contributes 63% to flood risk assessment while slope and land cover account for 26% and 11% respectively. The flood risk map divided the area into three danger levels which included low danger areas and medium danger areas plus high danger areas that mostly existed in low-lying urban areas with gentle slopes. The predictions proved accurate because researchers validated them by comparing against actual flood data from previous events. The research demonstrates how AHP combined with GIS and Python creates an efficient flood risk assessment tool which helps with disaster planning and resource management. Future research could enhance the model by incorporating additional factors such as rainfall patterns, drainage infrastructure, and soil characteristics, further improving the accuracy of flood risk predictions.

Keywords: analytic hierarchy process (AHP); digital elevation model; flood-prone areas; geographic information system (GIS); python

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1. Introduction

Flooding ranks among the most common and most destructive natural disasters which impact the entire globe because it affects millions of people each year. The phenomenon occurs when water flows into regions that normally remain dry because of intense rainfall and storm surges and fast snowmelt. The effects of flooding produce deep consequences which result in human fatalities and force people to leave their homes and cause extensive financial losses through the demolition of public facilities and private residences and farmland. The regions of South Asia and Southeast Asia and Europe and parts of North America show high susceptibility to flooding disasters because climate change causes more frequent and severe flooding events which result from rising sea levels and unpredictable weather patterns [1–3].

Flooding has become a persistent problem that keeps increasing in severity throughout multiple areas of Malaysia, with Batu Pahat located in Johor being one of the affected regions. The increasing frequency and intensity of flood events create major risks which endanger human lives and damage property and infrastructure and harm the local economy. The research aims to find an answer to the main question which asks how to use GIS with AHP for mapping flood risk zones in Batu Pahat Malaysia. Urban growth together with climate change which causes heavier rainfall and more recurring extreme weather conditions

has created an urgent requirement for a higher level flood risk evaluation technique. Urban communities which lack proper stormwater management systems experience higher flood risks because standard flood forecasting techniques do not function effectively in these environments. GIS functions as a strong instrument for spatial data analysis and visualization while AHP enables the integration of expert assessments to identify the most critical danger elements. This combined methodology provides a stronger method for identifying flood risk locations and developing better emergency response capabilities.

The aim of this study is to develop a computational framework for flood risk mapping in Batu Pahat, Malaysia, by integrating GIS with AHP. The primary objectives include identifying areas most vulnerable to flooding, evaluating the effectiveness of spatial analysis in flood risk prediction, and providing a decision-making tool for disaster preparedness and mitigation.

The flooding problem in Malaysia occurs every year during the monsoon seasons because the country experiences two types of floods which include riverine floods and flash floods. Riverine floods typically affect low-lying areas adjacent to rivers following prolonged rainfall, while flash floods are increasingly prevalent in urban settings due to rapid urbanization and inadequate drainage systems. The East Coast states of Malaysia including Kelantan Terengganu and Pahang experience severe flooding during the northeast monsoon period. The states of Johor Perak and Selangor experienced major flooding events within the past year. The 2014 flooding event resulted in over 200000 people being displaced and caused extensive property damage [4].

Flooding impacts create physical destruction which extends beyond their immediate effects to damage the economy and societal functionality. Floods create financial losses which disrupt transportation systems and damage infrastructure and destroy agricultural production resulting in economic losses which impede regional development for multiple years. The psychological toll on affected populations is also significant, with increased incidences of trauma and long-term mental health issues reported among those displaced by floods [5-6]. Floods create major health hazards because they enable waterborne diseases like cholera and dysentery to spread through areas with broken sanitation systems [7]. The environmental consequences lead to soil erosion and habitat destruction and water body contamination which result in permanent damage to local ecosystems [8].

The global flood danger has increased because of multiple environmental factors which contribute to this problem. Climate change leads to more severe weather conditions which produce heavier rainfall and cause sea levels to rise. Urban areas and deforestation practices decrease landwater absorption capacity while the lack of proper flood control systems including poorly functioning drainage networks makes urban centers especially vulnerable to flood threats [9]. The lack of proper floodplain planning has resulted in urban development which leads to higher flood risks in developing areas by creating greater damage during flood incidents [10].

Governments and urban planners use flood risk mapping as their primary tool to reduce flood damage. Authorities implement Geographic Information Systems (GIS) together with Analytic Hierarchy Process (AHP) methods to assess multiple factors which include topography and rainfall patterns and land use and river networks for determining high-risk locations [11]. The risk maps serve as essential tools for urban planning and flood management and emergency preparedness in flood-prone nations like Malaysia since they support proactive flood mitigation efforts through infrastructure upgrades and drainage system enhancements [12-13].

The research study uses GIS spatial processing together with Analytic Hierarchy Process (AHP) to calculate flood risk index through its assessment of flood conditioning elements. Section 2 contains information about the GIS processes and AHP analysis methods which were used in this research.

2. Methods

The research project combines GIS technology with the Analytic Hierarchy Process to evaluate flood risk in the city of Batu Pahat. The proposed methodology workflow is displayed through Figure 1, which shows all the procedures that start from data preparation and end with flood risk mapping.

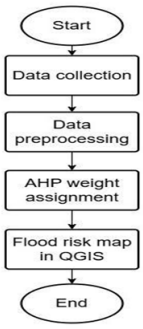


Figure 1. Flowchart

The team begins the project by gathering spatial datasets that include land cover data, slope information, and Digital Elevation Model (DEM) data. The team uses Quantum GIS (QGIS) to process the datasets after confirming that all datasets use the same coordinate reference system (CRS). The datasets undergo raster reclassification to establish standardized formats which enable precise comparison and examination. The AHP method assigns weights to criteria based on assessments made by expert evaluators. The process requires the creation of a pairwise comparison matrix which undergoes normalization to determine the weight of each assessment factor. The flood risk map results from

combining weighted layers through a weighted overlay analysis which QGIS implements to display areas with different risk levels that range from very low to very high. Base map imagery is obtained from Google Earth and processed using QGIS (version 3.32.3) [14].

2.1 Study Area

Batu Pahat is a district that exists in the western region of Johor which is a state in Malaysia because the area features extensive agricultural land and developing urban regions. The district encompasses both countryside and cityterritories because local agricultural activities which include oil palm and rubber cultivation serve as essential components of the regional business activities. The main urban center of the district which is Batu Pahat town (1.8548° N, 102.9325° E) has undergone extensive development during the past few years which has resulted in increased building activities and the expansion of city areas. The Batu Pahat River which flows through the district functions as an essential water supply system while it creates flooding problems during times of intense rainfall. Figure 2 shows the area of the Batu Pahat district.



Figure 2. Batu Pahat district

The region experiences a tropical climate with significant rainfall during the northeast monsoon, particularly from November to March. The study uses Geographic Information Systems (GIS) to create flood risk maps of Batu Pahat by examining essential elements of topography and land use and the digital elevation model. The study creates flood risk maps which show the areas that are most likely to experience flooding, which include from agricultural lands to urban centers. The local authorities need these insights because they help them to improve their flood preparedness operations and develop infrastructure that can withstand disasters and execute specific flood reduction programs which will help the community and preserve sustainable growth in Batu Pahat.

2.2 Quantum GIS Tools

Although flood susceptibility may be influenced by additional variables, this study focuses on land cover, slope, and DEM due to data availability and their strong physical relevance to flood accumulation in the study area.

Quantum Geographic Information System (QGIS) was used to process and analyse the spatial datasets required for flood risk mapping in Batu Pahat. All spatial layers, including land cover, slope, and Digital Elevation Model (DEM), were first imported into QGIS and projected to a common coordinate reference system (CRS) to ensure spatial consistency across datasets. The study area boundary was then used to clip each raster layer, limiting the analysis strictly to the Batu Pahat district.

The slope layer was derived directly from the DEM using the *Slope* function available in the terrain analysis tools. Each criterion layer was subsequently reclassified based on its contribution to flood susceptibility. For land cover, higher flood risk values were assigned to urban and built-up areas, while lower values were assigned to vegetation and forested regions. The slope layer was reclassified such that flatter areas received higher flood risk scores, reflecting their greater potential for water accumulation. Similarly, the DEM layer was reclassified to assign higher risk values to low-lying areas and lower values to higher elevations.

The standardized raster layers were combined through weighted overlay method after their reclassification process. The Raster Calculator in QGIS was used to apply AHP-derived weights to each criterion layer. The study area flood risk index was represented by the composite raster which divided the area into five different flood risk categories that included very low, low, medium, high, and very high. The final flood risk map used in the analysis was created from these classified outputs.

2.3 Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) was used in this research to determine weight values for three flood-conditioning criteria which include land cover and slope and Digital Elevation Model (DEM) data according to their flood risk assessment significance. AHP enables experts to transform their judgments into numerical weight values by using pairwise comparisons which maintain logical decision-making consistency throughout the process [15-16].

The researchers performed pairwise comparisons between the criteria using the Saaty scale which measures between 1 to 9 with reciprocal values used when necessary. The resulting pairwise comparison matrix is expressed in Equation 1, where the diagonal elements are equal to one and the reciprocal property $a_{ji} = 1/a_{ij}$ is maintained.

$$A = \begin{pmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{m1} & \cdots & a_{mn} \end{pmatrix} = \begin{pmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ \frac{1}{a_{m1}} & \cdots & a_{mn} \end{pmatrix} \quad (1)$$

To derive the relative weights, the pairwise comparison matrix was normalized by dividing each element by the

sum of its respective column. The weight vector was calculated by averaging the normalized values which were present in each row of the data. The priority vector was obtained by multiplying the comparison matrix with the weight vector, as shown in Equation 2.

$$[AW_i] = [A][W_j] \quad (2)$$

The maximum eigenvalue ($\lambda_{\max}$)was computed using Equation 3 to assess the consistency of the judgments.

$$\lambda_{max} = \frac{1}{n}\sum_{i=1}^{n}\frac{AW_i}{W_i} \quad (3)$$

The equations define n as the number of criteria and A as the pairwise comparison matrix and W as the weight vector. The pairwise comparison matrix was assessed for consistency through the consistency ratio (CR) which determined that values under 0.10 signal acceptable levels of consistency. A pairwise comparison matrix was created according to expert assessment to measure the importance of land cover and slope and DEM which is shown in Table 1.

Table 1. Pairwise Comparison Matrix

Criterion	Land Cover	Slope	DEM
Land Cover	1	1/3	1/5
Slope	3	1	1/3
DEM	5	3	1

The matrix was subsequently normalized, and the weights for each criterion were calculated by averaging the normalized values across each row. The normalized matrix and the resulting weights to Table 2.

Table 2. Normalized Matrix and Weights

Criterion	Land Cover	Slope	DEM	Weight
Land Cover	0.1111	0.0769	0.1304	0.1061
Slope	0.3333	0.2308	0.2174	0.2605
DEM	0.5556	0.6923	0.6522	0.6334

The weights obtained demonstrate how much each criterion should be weighted according to its importance: land cover 11%, slope 26%, and DEM 63%. The researchers used the eigenvalue method to evaluate the consistency of their pairwise comparison matrix. The maximum eigenvalue was ($\lambda_{\max}$) = 3.040, which resulted in *CI* = 0.020 and *CR* = 0.035, while *RI* = 0.58. The results show that the judgments maintain consistent patterns because they fall below the acceptable threshold of 0.10.

When evaluating risk scores, it is important to consider land cover, slope, and DEM criteria simultaneously. This approach, commonly employed in risk assessment, was expressed by numerous scholars in Equation 4.

$$Flood\ Risk\ Index = (W_1.Land\ cover) + (W_2.Slope) + (W_3.DEM) \quad (4)$$

2.4 AHP Implementation in Python

The procedure for flood risk assessment developed better accuracy results and improved operational efficiency through the implementation of Analytic Hierarchy Process (AHP) which used Python programming language. AHP needs the creation of a pairwise comparison matrix which helps assess the flood risk by measuring the importance of land cover and slope and elevation criteria. The manual process of handling large datasets requires extensive time while it increases the chances of making mistakes.

The Python programming language enabled process automation for several essential tasks after this execution. The first step involved Python development of a pairwise comparison matrix which experts evaluated using the Saaty scale where they assigned values from 1 to 9 to determine each criterion's importance. The matrix was normalized through Python numerical libraries which included NumPy because all elements were divided by their column total. The normalization process established appropriate scaling for analysis purposes which weighed each criterion according to its relative significance.

Next, Python was employed to calculate the weight vector, which showed the relative importance of each criterion through measurement of normalized values across all matrix rows. Python was used to calculate the consistency ratio (CR) according to the eigenvalue method as a way to verify the validity of pairwise comparisons. The pairwise comparisons needed to be redone because the CR value exceeded 0.1 threshold. Python automated these procedures which led to better AHP process efficiency and reproducibility while decreasing calculation time and reducing manual mistakes. The AHP analysis produced weightings which were then applied to QGIS for spatial analysis and flood risk map creation.

3. Results and Discussions

This section presents the outputs of the GIS–AHP workflow using three flood-conditioning criteria: land cover, slope, and DEM. The criteria were processed in QGIS and integrated using AHP-derived weights to generate the flood risk index for Batu Pahat. The resulting criterion maps, weighted overlay output, and final flood risk zonation are discussed in the following subsections.

3.1 Data Preparation

The flood risk mapping workflow began with preparing three spatial datasets: land cover, slope, and Digital Elevation Model (DEM). All datasets were imported into QGIS and reprojected to a common coordinate reference system (CRS) to maintain spatial consistency. The Batu Pahat district boundary was then used to clip each layer, ensuring that subsequent analyses were restricted to the study area. Slope was derived from the DEM using the *Slope* tool available in the terrain analysis functions [17]. Each criterion layer was then reclassified into standardized flood-susceptibility classes. Land cover categories were assigned higher susceptibility values for built-up or urban areas and lower values for vegetated areas. Slope values were

reclassified such that flatter terrain received higher susceptibility scores due to its greater tendency to retain surface water. Similarly, the DEM layer was reclassified to assign higher susceptibility scores to low-elevation areas and lower scores to higher elevations [18].

The standardized raster layers after reclassification were combined through a weighted overlay method. The AHP-derived weights were applied to each criterion through the Raster Calculator, producing a composite flood risk index layer. The index immediately divided into five flood risk zones which included very low risk, low risk, medium risk, high risk, and very high risk. The final flood risk map produced in this section used these five flood risk zones as its foundation [19].

The most critical element which affects flood occurrence patterns requires assessment of the area's elevation [20]. Water flows through the drainage system from mountain summits toward valley bottoms at a rapid speed. Sudden and intense floods occur more frequently in low-lying areas than in higher elevation regions according to studies conducted by researchers [21-22]. Floods happen more frequently at lower elevations because of two factors which include increased river discharge and rapid flooding during high water events. The elevation distribution across the study area is shown in Figure 3.

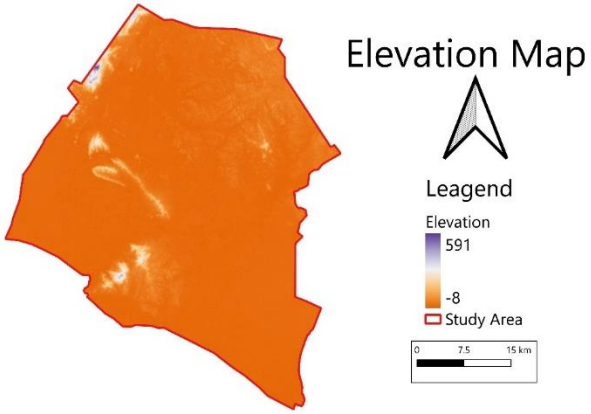


Figure 3. Elevation map

The likelihood of a flood occurring is higher when the slope of an area is lower. Additionally, it controls the course of water movement, making it a reliable indicator of vulnerability to flooding. According to [23], the infiltration rate has an inverse relationship with the slope angle. This means that surface flow rises in areas with higher slopes. However, when there is an abrupt drop in slope, a large amount of water becomes immobile, leading to flooding. The slope variation within Batu Pahat is displayed in Figure 4. The components of flood incidents depend on Land Use and Land Cover (LULC) because it serves as a primary environmental factor. A comprehensive comprehension of Land Use and Land Cover (LULC) is crucial for addressing environmental and natural threats [24]. Vegetation cover obstructs atmospheric water movement to the ground which leads to decreased runoff water production [25]. The spatial pattern of land cover types in Batu Pahat is presented in Figure 5.

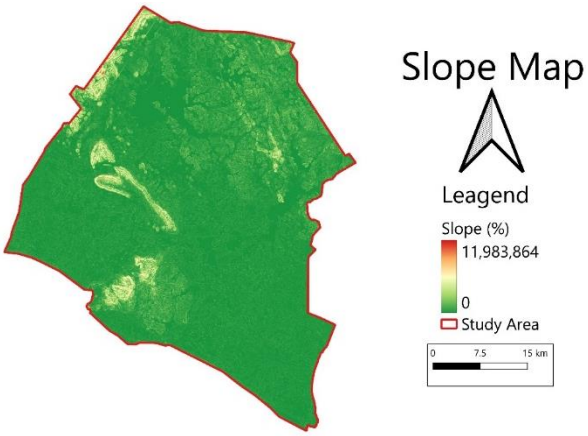


Figure 4. Slope Map

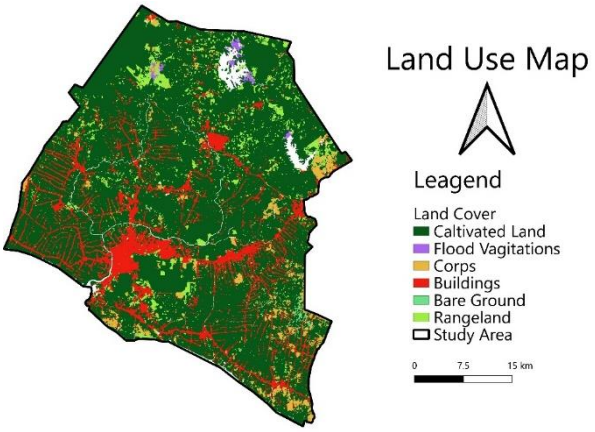


Figure 5. Land Cover Map

3.2 AHP Weight Assignment

The criterion weights obtained from the AHP analysis were used to quantify the relative influence of land cover, slope, and DEM in determining flood risk. Based on the computed weights, DEM contributed the highest influence (63%), followed by slope (26%) and land cover (11%). This indicates that elevation plays the dominant role in shaping flood susceptibility in Batu Pahat, while slope provides a secondary influence through its control on surface runoff and water accumulation.

Land cover contributed comparatively less; however, it remains relevant in distinguishing between urbanized and vegetated surfaces that differ in infiltration and runoff behaviour. These AHP-derived weights were subsequently applied during the weighted overlay procedure in QGIS to generate the composite flood risk index used for zoning and mapping in the next subsection.

3.3 Flood Risk Analysis

The flood risk map created for the study area effectively combines the reclassified and weighted layers of land

cover, slope, and DEM. The map displays flood risk zones which it divides into five categories that include very low risk, low risk, medium risk, high risk, and very high risk. The classification used natural breaks which are known as Jenks to determine the flood risk index values. High-risk areas are mainly found in low-lying regions and flat terrains, while low-risk zones are typically located in higher elevations and steeper slopes. Figure 6 shows the completed flood risk map for Batu Pahat.

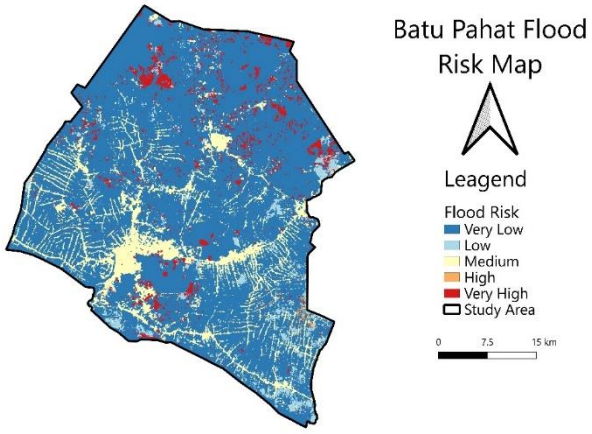


Figure 6. Flood Risk Map of Batu Pahat

Elevations had the greatest impact which is 63% because of its strong role in controlling water flow and accumulation. Slope followed with a 26% influence, and land cover contributed 11%. These weights were consistent with the expert judgments used in the AHP process.

Mountain slopes have an obvious impact, which shows that flooding occurs more frequently on flat surfaces. Urban areas face increased flood danger because of their impermeable surfaces which stop water from entering the ground. Low-lying areas face increased exposure to flooding because their elevation remains below surrounding land, which surrounds them.

The flood risk map generated in this study has significant real-world applications. The map enables local authorities to decide which flood defense projects require funding, which includes drainage system upgrades and urban development in areas that face high flood risk. The map can distribute resources during flood emergencies, which allows emergency personnel to concentrate on areas that present the highest danger. The study results demonstrate that GIS and AHP effectively predict flood-prone areas which match actual historical flood data. One notable advantage of using the AHP method in flood risk mapping is its ability to combine expert knowledge and subjective criteria in a structured way. However, AHP relies heavily on expert judgment, which may introduce inconsistencies or biases, especially with many criteria. While the pairwise comparison matrix used in this study was tested for consistency, it remains important to consider the limitations of this approach in real-world applications.

The AHP-GIS combination offers an all-encompassing approach to flood risk assessment through its structured evaluation method despite existing limitations. Future studies could further refine the model by incorporating additional data such as rainfall patterns and drainage infrastructure to enhance the accuracy of flood risk predictions.

4. Conclusions

The researchers created a flood risk map for Batu Pahat through their study which used GIS tools together with the Analytic Hierarchy Process (AHP) method to identify flood-prone regions. The results showed that flood-prone areas most often occur in low-lying regions that have been developed into urban areas which contain gradual sloping terrain that matches previous documented flood sites. The study found that elevation was the most important factor which determined flood risk with 63 percent of the impact followed by slope with 26 percent and land cover which contributed 11 percent. The study found that urban areas with sealed surfaces and low-lying areas faced the highest risk of flooding. The flood risk map delivers essential information which aids disaster management and flood control efforts by enabling decision-makers to detect high-risk zones and select appropriate measures. The study demonstrates how AHP combined with GIS produces accurate spatial flood risk assessments while providing a practical assessment method which researchers can use in future studies across different geographical locations. The model will benefit from increased accuracy and prediction capabilities through the inclusion of additional elements which include rainfall patterns and drainage systems in future research.

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