

Characterizing the Flood Hazard Risk Zones Using ArcGIS Pro Software: A Case Study of Baling Kedah, Malaysia

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Abstract

Floods are the most recurrent kind of natural disasters for it is the overflow of water that gets to cover areas usually perceived as dry. In order to increase the community's resilience against future flood disasters, this research aim to create a flood hazard mapping of Baling, Kedah, Malaysia. This study's primary goal is to identify flood risk factors and investigate the areas of Baling Kedah that are more likely to experience a flood disaster. The specific objectives of the study are to identify which part of Baling has the higher risk of flood disaster and further to produce a flood hazard mapping in Baling Kedah Malaysia. The study was carried out in stages by compiling data from a variety of open sources, including ArcMap, NASA Power Dave, the USGS, ESRI Sentinel-2 Land Cover Explorer, and precipitation, land use, and boundary data, in various formats to perform data processing. Many methods have been used to process the data obtained from many open sources in the past to provide data on precipitation, river distance, flow length, slope, elevation, and land use using ArcGIS Pro software. Following that, the flood hazard map for Baling, Kedah, is created using the Reclassify and Weighted Sum tools, both of which are included in the ArcGIS Pro software. Data analysis can be done using the flood hazard map to extract important information that is contained within the map. This study's primary finding indicated the possibility and risk of flooding in the Baling Kedah area. To sum up, this study was critical in mapping flood dangers and pinpointing the parts of Baling most vulnerable to floods.

1. Introduction

Floods have affected human lives and been a part of nature since the beginning of humanity. There aren't many places on the planet where people can live without fear of flooding. Any area that receives rain is vulnerable to flooding, even though there are other elements that might also contribute. A flood occurs when water overflows a riverbank and/or submerges an area that is typically dry. This can happen in a few different ways. Overflowing rivers and streams are the most common incident. When a dam or levee breaks and a river overflows, it can spread across the adjacent land known as a floodplain. Conversely, coastal flooding occurs when a powerful storm or tsunami causes the sea to surge inland (Zakaria, et.all, 2017).

In Malaysia, there have been numerous flood disasters in Baling, Kedah. Indeed, for a variety of causes, the district experienced the biggest flood calamity which at least 2,000 people had to be moved from their houses to relief center's and disrupting regular activities like schooling. With the following of an intense rain, the Ketil River near Kuala Pegang in Baling rose 50 cm above the alert level up to 36.05 meters, after a period of heavy rain.

Floods also have been becoming a more serious issue worldwide due to climate change, deforestation, and urbanization. In recent years, Baling has been hit by flood due to many certain reasons including deforestation, which is the logging activity of the Musang King Project. Observation shows that deforestation increases flood risk due to the loss of water-retention capacity and absorption rate. This scenario also may cause soil erosion which will greatly impact their vegetation. Also, the hilly terrain that surrounds Baling, for example Gunung Inas, is also one of the reasons why flood disaster may occur. This is because high and low elevation have an impact on floods by affecting water depth and flow velocity. As said earlier, deforestation may decrease the absorption rate, increasing the velocity of the water flowing from high to low elevation. Next, the water depth of the river flowing from high elevation may also rise which may increase the risk of flooding in low elevation areas since the river flowing in Baling, Kedah are from high to low elevation.

Moreover, high amount of rainfall also may be one of the reasons why the flood has occurred. The prolonged rainfall will cause the land around rivers to become saturated. If this prolonged rainfall keeps going, there is going to be more rainfall that cannot be soaked up, so it will run on the surface which is known as surface run-off. Other than that, the heavy rainfall may decrease the chance of rainfall to being soaked up by the soil which is infiltration. So, the rainfall will run off into the river. The faster the water reaches the river, the higher the chance of flood disaster happening.

Thus, the importance of flood hazard assessment and mapping which are used to identify areas at risk of flooding and improve flood risk management and disaster preparedness. Flood hazard assessments and maps typically look at the expected extent and depth of flooding in each location, based on various scenarios. It also needed to measure and improve preparedness which can include changes in land-use planning, implementation of specific flood-proofing measures, and creation of emergency response plans. Flood hazard assessments can be further expanded to assess specific risks, which take into consideration the socioeconomic characteristics (Matthew & Robert, 2010).

This study's primary goal is to identify flood risk factors and investigate the areas of Baling Kedah that are more likely to experience a flood disaster. The specific objectives of the study are to identify which part of Baling has the higher risk of flood disaster and further to produce a flood hazard mapping in Baling Kedah Malaysia. This project is very significant for persons, property and money, in the flood prone regions in a bid to protect lives, property and funds. The well-developed and readily understandable flood hazard map can contribute a lot to minimizing the impacts of floods and open the doors for a safer and secure future. These are important tools for its purpose to achieve a faster rate of recovery after Flood, preventing loss of assets as well as the loss of lives. For example, it facilitated the creation of flood hazard map which significantly reduced effects of floods and raised awareness among the communities.

2. Background Studies

2.1 Flood Disaster

Natural disasters like floods can have serious socioeconomic repercussions. Urban areas that experience rapid population growth, uncontrolled urban development, an unregulated municipal system, and an unplanned change in land use are considered highly sensitive areas where flooding can result in severe economic and social losses. The approach takes into account six variables that are pertinent to the risk of flooding in cities: elevation, inclination, separation from the sewage system, proximity to the water's surface, water table, and land use (Gigović, L., Pamučar, D., Bajić, Z., & Drobnjak, S., 2017). One of the most damaging natural events that occurs in the world is flooding, which can result in the loss of life as well as damage to infrastructure and property. Adopting real-time technologies for mapping flood hazards and risks is necessary due to the increasing frequency and intensity of flooding occurrences brought about by the interaction of anthropogenic factors and climate change (Antzoulatos, G., et. All, 2022).

2.2 Geographic Information System (Gis)

A Geographic Information System (GIS) package was utilised to compute and evaluate various data sets. A flood hazard susceptibility map of the region has been created through the use of several data sources, including geologic maps, Landsat-8 imagery, land use, and soil type related to fieldwork and data gathering. A spatial database was created at Wadi Bada'a with elements that were at risk as well as associated features and attributes. In order to create an inventory map with testing data, training data were generated at random in the study area (El-Magd, 2019). The technical foundation of a Geographic Information System (GIS) is provided by hardware and software for computers. It focuses on geographical data pertaining to all or a portion of the surface of the earth. Geographical data can be gathered, stored, managed, computed, analysed, displayed, and described using it. In addition to its inherent benefits, it is a crucial tool for managing the risk of natural disasters, planning for sustainable urban development, and the sustainable detection of natural resources. As a result of the ongoing

advancement of technology, new geographic information systems and completely new development paths are produced when GIS is integrated with cutting-edge technologies like big data, cloud computing, and artificial intelligence (Li, X., et.al, 2023).

2.3 Flood Hazard Mapping

The technique of mapping flood hazards is widely used to assess the risk of flooding and investigate flood features like floodwater velocity and depth. This method has been greatly enhanced and incorporated into the planning and decision-making processes for policies in flood-prone areas over the past few decades. The purpose of this map was to alert people to the risk of flooding so they could take the necessary precautions to protect their homes and themselves (Abdelgawad, A. G., Helal, E., Sobeih, M. F., & Elsayed, H. (2024). Flood hazard mapping and analysis is a crucial component of early warning systems or strategies for the prevention and mitigation of future flood situations. It determines the most vulnerable areas based on physical attributes that suggest a likelihood of flooding. An essential part of planning for land use in flood-prone areas and developing mitigation techniques is mapping flood hazards. Using simple-to-read charts and maps, flood hazard mapping enables planners to pinpoint risk areas and rank mitigation efforts (Hagos, Andualem, Yibeltal, & Mengie, 2022).

2.4 Flood Causative Factors

Globally, catastrophes and climate change are regarded as pressing issues that will affect many nations' long-term socioeconomic and environmental viability. In the observational record, many of the changes in the climate system are characterized as unprecedented. Reports are provided regarding projected percentage changes in extreme climate events, such as the frequency and intensity of simultaneous heatwaves, droughts, and precipitation. Worldwide, the share of the population that is vulnerable to flooding has increased. In most of Asia and Africa, extreme precipitation and the ensuing flooding are expected to become more common (Munpa, et. All., 2022). A flood is actually an increase in the river's water level, an outburst of water from the river, and the occupation of a portion of the plains along the river's edge. These events can cause the area to flood, damaging nearby public buildings and inflicting fatalities on people and animals. Severe winds will be impacted in certain situations where flooding is also caused by rising lake or sea levels. Rain and snow cause some water to be absorbed by plants and soil, some to evaporate, and the remaining water to flow—this is known as runoff. When precipitation cannot be absorbed by the soil and plants, a flood results and the river's natural channel becomes unusable. 30% of precipitation on average is turned into runoff, and this percentage rises as snowmelts. The area known as the flood near the river is created by the various types of floods (Javadinejad S., 2022).

2.5 Flood Impacts

Floods rank among the world's most catastrophic natural disasters, making up 44% of all disaster occurrences between 2000 and 2019. Floods typically result in significant economic losses as well as fatalities. Flood-related mortality has somewhat decreased with the adoption of disaster reduction and flood control measures. Nonetheless, the Global Risks Report states that, despite the combined effects of socioeconomic advancements and climate change, flooding remains one of the major global threats. The frequency of heavy precipitation events is increasing due to climate change. Severe rainstorms, like the one that swept through central Europe in 2021 and the strong storm that hit Zhengzhou, China, on July 20, 2021, are typically the cause of extreme floods (Yu, Wang, & Li, 2022). Numerous factors contribute to this, including excessive rainfall, residential society-related deforestation, illicit logging, and drainage overflow. Floods have both beneficial and detrimental effects on the environment. The extent and size of the flood determines what happens afterward. Severe floods can be disastrous not just for the environment but also for agriculture, livestock, infrastructure, and the economy. However, smaller-scale floods are more likely to benefit the environment than harm it. The natural biodiversity of the world may be fortunate for the flood, but the human population may suffer greatly from it (Aldardasawi & Eren, 2021).

3. Methodology

This research is involved 3 stages of procedures which are Boundary Data, Precipitation Data, River Distance Data, Flow Length Data, and Slope Data, Land use Data, Reclassify, Weighted Sum and Analysis. The flowchart of the project as per shown in Figure 1 below.

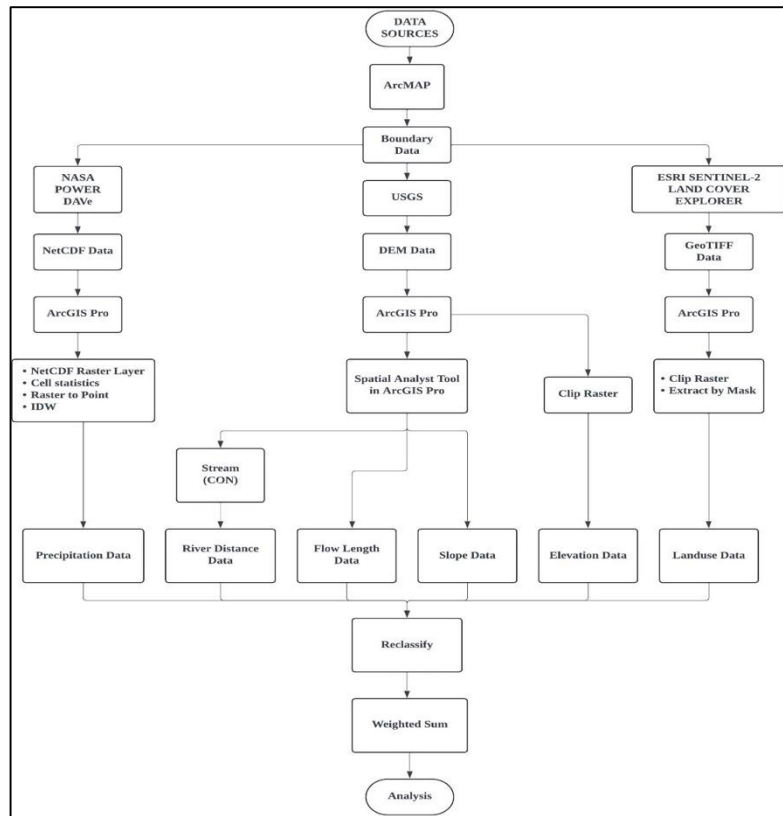


Fig. 1 Flowchart of overall data process procedure

Correspondingly, there are numbers of software used for the project as shown in Table 1 below.

Table 1 Software used across the project mapping.

| No | Software Use | Description |
|----|---------------------|--|
| 1 | USGS Earth Explorer | a website for obtaining geo-spatial datasets |
| 2 | Esri Land Cover | location intelligence, and mapping |
| 3 | Nasa Power DAVE | to obtain the precipitation data |
| 4 | ArcGIS Pro | to produce precipitation data, river distance data, flow length data, slope data and land use data which is to generate a flood hazard map |
| 5 | ArcMap | represents geographic information as a collection of layers and other elements in a map |

The data processing method started with boundary data, which is found using ArcMap software to determine the most suitable boundary, which is Kedah, encompassing Baling. Subsequently, the needed boundary is chosen and exported in shapefile format. The data is then imported into ArcGIS Pro to be processed. Following that, the precipitation data is provided by an open source which is NASA Power DAVE. The downloaded data was in the NetCDF. In order to convert from NetCDF to Raster, the ArcGIS Pro tool named Make NetCDF Raster Layer is utilized. After that, Export Raster is used to export the raster layer. Then, for the processing, tools provided in the ArcGIS Pro software is used to produce precipitation data.

River distance, flow length, and slope data were simultaneously produced through analysis from the Digital Elevation Model (DEM) data. The DEM data is made available via GMTED2010, an open-source tool from USGS Earth Explorer. Following that, the DEM data has to be clipped in accordance with the Baling border map using the Clip Raster tool. Additionally, the flow length and slope data are produced by ArcGIS Pro's spatial analyst tools using the clipped DEM data. Further, the clipped DEM data is processed using spatial analyst tools and stream (CON) for river distance data.

The land use data is downloaded from an open source which is ESRI, using Sentinel-2 Land Cover Explorer. The downloaded land use data which is in GeoTIFF format then will be imported into ArcGIS Pro software. The

data will be processed using several tools provided as mention below in the ArcGIS Pro software. Then, all the land use, flow length, slope, river distance, precipitation and elevation data is reclassified through Reclassify tools provided in ArcGIS Pro software from 1 – 5 value. This tool is used to change the values in a raster. After that, Weighted Sum tool provided in ArcGIS Pro software is used which the input raster was all of the data that has been reclassified earlier by overlaying all of the reclassified data into one single layer to get the flood hazard map as the final output. The importance of this toll is to overlays raster, multiplying each by their given weight and summing it together.

At the end of project, the flood hazard map of Baling, Kedah is presented which is also complete with the well explained analysis about the map. The result that is shown has its own value which scales from zone 1 to 5 (very low to very high). This analysis is crucial in order to extract all of the valuable information’s available within the map.

4. Data Collection, Analysis and Results

Baling District is the second largest district in the state of Kedah with an area of 1,530 square km or 590.32 square miles. It is bordered by the country of Thailand and the state of Perak on the East side, bordered by Sik and Kuala Muda districts on the West side and Kulim district on the South side. The topography of Baling district is covered with lowland areas in the middleland hilly areas on the Thai border. To get the boundary of the study area, the boundary of Kedah is searched on ArcGIS Online and downloaded it in shapefile format. Then, the boundary of Kedah added into ArcMap to extract the boundary of research area which is Baling. The boundary of Kedah’s attribute table is used to select the desired district and click Export Data. Lastly, the boundary of Baling data is saved in shapefile format.

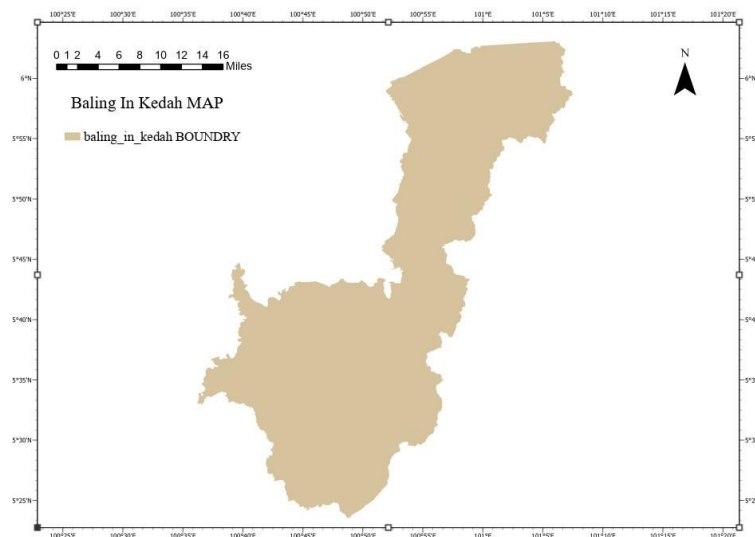


Fig. 2 Study Area for Baling, Kedah

4.1 Precipitation Data

Precipitation is important in this task because flooding is often caused by rainfall. This is because, when the river system and infiltration is being prevented from transporting the excess water from the rainfall, it will flow down the hill due to the gravity existence. Based on the figure below, the value shows that the lowest precipitation (Dark Green) is 2.71.1114 - 2.7512789 meter on the left side of Baling and the highest precipitation (Red) is 2.795.0891 - 2.833.2568 meter which is more biased towards the right side of Baling.

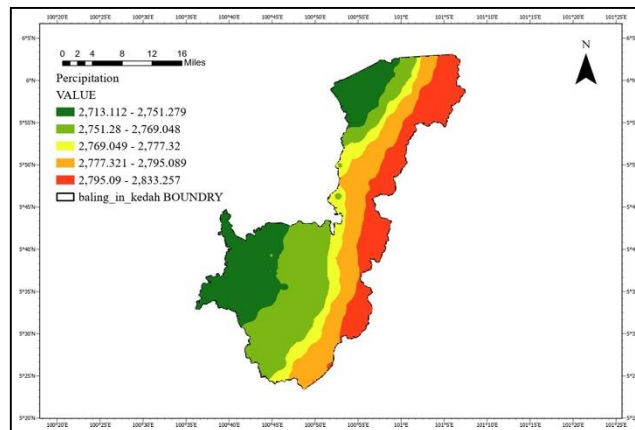


Fig. 3 Precipitation Data

4.2 Slope Data

The chance of a flood rises with decreasing area slope. Slope affects the amount and path of runoff water that reaches a site. Rapid runoff can be facilitated by a level surface, making the area more vulnerable to flooding. On the other hand, a rough surface could delay flooding by slowing down runoff. Figure 3.10 demonstrates the map of slope in Baling. The value of slope is in the unit of degree. The values ranked from lowest (Light Brown) is 0.01 - 3.77 meter to the highest (Dark Brown) is 19.542 - 36.904 meter.

To obtain the data, the clipped DEM data with the boundary data is used, then a spatial analyst tool which is Slope is used to identifies the slope (gradient or steepness) from each cell of a raster. Then, reclassify tool is used to change the values in a raster. Lastly, weighted sum is used together with reclassified flow length, reclassified precipitation, reclassified river distance, reclassified land use, and reclassified elevation to overlay raster, multiplying each by their given weight and summing it together.

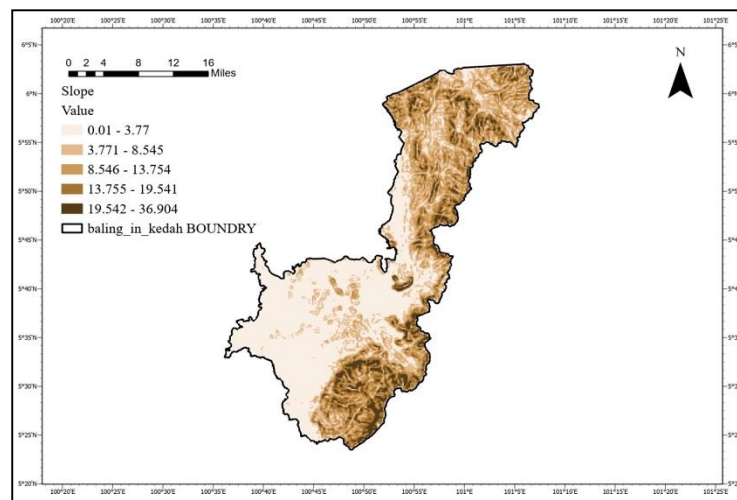


Fig. 4 Slope Data

4.3 Flow Length

To obtain the data, the clipped DEM data with the boundary data is used, then a spatial analyst tool which is Slope is used to identifies the slope (gradient or steepness) from each cell of a raster. Then, reclassify tool is used to change the values in a raster. Lastly, weighted sum is used together with reclassified flow length, reclassified precipitation, reclassified river distance, reclassified land use, and reclassified elevation to overlay raster, multiplying each by their given weight and summing it together.

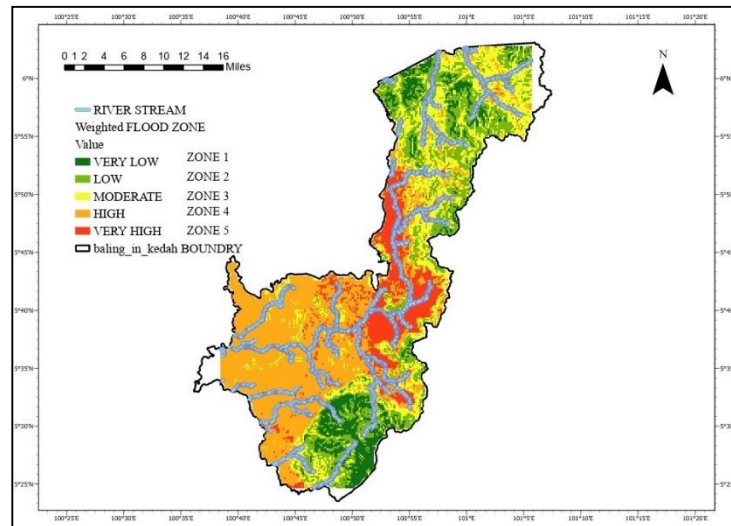


Fig. 5 Flow Length Data

4.4 River Distance

River distance is crucial to compute, for each cell, the horizontal or vertical component of downslope distance, following the flow paths, to cells on a stream into which they flow. In case of multiple flow paths, minimum, weighted mean, or maximum flow distance can be computed. If an optional flow direction raster is provided, the down slope direction(s) will be limited to those defined by the input flow direction raster. Based on the figure below, the value shown that the lowest distance (Dark Green) is 0.001-0.031 meter while the highest distance (Orange) is 0.171-0.246 meter. To obtain the river distance data, Euclidean Distance tool is used to calculate, for each cell, the Euclidean distance to the closest source. The output of Stream to Feature is used as the input for this tool. Then, reclassify tool is used to change the values in a raster. Lastly, weighted sum is used together with reclassified slope, reclassified flow length, reclassified precipitation, reclassified land use, and reclassified elevation to overlay raster, multiplying each by their given weight and summing it together.

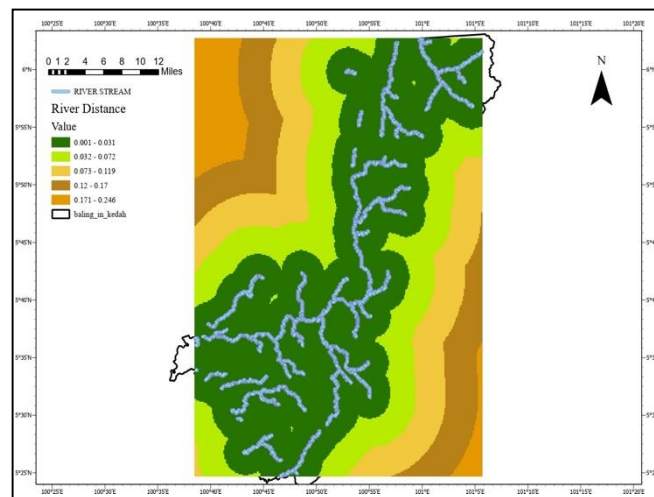


Fig. 6 River Distance Data

4.5 Elevation

Elevation was one of the most crucial factors to produce an output of height elevation of the selected study area. This is because low elevation areas are more prone to flash flooding than the higher one. Using USGS Earth Explorer, we extracted the DEM data of Baling, Kedah using GMTED2010 dataset. Based on the map, the lowest elevation value (Dark Green) is ranging from 5.001 - 197.071 meter, while the highest elevation (Red) is ranging at 1079174 - 1819000 meter.

To obtain this, by using DEM data, then Clip Raster is used to clip the data according to the boundary of Baling, Kedah. Simply change the color on its properties to make the values visible on the map. Then, Reclassify tool is

used to change the values in a raster. Lastly, weighted sum is used together with reclassified slope, reclassified flow length, reclassified precipitation, reclassified river distance, and reclassified land use to overlay raster, multiplying each by their given weight and summing it together.

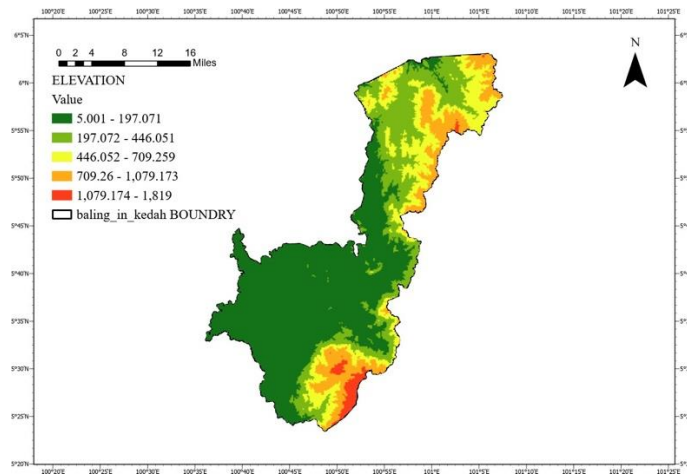


Fig. 7 Elevation Data

4.5 Land Use

Land use and land cover are important in flood mapping as it is related to soil stability and infiltration. It is also crucial to identify the risk of being flooded for each building within the boundary. Based on the figure below, it states that there are five feature class that has been identified in Baling, which is River (Blue), Forest (Dark Green), Vegetation (Light Green), Buildings (Orange), and Bare Land (Dark Brown). To obtain this, Clip Raster tool is used to clip the land use data according to the Baling, Kedah boundary. Then, Extract by Mask is used to extract the cells of a raster that correspond to the areas defined by a mask. Then, reclassify tool is used to change the values in a raster. Lastly, weighted sum is used together with reclassified slope, reclassified flow length, reclassified precipitation, reclassified river distance, reclassified land use, and reclassified elevation to overlays raster, multiplying each by their given weight and summing it together.

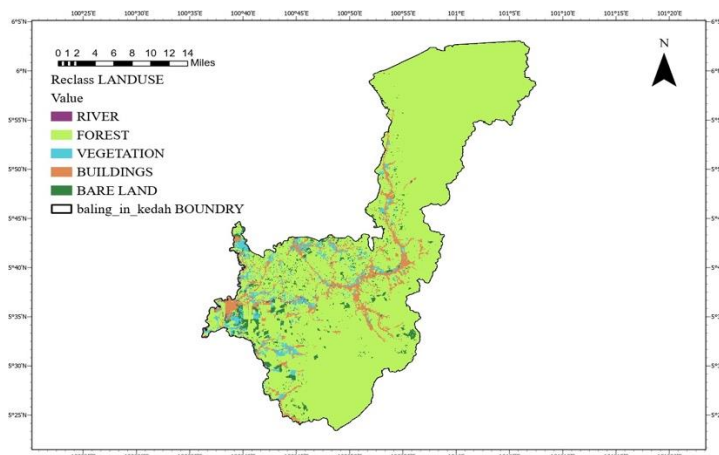


Fig. 8 Land Use Data

Based on the map, it can be analyzed that the highest risk (red) Zone 5 of flooding is prone to the middle part of Baling, Kedah while the lowest risk (dark green) Zone 1 is prone to the north and south side. According to the elevation and slope map, the surroundings of Baling are mostly hilly terrain which also indicates that it has a low risk of flooding in the flood hazard map. Other than that, the high-risk part of flooding is prone to the foothill of Baling, where the urban and vegetation is being develop there. Next, the precipitation data shows that the amount of rainfall occurring is more to the side of the hilly terrain.

This can be said that the flooding risk may rise because of several reasons. First, the land clearing activity that is active in Baling. The land clearing activity may decrease the absorption rate of the excess water flowing from high to low elevation. Also, the amount of river flowing from the high elevation area which scatters the most at the high-risk area (low elevation area) may rise due to the high amount of excess water from precipitation.

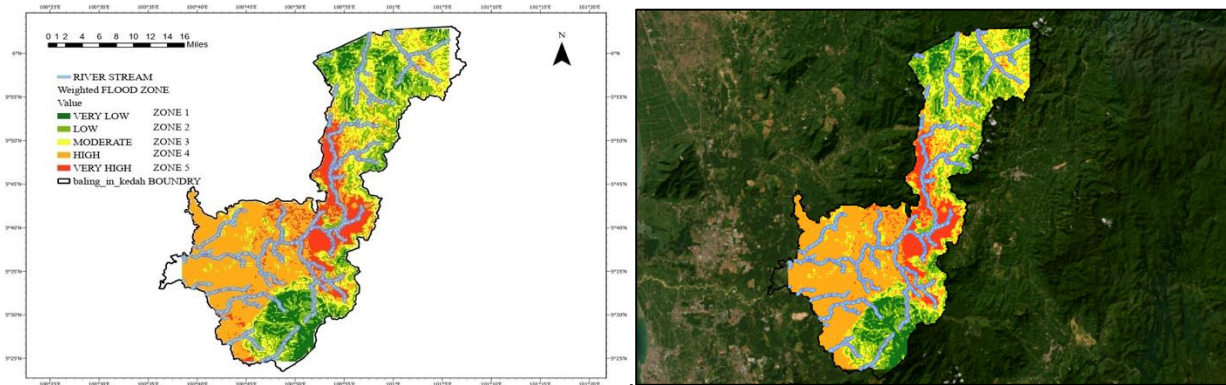


Fig. 10 Flood Hazard Map and Area of Baling, Kedah

From Figure 10, the flood risk distribution indicates that most areas fall under the "Moderate" to "Very High" risk categories, this is because the map's zone is primarily in a low-lying area, especially in the eastern and central portions of the area. In the zone between 1 and 2, the Northern and Southern sections of the map correspond to the "Low" and "Very Low" risk categories. The majority of these areas are found in the respective regions' highlands. This area is not likely to flood in anyways.

Moreover, areas with "Moderate" to "Very High" risk is more likely to have built up and vegetation features such as Kampung Iboi and Kampung Tanjung Luas which located in Mukim Kupang. This may increase the flood impact percentage that also creates a great loss for all residents within the area.

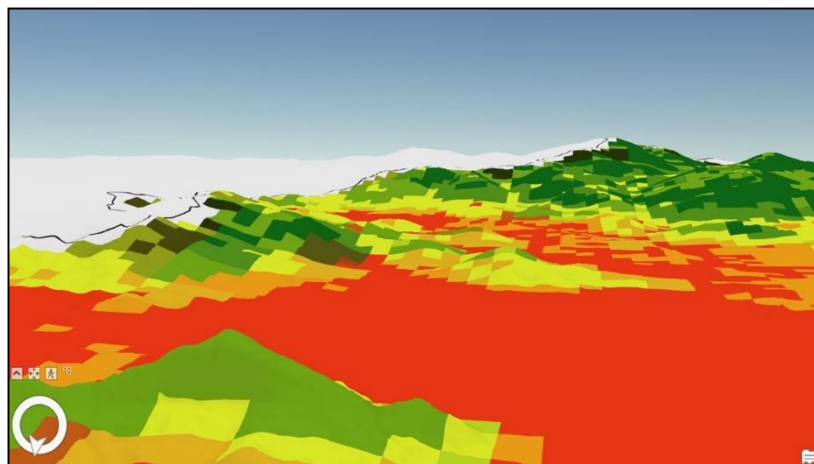


Fig. 11 3D Flood Hazard Map of Baling, Kedah

From Figure 4.3, it shows about which part of Baling, Kedah has the higher risk of flooding based on its elevation using the color-coded system in 3D mapping. This 3D map is produced using ArcGIS Pro software. As shown in the figure, the high elevation area covered in Dark Green and Light Green in color which indicates that it got the less possibility of flooding while low elevation area covered in Yellow, Orange and Red in color which indicates the higher possibility of flooding. Also, it shown that the precipitation which is rainfall will flow from high to low elevation area due to slope and gravity existence which contributes in increasing the possibilities of flooding in low elevation area.

5. Conclusion

In conclusion, all the objectives that have been set for this project has been achieved. Based on the result, which part of Baling that is more vulnerable to flood disaster has been identified. This is important in order to extract and interpret the information available based on the map result. Also, for the second objective, a flood hazard map of Baling, Kedah has successfully produced which indicates that the first objective is accomplished. The map has its value, and which also has been divided into 5 different zones ranging from very low to very high.

Furthermore, based on the flood hazard map, the flood is more likely to occur in the middle part of Baling which is a part that has the river the most. This may be one of the reasons for the flooding since the surrounding ground elevation of Baling is mostly hilly, for example, Gunung Inas. Also, the precipitation data shown that the most amount falls on the highest side of the slope which affects the amount and path of runoff water from precipitation that will reach the site. Rapid runoff can be facilitated by a level surface, making the area more vulnerable to flooding. Next, the river system and infiltration may be being prevented from transporting the excess water of precipitation, thus the water will flow down the hill due to the gravity existence. As for the recommendations, it is the best that the source of each data needed to be asked and taken from the government like Jabatan Pengairan dan Saliran (JPS) or Pusat Geospasial Negara (PGN) since the data provided by these organizations are fully trusted and have an accurate source of data. Also, these organizations are recommended as the source of data because of the prevention from the missing information and privacy matters.

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Conflict of Interest

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

Author Contribution

The authors confirm contribution to the paper as follows: **study conception and design:** Airell Harith Azri, Saiful Shahaziq Abdul Halim; **data collection:** Airell Harith Azri, Saiful Shahaziq Abdul Halim; **analysis and interpretation of results:** Airell Harith Azri, Saiful Shahaziq Abdul Halim; **draft manuscript preparation:** Mohd Najib Husin. All authors reviewed the results and approved the final version of the manuscript.

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