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Spatial Identification of the Flood-Prone Area in Jeli, Kelantan

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Abstract. Flooding is a serious environmental threat with no quantitative assessment of its consequences. It is necessary to understand which places are at risk of flooding to implement flood mitigation strategies. However, landscape factors are still lacking in the development of a flood-prone area map. This study aims to examine the landscape structure that has the potential to cause flood events in Jeli and develop a flood-prone area map in Jeli. The study used satellite images, ground truthing technique, image classification, landscape structure analysis, and the analytic hierarchy process (AHP). The results indicate that the higher density of the built-up area, the area near the water bodies, lower elevation ground surface, and surfaces with a steep slope have a high level of flood-prone areas and are the most vulnerable to flood. 38.11 % of the land use/land cover has a high level of flood-prone area, 43.13 % for medium level, and 18.75 % for low level. The findings can contribute to the sustainable planning and management of land use for flooding mitigation strategies.

1 Introduction

Floods are growing progressively common in various Asian countries, including Malaysia [1]. Flooding is regarded a serious environmental threat with no quantitative assessment for its consequences. Flooding is an excess of water that covers normally dry area and often referred to as a subsurface cover [2]. According to Kron et al. [3], flooding occurs as a result of torrential rainfall and causing rivers to overflow their normal borders and submerge territory that was not previously covered by water. Floods are typically produced by persistent rain, which causes the amount of water in the river to rise above normal levels and overflow into the river [2]. Floods are among the most common natural hazards, claiming

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human lives and generating massive economic losses globally [1]. Flooding can also occur due to various circumstances, including heavy rainfall, low topography, riverbank erosion, and rising water levels induced by global warming [2].

Therefore, new approaches to lessen the impact of floods necessitate a significant amount of work, particularly in data collection. The area of Malaysia that was prone to flooding made up approximately 33,298 km^2, or 10.1%, of the geographical total area. More than 21% of the population, or around 5.7 million people, are directly impacted, and annual flood damages are estimated to be over RM1.15 billions [4]. 85 of Malaysia's 189 river basins, according to the Department of Irrigation and Drainage (DID), are susceptible to recurrent land inundation [5]. Time is one of the most critical variables in natural hazard management, particularly in flood management. Hence, the model used must always be rapid for the purpose of helping with immediate action and mitigation. Natural elements that cannot be regulated include rainfall, river soil deposition, and the area's terrain. The process of urbanization, construction-induced river erosion, and inadequate drainage systems are examples of how human development has an impact on flooding [6].

Choosing the proper design concept during product development is difficult [7]. Inaccurate results will lead to an incorrect outcome. Consequently, among the approaches that can be used to detect flood-prone locations are ArcGIS software, image processing, ground truthing, ecological landscape analytics, and statistical analysis [8]. Flood-prone areas can be identified spatially using a geographic information system (GIS). Flood is one of the major disasters that arise in Kelantan annually. Jeli is one of the districts that has been devastated by flood and, in certain years, severely flooded [9]. This is a substantial problem in densely populated places, where the drainage system is weakened and cannot withstand a major flood event. It is necessary to understand which places are at risk of flooding to implement flood mitigation strategies. Flood detection is difficult in reservoirs that are not assessed. The geographic information system (GIS) is implemented because it identifies flood-prone areas [7, 9].

According to previous research, flood events occur because it is difficult to identify flood-prone areas [9]. Various flood-prevention methods have been implemented. However, there is still a lack of identification of the landscape factors that caused the flood event and spatial approaches to developing the flood-prone area map. Estimating flood-prone areas is a field of study that has not been thoroughly explored, particularly in emerging nations like Malaysia. The size of the landscape that might induce flooding is currently unknown. The size of a landscape refers to the total area of each land use/land cover. It is also still unknown what type or form of slope and elevation have a high risk of flooding. The distance between a water body and land use/land cover is also a landscape factor that needs to be considered in identifying flood-prone areas. According to Qiu [8], it is still unknown whether large or small fragmented natural covers could lowered the peak runoffs. The traditional flood design and estimation techniques, may not be appropriate for identifying flood-prone areas. Mapping flood susceptibility is one method of determining areas that are vulnerable to flooding. These mapping techniques are essential for emergency response systems, early warning systems, future flood mitigation and prevention, and the implementation of flood management strategies [9]. Thus, by analyzing the landscape elements that may contribute to flood events in Jeli, Kelantan, this study aims to develop a map of the area that is prone to flooding in Jeli.

2 Materials and methods

2.1 Study area

Kelantan is a state on the East Coast of Peninsular Malaysia. The state of Kelantan has numerous fascinating natural and geological features. From November through January, the state is exposed to the winds of the Northeast Monsoon, making it vulnerable to floods [10]. Jeli is one of the Kelantan districts at risk of flooding. As a result, it is implemented as the study region to meet the project's goals of identifying the landscape characteristics that cause flooding, examining the land structure that causes flooding, and developing a map of flood-prone areas. Jeli coordinate is 5°42′N 101°50′E and the area is 1, 280 km². Jeli can be reached from the west via Gerik, the east via Tanah Merah, and the south via Kuala Krai (Figure 1). This study was conducted in the Jeli district, consisting of unique geological landscapes and landforms, hot springs, gold deposits, hills, caves, rivers, and waterfalls [9]. Located in the western part of the state, Jeli district is one of ten districts in Kelantan [2]. It is positioned strategically close to Kelantan and Perak's state borders and Malaysia and Thailand's international borders. This district is separated into three sub-districts: Jeli, Batu Melintang, and Kuala Balah. Its total area is approximately 52479.74 hectares [1].

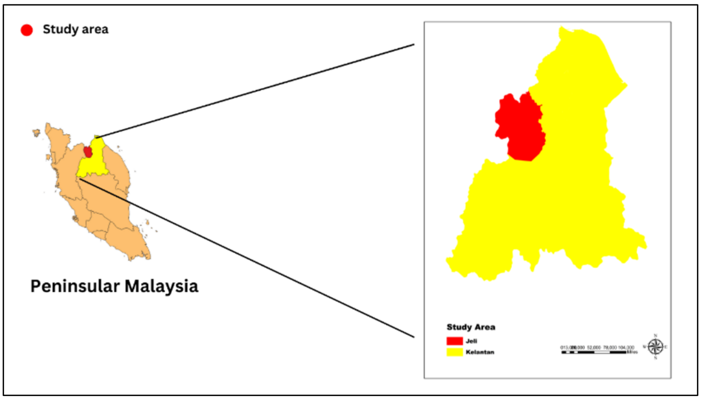

Fig. 1. The study area of Jeli in Kelantan

2.2 Methods

2.2.1 Data acquisition

Satellite images of Jeli district were acquired from The United States Geological Survey (USGS) to create a land use/land cover map in Jeli. The clear and less cloud cover images were downloaded to ease the image processing. Image processing involves band stacking, image enhancement and image classification. Next, Jeli's boundary was downloaded from DIVA-GIS (https://diva-gis.org/). The other map collected included an elevation map, a slope map, and a distance from river map.

2.2.2 Ground truthing

Using ground truth enables comparing picture data with actual ground characteristics and materials [11]. Ground truthing techniques involved coordinating built-up areas, water bodies, cleared land, and vegetation in Jeli, collected at a distance. The distance between one location and another was at least 20 meters. The Global Positioning System (GPS) was used to record the coordinates of the built-up areas, water bodies, cleared land, and vegetation in Jeli during ground truthing. The GPS had collected 25 coordinates per LULC type for the accuracy assessment. Ground truthing and collecting ground-truth data on location allow for the standardization of remote-sensing data and the interpretation and analysis of what is sensed.

2.2.3 Satellite image processing

ArcGIS software has been utilized to process the land use/land cover (LULC) type and land structure data. Data processing includes image enhancement, classification clipping, and conversion analysis. Arc Toolbox from ArcGIS software was used to process all of this data. Image enhancements are developed to make it simpler for viewers to analyze and comprehend visuals [12]. The image enhancement process can alter the digital pixel values of an image, making a picture easier to understand for a specific purpose. The analysis used for this image enhancement is raster processing under data management tools [13]. The significant aspects of raw, remotely sensed data become easier for the human eye to understand [14]. Classifying land use and land cover is called the image classification process [15]. In ArcGIS, The method used is maximum likelihood classification. This technique has been applied to the obtained land use/land cover map to get all needed land use/land cover classes. The accuracy assessment is used after processing all the Jeli land use/land cover map data. In an accuracy assessment, the map is compared to another data source assumed to be valid or to data from ground truthing. The value for accuracy assessment was over 80%, which is acceptable for the next process. The clipping process is extracting only the desired area from the map. Conversion analysis was implemented to convert the data (vector map) into raster data. This conversion analysis is referred to as polygon to raster.

2.2.4 Landscape factors analysis

The land use/land cover, elevation, slope, and distance from the Jeli river map have been analyzed using ArcGIS and FRAGSTATS software. Land use/land cover, slope, elevation, and distance from rivers are all landscape factors that are considered to produce flood-prone area maps. ArcGIS was used to convert the Jeli land use/land cover map into raster data. The map was then imported into the FRAGSTATS software to analyze the landscape factors. The method and analysis utilized for land use/cover, elevation, slope, and distance from the river map of Jeli are shown in Table 1.

Table 1. The method and analysis utilised for land use/ land cover, elevation, slope, and distance from the river map of Jeli

Criteria	**Input data sources**	**Analysis used**	**Reclassification of maps**	**Output data**
Land use/land cover	Acquire from USGS Earth Explore	Supervised image classification	• Built-up area • Commercial agriculture • Forest • Water body • Paddy • Others agriculture	Land use/land cover map of Jeli
Elevation	Acquire from USGS Earth Explore	3D analyst tools	• 0-150 m • 150-300 m • 300-1000 m • 1000-2158 m	Elevation map of Jeli

Slope	Acquire from USGS Earth Explore	Spatial analyst tools	• 0-5° • 5-15° • 15-25° • >25°	Slope map of Jeli
Distance from river	Acquire from USGS Earth Explore	Proximity analyst tools	• 0-8.3 m • 8.3-16.6 m • 16.5-24.9 m	Distance from river map of Jeli

2.2.5 Data analysis

Finally, all of the maps and data were converted into ArcMap to create a final flood-prone area map in Jeli. The flood-prone area map was developed using ArcGIS software by integrating the land use/land cover (LULC) from the FRAGSTATS software. The weighted overlay analysis was applied to know the level of flood vulnerability in Jeli. The percentage of influence in the weighted overlay table was determined from the analytic hierarchy process (AHP). The set of factors should be kept to a minimum to reduce the complexity of the evaluation process. In this study, four factors are involved. The factors include land use/land cover type, elevation, slope, and distance from the river. Using many layers of dependent or independent qualitative and quantitative information, the analytical hierarchy process (AHP) is a multicriteria decision-making tool that offers a systematic strategy for evaluating and integrating the implications of numerous aspects [16]. The level of the flood-prone area map has been classified into low, medium, and high flood risk. In this case, green color indicates low or no risk, yellow indicates medium risk, and red indicates high risk of flood-prone areas.

3 Result and discussion

3.1 Landscape factors that have the potential to cause flooding and flood vulnerability in Jeli.

3.1.1 Land use/landcover of Jeli in the year 2020

The land use of Jeli had been illustrated based on their color for different classifications. The total land use/land cover of Jeli is 133599.39 ha. Figure 2a shows the six classification classes of Jeli land use/land cover: forest, commercial agricultural, built-up area, paddy, water body, and commercial agriculture. The prominent land use/land cover of Jeli in 2020 is a forest, with a coverage of 60.27%. The lowest land use/land cover of Jeli is other agricultural, where the coverage area is 0.02%. Commercial agriculture was identified to cover 38.6% of the total. The built-up regions covered 0.7%, water bodies covered 0.32%, and paddy covered 0.11%. The presence of water bodies helps identify the drainage system that caused flooding incidents. Both the rate of surface runoff and water retention are influenced by land use. The build-up area is located in the low slope area, which is, unfortunately, where development is allowed [17]. Floods are known to occur due to unplanned rapid urbanization, changes in land management, and poor watershed management [1]. As built-up regions and highways increase overland flow, urbanization may cause a flood [18]. As a result, the area's most vulnerable to floods show where additional development should be avoided or limited and where emergency plans should be developed [19]. The stability of a landscape is primarily controlled by elevation and slope [17]. The slope impacted the amount and direction of surface runoff or subsurface drainage that reached a location [20]. Lower-slope areas experience a high frequency of floods because the water cannot drain instantaneously [14].

3.1.2 Weighted overlay analysis using Analytical Hierarchy Process

Alternatively, multicriteria analysis techniques can be used to evaluate flood risk. The most popular multicriteria analysis technique is the analytical hierarchy process, employed in various scientific domains [21]. Numerous scholars evaluated flood risk using pairwise comparison, the analytical hierarchy process approach (AHP), and geographic information systems (GIS) [22]. The analytical Hierarchy Process consists of four stages. According to Saaty (2003), the stages in the Analytical Hierarchy Process include important scale, normalization, weightage, and checking of consistency. The flood-prone area measures the area's vulnerability to damage [9]. The analysis used to produce the flood-prone area of Jeli is weighted overlay analysis. The Weighted Overlay analysis lets users implement several steps within a single tool in the general overlay analysis process. This analysis was done using ArcGIS software. As the weighted overlay table only supports raster format, all the maps that were being overlaid were converted into raster format. The input raster was multiplied using the raster's weight, which contains cell values. The final output raster was then created by adding the resultant cell values. The resultant raster was used to create a map of regions that were particularly vulnerable to floods. The land use, elevation, slope, and distance from river raster datasets were overlaid using the weighted overlay methodology after being classed using the standard measurement scale and weights. Figure 2 shows the process of weighted overlay analysis.

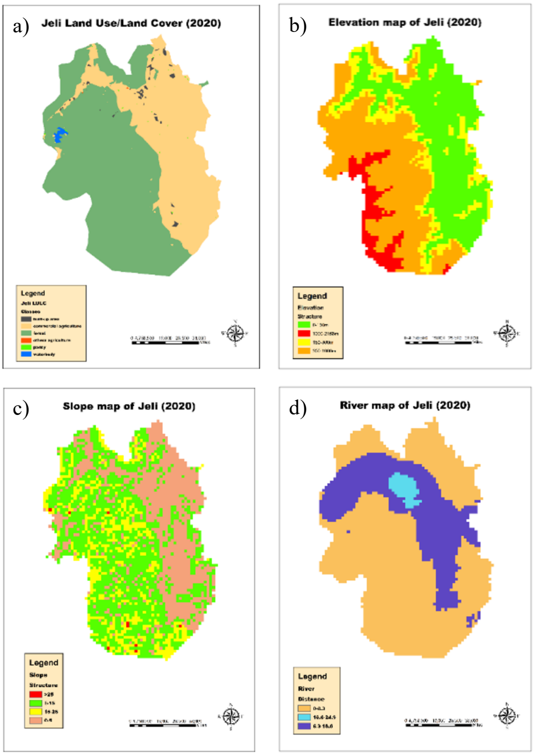

Fig. 2. Maps for weighted overlay analysis a) land use/land cover map of Jeli (2020) b) elevation map c) slope map d) river map of Jeli in raster format

3.1.3 Flood-prone area map in Jeli

The flood-prone area of Jeli, Kelantan, shows the total area and percentage for each flood-prone area level (High, 47623.8, 38.11%; Medium, 53895.8, 43.13%, Low, 23439.0, 18.75%) (Figure 3). Additionally, locations of high-level flood-prone areas are presented in red. Areas near rivers and other areas with many water bodies are more flood-resistant. Consequently, the moderate susceptibility was shown as yellow, indicating those areas had been at risk of flooding. Meanwhile, low levels of flood-prone areas are green. Some riverside sites are highly vulnerable, whereas others are only moderately vulnerable. Unplanned land use changes, such as deforestation, and other aspects, including slope, elevation, and distance from rivers, could contribute to the area's vulnerability to flooding [23].

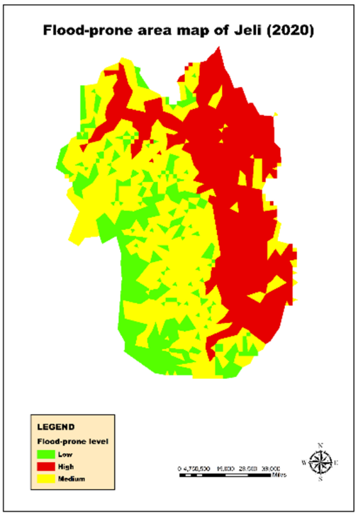

Fig. 3. Flood-prone area map of Jeli

Landscape ecology analysis was conducted using FRAGSTATS software. The landscape metrics used included total area (TA), largest patch index (LPI), number of patches (NP), patch density (PD), and Euclidian nearest neighbour distance (ENN). Those landscape metrics can be applied to access a country's landscape configuration. Table 2 shows the FRAGSTATS results of class metrics. The patch density of the built-up area is higher than the patch density of the forest. When the density of the built-up area is larger than vegetation, the level of flood vulnerability is also high. Handayani et al. [24] conclude that the growth rate of built-up areas shows a very large level of urbanization. Urban and possibly urban regions have had notable flood vulnerability. The spatial patterns were influenced by unpredictable events such as flood events. Forest has the highest LPI value. The higher largest patch index (LPI) indicates that the size of patches is also bigger [7]. This further reveals that the forest is divided into bigger mean patch regions. Based on Table 2, the value ENN of the forest is the highest. This indicates that the forest is highly fragmented, so the distance between the patches is high. A severely fragmented forest cannot effectively absorb surface runoff due to the limited size of each patch and the huge distance between them [25]. Thus, this will increase the probability of flood. The distribution of land use/land cover in Jeli, Kelantan, showed a different spatial pattern of landscape and class metrics level. At the landscape level, the landscape metric values showed that the Euclidean nearest neighbor (ENN) is the largest, followed by the number of patches (NP), largest patch index (LPI), and patch density (PD).

Table 2 FRAGSTATS result of the class metrics

Classes	TA	NP	PD	LPI	ENN
Commercial Agriculture	51515.2006	1.0000	0.0035	7.8860	75.3153
Forest	80565.1003	23.0000	0.0011	11.4960	134.1488
Paddy	103.5527	7.0000	0.0042	0.0024	74.6601
Built-up area	912.8393	27.0000	0.0051	0.0203	93.5843
Others agriculture	20.2603	33.0000	0.0003	0.0023	0.0000
Water body	424.3408	2.0000	0.0002	0.0654	0.0000

4 Conclusion

This study produced two maps during the data processing: a land use/land cover map of Jeli and a flood-prone area map in Jeli. The land use/land cover of Jeli was classified into five classes which were forest with coverage of 60.27%; other agricultural where the coverage area is 0.02%; commercial agriculture was identified to be covered at 38.6%, the built-up regions covered 0.7%, water bodies covered 0.32% and paddy covered 0.11%. It shows that the forest has a higher percentage of land use/land cover compared to other classes. The landscape structure that has the potential to cause flood events in Jeli has been examined using the landscape metrics: Patch metrics, class metrics, and landscape metrics. The landscape structure considered includes land use/land cover of Jeli, elevation, slope, and distance from the river. The area near the built-up area has a high level of flood-prone area. The area with low elevation and steep slope has a high flood-prone area. The area near the water body also has a high flood-prone area. The last objective of this study is to develop a flood-prone area map in Jeli. Weighted overlay analysis is the main analysis applied to create this flood-prone area map. There is 38.11 % of high flood-prone area level, 43.13 % of medium flood-prone area level and 18.75 % of low flood-prone area level. The built-up region has a high area flood risk concentration. Urbanization should be taken into account in the flood management strategy. Decision-makers, stakeholders, and planners can use the findings of this study to organise and design a flood-prone area map. Effective flood susceptibility mapping can assist in initiating a realistic solution to flood vulnerability areas and their effects on natural and anthropogenic systems.

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