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Geospatial analysis of river flood hazard assessment

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Abstract. Floods are one of the most damaging natural disasters which occur frequently in the world. They occur every year in Malaysia due to higher precipitation rates, river meandering, and heavily populated suburban areas. Monsoon rains are the major cause of floods and occur two times per year. The heavy floods in the Kelantan River Basin have shown an increasing trend in recent years. Terrain characteristics of the land and meteorological properties of the region are the main natural factors for this disaster. In this study, the Kuala Krai district of the Kelantan River is selected to be reviewed as the case study for flood risk analysis. Geographical Information System (GIS) integrated with Multicriteria Decision Analysis (MCDA) can be used to evaluate the potential flood risk areas. Historically flooded areas can be extracted from the satellite images to determine flood causing factors for the analysis. At the end of the study, a map of flood risk areas can be generated and validated to assist decision-makers on the menace posed by the disaster. The expected results obtained from the study will help the guidance city planners and administrators to choose safe sites for construction and development. This study will also help to provide flood mitigation and quick relief response for the red zone areas which are more likely to hit badly from flood hazards. The study will help the Malaysian government to reduce natural flood risks in Malaysia which are one of the top causes of damage.

1 Introduction

Annual rain, basin slope, soil type, and drainage network are the causative factor for the river flood in the watershed areas. Floods cause loss of life and destruction of properties [1]. Fig 1(a) shows the number of natural disasters that occurred in Asia from 1997 to 2014 [2]. Human activities of deforestation and urban land use are causing climate change with changes in flood trends [3]. Research suggests that one of the common causes of natural disasters is river flows in Malaysia affecting 22% of the Malaysian population [4]. This disaster is expected to increase in the upcoming years as people are migrating from rural to urban areas without proper flood mitigation measures [5]. Another major cause of floods in the country is sea level rise with more frequent rainfalls [6]. The annual rainfall rate of Malaysia from 2500 mm to 3500 mm is one of the highest precipitations in the world, which makes the country more vulnerable to flood disasters [7]. Monsoon floods are the most

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common type of flood in Malaysia which occur twice a year. Disasters caused by floods in Malaysia are managed by four phases including prevention, preparedness, response, and recovery. Out of these four phases, disaster prevention and preparedness are the most important phases of flood management because disseminating reminders related to the dangers of flooding could reduce the potential loss of between 6% and 60%. According to literature, Kelantan state is the most vulnerable state of Malaysia where more than half of its population is affected during floods [8]. In the Kelantan state, the precipitation trends change. The average precipitation from 1985 to 2014 is shown in Fig. 1(b). Kelantan river basin precipitation ranges from 2758 mm/year to 2044 mm/year in south to western and in the south to eastern it is greater than 4000 mm/year. It is observed that from north to south it is decreasing trend rainfall pattern [9]. This method utilizes cost and time-effective strategies to predict flood-prone areas in the country before inundation which will help in reducing the losses sustained through a natural hazard.

The objective of this paper is to review the river flood hazard mapping analysis and identify the appropriate and efficient method. From the literature, it is observed that the Geographical information system (GIS) with integrated Multicriteria decision Analysis (MCDA) is an efficient method for river flood hazard mapping. MCDA method is used to solve the integrated complex problem on non-comparable data and required criteria. MCDA is mostly used by the researcher for flooding, but it has not been used on river analysis. By using the MCDM with GIS to create clear flood hazard maps for the planers and the administrators is a novelty of this research.

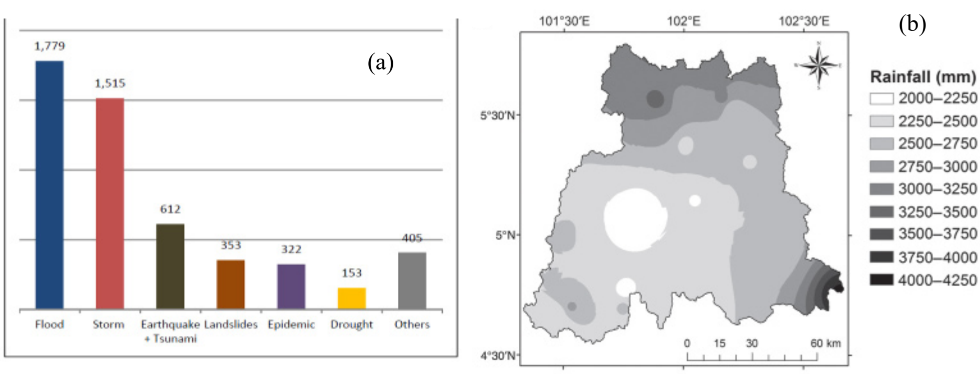

Fig. 1(a) Natural events in the asia and pacific types (1997-2014) [2] **(b)** Mean average precipitations from 1985 to 2014[8].

1.1 Problem faced during river flood

Flood and the monsoon are natural disasters frequently occurring in Malaysia. They are climate-oriented and affect the hydrological phenomenon all over the world. The flood also affects the agriculture, environment, infrastructure, human health, and property. In Malaysia, every year 29000km^2 of the area and 22% of Malaysian are affected by floods [10]. In 2015, Malaysia suffered a loss of 3.59RM and 21 people lost their lives [11]. Through the river flood, many problems are faced by the society such as loss of life, property damage, water pollution, economic loss, agricultural loss, food shortage societal vulnerability, river catchment areas inundation [10]. In Malaysia, it is important to note that most of the economic centers are located near the coastal and low-lying terrain. When river flooding occurred, these economic centers are vulnerable and are at high risk. Through the river flood, the irrigation system will also face serious damages.

2 Literature review

2.1 River flood hazard mapping in all over world

Bartłomiej Wyżga used an effective method for the mitigation of river floods in Poland. Their data was based on 2021–2050 and 2071–2100 river flow and sediment for fluvial transport. They used the five flood management strategies such as flood defense, flood risk prevention, flood mitigation risk, flood recovery, and flood preparation. They proposed many alternatives for flood risk reduction in the study area with application examples. They also suggested different alternatives with practical applications to reduce the flood risk and utilized the flood water in an application. They worked on a water paradigm through that they proposed flood control and adopting alternative strategies enhances the flood risk management in the region [12].

Chad Furla has studied hydrometeorology of the catastrophic Blanco River flood in South Texas, USA and they used 2015 rainfall data and they also discussed flash flood forecasting. In this study, GSSHA (gridded surface, subsurface hydrological analysis) model was used. This model is iteration-based and in this model, two main parameters are rainfall location and storm motion played an important role in the peak flow. When an intense headwater cell was started over the volume of the runoff remained similar. To check the rainfall across the motion of water, the basin, detail of the structure, and the rainfall catastrophic development the synoptic-scale and mesoscale weather patterns were examined. The change in the hydrometeorological condition which caused the Blanco River flood was also explained. The main variables of this study are basin precipitation, storm properties, precipitation transposition, and flood hydrology [13].

Murphy and Mohammed studied the Tarlac River, the Philippines in 2019. They studied river flood hazard modeling with a focus on forecasting flood hazards for disaster risk reduction planning. They used 2, 5, 10, 15, 25, 50, and 100-years rainfall data. In this study, one-dimensional models were used such as DEM, HEC-RAS, and HEC-HMS. The variables used were rainfall and river flow. This study used rainfall data of 100 years. The flow meter was also installed to measure the base flow on the river. To analyze the river data by using the DEM, then hydrology of the river was analyzed by using the HEC-RAS and the flood hazard risk was calculated by HEC-HMS. The non-structural model was used to control the river flood which is a cost-effective and handy method to control the river flood [14].

Lorenzo Alfieri has done the research on the multi-model projection for the river flood risk analysis in Europe they used 30-year data between 1976–2005. This research is to find out the river flood risk from the global warming temperature. In this study, the global warming effect was observed through the river flood at 1.5, 2, and 3-degree centigrade. Three models were used in this study as hydrological and flood modeling, climate forecasting, and impact assessment. In most western and central European countries, global warming was linked to a substantial increase in the flood risk, smaller changes observed in the eastern countries. Multi-model is used to find out the climatic changes in the region and flood risk. In the Kundzewicz et al study some parts of the European countries were studied for the future prediction of floods by using the global warming dataset. But in Lorenzo's research quantitative comparison is also done to know that how many regions get affected by the river flood caused by global warming [15].

Matej Vojtek & Jana Vojteková has studied river flood risk assessment and flood hazard at Nitra River Basin in Slovakia. The flood maps play an essential role in the planning of flood prevention and municipality planning. They used the data of the years such as 1994, 1995, 1999, 2010, and 2013 of different months. The RS GIS and hydraulic models were used to assess and mitigate the river flood at the local spatial level. The variables used in this study are flow velocity and water depth. The results maps are also used in the environmental impact assessment and insurance industries. To generate the local geospatial maps for municipal planning to prevent flood hazards. Traditional maps are most useful for flood protection and flood risk management. By using the unit hydrograph method with spatially differential or non-differential level one should be able to find out the flood risk, but the accuracy of the flood depends on the methods to be chosen [16].

Shiva prasad has used the techniques Multi-criteria analysis (MCA) for the river flood risk analysis in the Indian River. They used the precipitation data from 1998 to 2015. The parameters for the socio-economic are land use, vulnerability cropped, census variables, road network, infrastructure, and uncropped areas. It is found out that the 132 suffered in high infrastructure vulnerability zone, 82% of villages whose agriculture is the main income source come under high vulnerability zones. GIS and MCA models were used to find out the flood hazard zone with the infrastructure, social, and land use vulnerability. IN this study, the MCA with GIS is used which is not used in this study area and its zone is divided into low, moderate, and high flood risks [17].

2.2 Flood risk assessment in Malaysia

Hossein Mojaddadi studied a machine-learning-based geospatial approach for flood risk assessment using 2010-2015 precipitation data in Malaysia. In this study, the frequency ratio and support vector machine are used for flood estimation. The 13 parameters used in this study were slope, altitude, stream, aspect, stream power index, topographic wetness index, curvature, topographic roughness index, sediment transport, soil geology, distance from the river, land used, and surface runoff. Each parameter is measured with the help of frequency ratio and used as input for the SVM model to make the flood hazard map. The main flood triggering factor used in this study is daily rainfall. The 2D hydraulic model is used to find out flood inundation depth and these models proved to be good for flood hazard management. In this study efficiency of the GIS model also demonstrated and flood probability of the Damansara River catchment in Malaysia. This study consists of 13 parameters that are the most important cause of the flood. Annual rainfall was also predicted in this study [18].

Ahmad ShahiriParsa has studied the Maka river flood hazard by using the CCHE-2D with HEC-RAS in Malaysia. They used spatial data such as geographical characteristics, river location, and attribute data. In the HEC-RAS model, plain data is used such as hydraulic design, geometric data, and flow data. In this study, 1D and 2D models were used. The finding of this study is primarily to find out from the topographical condition to analyze the flood retention zone. The water spread over the large surface along with the floodplain also increased. The topographical condition is increased as the difference in the main river level of flood retention on the many parts. In this study, 1D and 2D models were used and the results showed the matching in many sections. The difference in the results was the shape of the river Sungai Kelantan (Kelantan River). In this study, the parameters considered are the magnitude of the flow, flood plain, and riverbed (sediments, sediment transport, water quality flow simulation and scour phenomenon were observed) [19].

Alaghman has studied GIS-based River Flood Hazard Mapping in Urban Areas of Malaysia. The GIS, HEC-RAS software uses the parameters such as river flood velocity and water depth. Previously all the analytical, historical, and physio-graphical methods were used. Nowadays scientists have moved towards cost-effective methods such as computer modeling. The data used in this study range from 20-100 years existing, intermediate, and ultimate river basin development conditions using rainfall events with 60 minutes duration

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with 9 scenarios. The rainfall magnitude gave more impact on the river flood hazard as compared to land use development. The study generated the flood hazard map and calculated the risk of flood in the surrounding areas. Researchers used these maps to manage the flood hazard in the Kayu Ara river basin Malaysia. They observed that the rainfall magnitude gave a severe impact on the river flood hazard pattern. The river flood was more influenced by the water depth as compared to the flow velocity [20].

3 Methodology

3.1 Study area

In this study, the Kuala Krai district of the Kelantan River is selected to be reviewed as the case study for flood hazard mapping and assessment. The map of Kelantan state is shown in Fig.2. Kelantan river basin is situated between 4° to 6° North latitudes and 101° to 103° East longitude with a 12000-kilometer area. Kelantan river is 248 kilometers long, starts from the Tahan mountain, and ends in the China sea [7].

Fig. 2. Base map of Kelantan state Malaysia.

3.2 Data collection

Different data were collected from different sources as shown in Table 1.

Table 1. Data collection sources for the study area.

Data	Source	Data	Source
Soil physical and chemical value	Department of Agriculture Kuala Lumpur (DOA)	Soil map	DOA Kuala Lumpur
Terrain	DOA Kuala Lumpur	Rainfall precipitation	Department of irrigation and drainage (DID)
Drainage network 1:25,000 scale	DOA Kuala Lumpur	Flood map 1:30,000 scale	DID

The criteria used in this study [17] were selected due to their relevance in the study area, the spatial data is converted into digitalized data. The annual precipitation with latitude and longitude were converted into the rainfall interpolation surface by using the inverse distance weighted method. The drainage network is drawn by using Arc GIS software. From the topographic map terrain data were collected for each soil type and displays in the GIS layer.

3.3 Multi-criteria analysis

In the first phase, the causative factors of the flood multi-criteria analysis are applied and integrated with spatial data. The risk area, drainage network, rainfall layer, and slope were first numerically produced. The selection of the criteria is done by the expert opinion and availability of data. Boolean overlay method is used for the overlay data. Intersection and the union logical operator were used for all criteria combinations. In the second phase ranking method is used for understanding the rank of the criteria for the decision-maker. To estimate the significant cause of flood each criterion was weighted. For this factor inverse ranking was applied. Factor ranges from 1 to 8. In the third phase Saaty method, the pairwise comparison method is used to determine the weight of each criterion [21]. The pairwise criteria method gives the comparison of two criteria at a time. It can convert subjective assessments of relative importance into a linear set of weights. It could estimate the weight of rainfall, slope of basin, soil type, and drainage network. To generate the criterion values for each evaluation unit, each factor was weighted according to the estimated significance for the flood potential project [17].

4 Results and discussion

The Kelantan basin has two monsoon seasons, southwest and northeast monsoon season. The rainfall intensity of the northeast is 993 mm/year, and the northwest has 1530 mm/year. The Kuala Krai is situated downstream, and it experiences severe flood hazards in the Kelantan state [22]. The DEM elevation model of Kelantan state is shown in fig 03. The elevation ranges from 0 to 1600 meters. The white part shows the area at 0-meter elevation and the dark Gray shows the 1600m. The Galas River at Dabong, Gua Musang has the highest flood level was 46.47 m where the danger level is 38m. Lebar river at Tualang, Kuala Krai has the highest recorded level was 42.17m (danger level: 35m). Kelantan river has the highest recorded level was 34.17m where the danger level was 25m at Tanga krai, Kuala Krai, and 22.74m (danger level: 16m) at Guillemard bridge. The Sungai Golok at Rantu Panjang has the highest recorded water level was 10.84m which is more than 9m of danger level. In Table 2 the comparison of Kelantan River between 1967, 2004, and 2014 was shown. The recorded water levels were highest in 2014 at 34.17 m and 33.61 m in 1967. According to the DID they set the level of the water in the Kelantan state. [23]. In Malaysia which as of Dec 21st, Malaysia’s Agensi Pengurusan Bencana (NADMA) has reported 33 districts in 8 states affected by floods and flash floods with a total of 62,999 persons displaced in 430 evacuation centers. In Kelantan state 1,083 families/3,593 persons displaced in 33 evacuation centre (4 districts) [24].

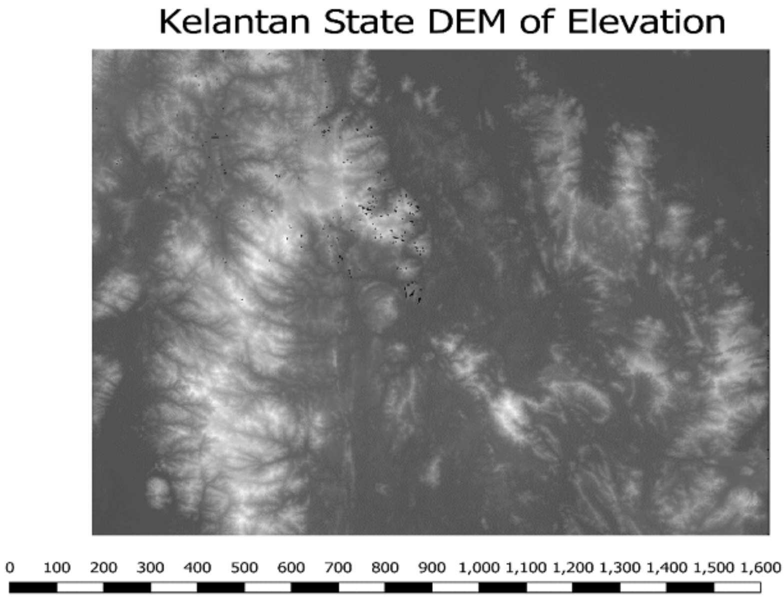

Fig. 3. Base map of Kelantan state Malaysia.

Table 2. Data collection sources for the study area [22].

River	Gauge site	Danger level (m)	1967	2004	2014
Kelantan	Tangga Krai	25.0	33.61 m	29.70 m	34.17 m
Kelantan	Tambatan Diraja	5.0	6.22 m	6.70 m	7.03 m

5 Conclusion

A flood is a natural disaster that affects human health, property damage, and environmental degradation. Malaysia is affected by floods every year. To mitigate the river flood risk structural and non-structural measures can be applied. Structural measures are to construct the dams, ring bound, canalization, and other storage structures. The non-structural mitigation measures such as preparation of guidelines, integrated river basin management, resettlement of population designed standard warning, and flood forecasting. The structural methods are expensive, labour inducive, timing-consuming and ineffective. The non-structural method is cost-effective and time-efficient and thus they are more effective than structural mitigation measures. The modelling of the river flood risk hazard is good practice to mitigate the risk. Flood hazard mapping and assessment are some of the most essential parts of land use planning in areas prone to riverine flooding. It will work as a guide for city planners and administrators to distinguish the flood-prone and safe sites for development. This study will also help to provide flood mitigation and quick relief response for the red zone areas which are more likely to hit badly from flood hazards. The study will help the Malaysian government to reduce natural flood risks which are one of the major causes of damage. The results obtained from this study will have cost and time-efficient and the methodology applied here will be a universal one that could be applied to any part of the country. At the end of the study, a map of flood risk areas will be generated and validated to assist decision-makers on the menace posed by the disaster. The expected results obtained from the study will help the guidance city planners and administrators to choose safe sites for construction and development.

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