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DEVELOPMENT OF HYDROLOGICAL MODELLING USING HEC-HMS AND HEC-RAS FOR FLOOD HAZARD MAPPING AT JUNJUNG RIVER CATCHMENT

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Abstract

Climate change has resulted in severe disasters such as floods, droughts, hurricanes, etc. As the climate warms, precipitation events become more frequent and intense, resulting in severe rains that may overflow rivers, streams, and drainage systems. The Junjung watershed, like many other areas, is vulnerable to floods, which may significantly damage the environment, infrastructure, and the local populace. As a result, precise knowledge of the catchment's rainfall intensity and hydrological features is required, as is the development of effective flood danger mapping. This research aims to determine the rainfall intensity for the catchment area. The study also intends to create a flood danger map for the Junjung watershed using HEC-HMS. The rainfall intensity for 50- and 100-years ARI was computed using HEC-HMS. HEC-RAS was used to produce flood hazard models, which revealed that rainfall intensity rose from the 50-years to the 100-years ARI. This indicates that the catchment is more likely to flood during extreme weather events, possibly more catastrophic flooding during uncommon, high-intensity rainfall. The Junjung watershed, according to the flood hazard mapping data, is in danger of flooding after high rains, which may result in the river overflowing and flooding the adjacent regions. As a result, reliable flood hazard maps are critical for mitigating the effect of flood occurrences in the study region.

Keywords: Climate Change, Disaster Reduction, Flood Mapping, HEC-HMS and HEC-RAS

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INTRODUCTION

Flooding is a significant natural disaster that can damage people's homes and structures, make it hard for people to make a living, and even kill people. Climate change is likely to make floods happen more often and be worse when they do. Because of this, it is crucial to make accurate and valuable flood danger maps so that areas at risk can be found and steps can be taken to avoid or lessen potential flood tragedies (IPCC, 2014; Toriman et al., 2015; Saad et al. 2023). Penang, Malaysia, where the Junjung River flows into the sea, is at risk of floods. The catchment area is about 89 square kilometres and has more than 70,000 people. Because of where it is, the stream is at risk of flooding when it rains a lot. This is because the river can overflow and flood the area around it. Hydrological modelling was used to make accurate flood risk maps for the Junjung River basin. Hydrological modelling is a process that models how water moves in an area, including rain and flow, in order to predict how a river will act and whether or not it will flood.

The study aimed to learn as much as possible about the hydrological processes and amount of rain in the Junjung River basin and to use HEC-HMS to create a computer model. The study used different kinds of data, such as weather data, topographic maps, maps of how land is used, and data from stream gauges, to make the hydrology model. Observed stream flow data were used to test and confirm the model. The results were used to map flood danger based on different return times (50 and 100 years). Heavy rainfall events create a danger of flooding in the Junjung River watershed, according to the research, which might cause severe damage to infrastructure and force the relocation of communities. Results from the modelling were used to create flood hazard maps, pinpoint vulnerable locations and suggest solutions for dealing with floods, such as better drainage and installing early warning systems (Jaafar et al., 2010; Azid et al., 2015; Mustaffa et al., 2023). For this purpose, it is crucial to create hydrological models utilizing HEC-HMS and HEC-RAS to forecast how rivers would act during times of significant rainfall and to pinpoint locations likely to be flooded. To lessen the severity of future flood natural disasters in the Junjung River basin and other regions in danger of flooding, the findings of this research may be used to create efficient flood risk management methods and mitigation measures.

LITERATURE REVIEW

Flood Disaster

Damage to infrastructure, houses, and assets, as well as disruption of livelihoods and loss of life, are all regular results of floods, impacting many nations across the globe. Globally, climate change has been linked to more frequent and severe floods (Dilley et al., 2005; Kundzewicz et al., 2007). Flooding will become more severe due to global warming, according to the Intergovernmental Panel on

Climate Change (IPCC) (IPCC, 2012). As a result of this danger, several nations have created flood hazard maps to help pinpoint vulnerable locations and execute flood risk management plans (Meyer et al., 2009; Abdul Maulud, 2021).

These floods have destroyed homes and businesses, displaced thousands, and claimed lives. Because of its tropical environment, the state often experiences flooding, particularly during the monsoons (Chow, 2016). Baharom et al. (2015) found that in recent years, Penang flood occurrences have become more frequent due to climate change and land use changes. The research concluded that rainfall intensity and duration are the most important factors in determining flood risk in the Penang region. The fast urbanization and significant population growth in Penang have also increased the likelihood of flooding (Baharom et al., 2015). The terrible storm that hit Penang in November 2017 was just one of numerous significant flooding catastrophes the city has had to deal with in recent years. Since then, the state government has made steps to resolve the problem, such as funding flood mitigation projects and creating flood hazard maps to pinpoint vulnerable locations.

Flood hazard mapping is vital in flood risk management and catastrophe preparation. Authorities may take preventative actions against flood damage by pinpointing vulnerable sites. Thanks to flood hazard mapping in Penang, effective flood management strategies and sites for flood mitigation projects have been developed. However, like with any modelling technique, flood hazard mapping has its own caveats and uncertainties that must be considered when planning for flood management.

Flood Hazard Mapping

Mapping flood hazards is an important part of flood risk management. It entails locating potentially flooded regions and drawing maps to illustrate the full scope of the problem. Flood maps have various uses in flood protection and catastrophe management, including risk assessment, community development, and disaster preparedness. Flood maps are only as reliable as the information that goes into making them. Digital Elevation Models (DEMs) are crucial to creating reliable flood maps, and recent advancements in remote sensing technology, like Light Detection and Ranging (LiDAR), have made their generation feasible. More data sources, such as precipitation, stream flow, and land use information, can now be integrated and analyzed using Geographic Information Systems (GIS), creating more accurate and detailed flood danger maps.

Chen et al. (2021) produced a flood danger map for the Lower Mekong River Basin using hydrological modelling, LiDAR data, and GIS. The research concluded that by including LiDAR data in the flood hazard map, the accuracy of the map was much enhanced, making it an effective tool for pinpointing vulnerable locations and setting priorities for flood risk management. Using hydrological modelling, rainfall data, and GIS, Lam et al. (2019) created a flood danger map for Hong Kong. According to the results, the flood hazard map helps pinpoint vulnerable locations and guide land-use planning choices in high-risk flood zones.

Local groups have also helped with flood risk assessments. The People's Disaster Risk Reduction Network (PDRRN) mapped urban flood hazards in the Philippines to better inform local disaster risk reduction programs (Abiera et al., 2021). Disaster preparation and mitigation initiatives in India have benefited from flood risk mapping conducted by the Gorakhpur Environmental Action Group (GEAG) (Kumar et al., 2017). There currently needs to be defined terminology or agreed-upon techniques for flood mapping in Europe (Pardoe et al., 2020), even though such mapping is an essential component of flood risk management.

More precise information on flood danger zones and probable flood damage is provided by 2D flood hazard mapping, which is another benefit. Flood insurance, land use planning, and disaster preparation are just a few of the areas where community members may benefit greatly from having access to this data. Flood danger is better communicated to the public via 2D flood hazard maps, according to research by Chen et al. (2018). In addition, 2D flood hazard mapping might reveal vulnerable locations that have been missed or underrated. For instance, Smith et al. (2015) demonstrated that two-dimensional flood hazard maps were superior to one-dimensional ones in pinpointing potential flash flood zones. Effective flood control strategies and emergency response plans may be created using this data.

In conclusion, flood hazard mapping is crucial for controlling flood hazards. HEC-RAS and GIS advancements have made it simpler to create precise flood maps, which have various uses in flood defence and disaster management. Because of the significance of community involvement in controlling flood hazards, community-based groups have also participated in flood hazard mapping.

RESEARCH METHODOLOGY

Methods

The Junjung River Basin flood hazard map was created using HEC-HMS and HEC-RAS. Figure 1 depicts a flood danger map development. Hydrological data analysis and rainfall design for certain return periods employed the basin's topography and land use data. HEC-HMS computed basin runoff proportional temporal patterns. The research calibrated input data in HEC-HMS to create a synthetic unit hydrograph.

This hydrograph was created for a 50- and 100-year Average Recurrence Interval (ARI) for two basin development and land use scenarios.

HEC-RAS will flood calibration verify this data. The research will next compare simulated data accuracy to Junjung River Basin water level data. This method verifies flood calibration. The research must adjust parameters before creating the flood hazard map if simulation data is erroneous.

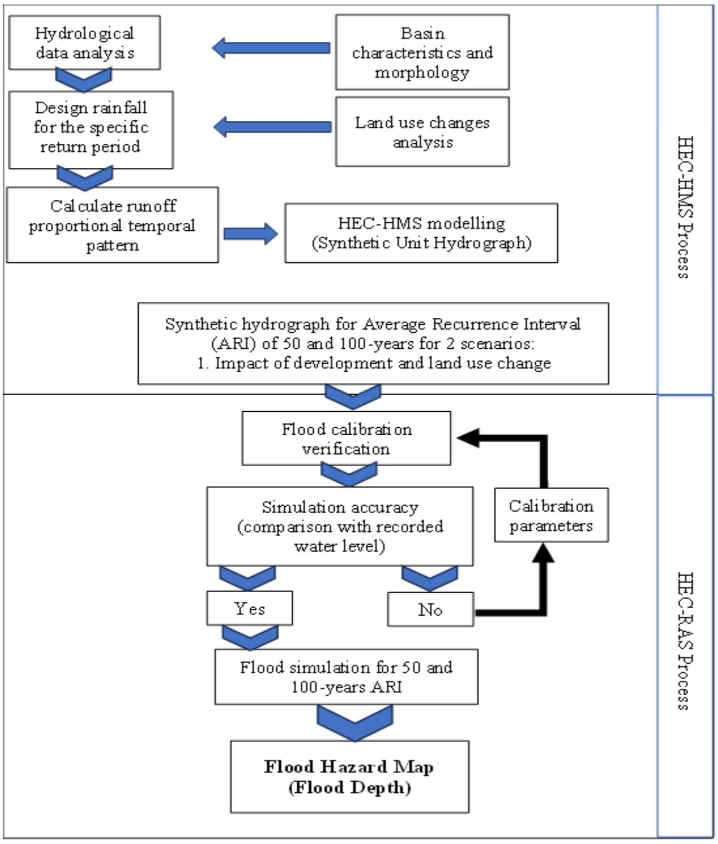

Figure 1: Flood Hazard Mapping Development Flow

Research Location

Penang is situated in Northern Peninsular Malaysia. The island and the mainland are only two of the five primary zone sections that make up this place. The island proper is divided into two major regions: the Southwest and Northeast Zone. In contrast, that happened in Seberang Perai, on the mainland. The three distinct areas are North Seberang Perai, Central Seberang Perai, and South Seberang Perai.

Penang's central Seberang Perai is located on the Junjung River. Its basin is around 154.8 km^2 in size. Numerous smaller tributaries, including the Cempedak River, Junjung Mati River, Perangin River, and Tok Subuh River, feed into it. The agricultural land usage in the Junjung Mati River Basin has expanded rapidly in the past 20 years to include industrial and residential developments. The eastern section of Penang is located in Bukit Batu Belah, the source of the Junjung River. The main channel of the Junjung River is 18.2 km long.

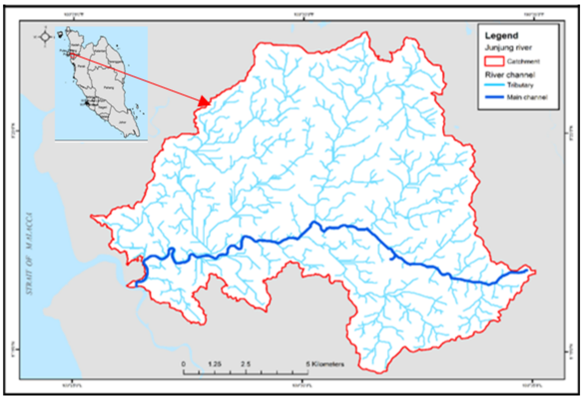

Figure 2: Junjung River Basin

RESULT AND DISCUSSION

Calculate Rainfall Intensity by using Thiessen Method

This study had done a development of Intensity-Duration-Frequency (IDF) to get the rainfall temporal design for each average recurrence interval with time specific and ratio of rainfall excess in the form of temporal pattern (Table 2). IDF curve developed using the annual maximum rainfall collected (Ariff, Jemain & Abu, 2015). In this study, IDF curve developed according to IDF curve with Thiessen method. Table 1 show the Thiessen weightage at Junjung river basin.

Table 1: Thiessen Weightage Factor at Junjung River Basin

Station	Area (km^2)	Thiessen Weitage Factor, w
5204048 - Sungai Simpang Ampat	71.088	0.535
5204049 - Ladang Batu Kawan	9.018	0.068
5304045 - Kolam Air Bukit Berapit	0.622	0.005
5205050 - Sungai Bakap	7.738	0.058
5206102 - Terap at Kedah	8.430	0.063
5303053 - Kompleks Prai	0.875	0.007
5304047- Kolam Air Cheruk To' Kun	10.079	0.076
5305001 - Kampung Dusun at Kedah	25.083	0.189

Rainfall intensity in the river basin area with Thiessen weightage (Thiessen, 1911) calculated using the equation as below:

$$l_{basin}=\frac{\sum_{i}^{n}=1\ l_i w_i}{\sum_{i}^{n}=1\ w_i} \qquad \ldots [1]$$

where, l_{basin} is an average weightage, $I_{i.}$ is a weightage and $W_{i.}$ is an area.

Table 2: Rainfall Intensity in Junjung River Basin

Rainfall Intensity (mm/hr)	**Average Recurrence Interval (Years)**	
Duration (min)	50	100
5	377.881	572.397
10	323.724	490.998
20	255.569	388.164
30	213.311	324.222
60	146.018	222.159
120	92.889	141.407
360	41.238	62.792
480	32.963	50.191
720	23.928	36.431
1080	17.303	26.341
1440	13.725	20.892
2160	9.885	15.045
2880	7.826	11.909
4320	5.625	8.559

HEC-RAS Modelling

HEC-RAS is designed to simulate hydrological process in dendritic river modelling system. This software can run various analysis and considered hydrological elements such as infiltration, unit hydrograph and hydrologic routing. It was developed for various geographical condition to solve hydrology problems.

Typical method to simulate rainfall losses used in the modelling are initial and constant rate. In this study, conversion of rainfall into runoff is using Unit Hydrograph SCS-CN. It needs to have main parameters; time of concentratuin (*Tc*), storage constant (*R*) and baseflow. Formulae for each parameter are shown as in equation [2] and [3].

$$\mathrm{Tc} = 2.3\mathrm{A}^{-0.1188}\mathrm{L}^{0.9573}\mathrm{S}^{-0.5074} \qquad \ldots [2]$$

where;
A = basin area (km^2)
L = length of flowpath (km)

S = basin slope (m/km)

$$R = 2.976A^{-0.1943}L^{0.9995}S^{-0.4588} \quad \ldots [3]$$

where;
R = storage constant
A = basin area (km^2)
L = longest flow path in river basin (km)
S = basin slope (m/km)

Baseflow estimation that needs to calculate the whole hydrograph design using Hydrological Procedure No.27 (2010) by Department of Irrigation and Drainage Malaysia (DID) as shown in equation below:

$$Q_B = 0.11A^{0.85889} \quad \ldots [4]$$

where;
Q_B = basin baseflow
A = basin area

HEC-HMS model at Junjung River Basin generated for rainfall design simulation for various frequency and time. Flood simulation carry out with calibrate and validate hydrological model using the spatial land use. Scenarios were designed for modelling listed in Table 3.

Table 3: Scenario Framework for Hydrology

Scenario	**Modelling Framework**	**Input**	
		Meteorology	**Land Use**
Scenario 1 Existing scenario	1. Schematic geometry 2. Input hyetograph of flood event	Latest rainfall data	Land use year 2015 - 2020
Scenario 2 Scenario impact of development and land use change	1. Validated model 2. Input: Synthetic hydrograph various ARI in future	50-years 100-years	Land use 2030

The selection of rainfall design to be applied shall covered the whole time of concentration (T_c) calculated for the whole basin area. Hence, designated rainfall event can be greater than the time of concentration of basin; some suggest for 3 to 4 times of time concentration (County, 1990), most of the design peak flow used 24 hours or same with the time of concentration (Levy and McCuen, 2001). However, this study used 12 hours of concentration to calibrate the rainfall and concentration (Table 4.).

Table 4: Summary of Peak Flow of Junjung River Basin of Scenario 1 and 2

ARI (years)	**Time**	**Sub-basin (m^3/s)**				
		Machang Bubok	**Junjung Upstream**	**Chempedak**	**Junjung Mati**	**Junjung Downstream**
50	12 Hours	82.8	101.6	68.2	130.1	16.9
100	12 Hours	96.0	118.8	79.6	149.6	19.5

In this study, the use of HEC-RAS model is to identify the locations that are easily flooded as a result of land use changes in the basin. This integration of flood modelling to assess the impact of land use and rainfall is crucial in determining the hazard area towards management plan development. The level of security, managing flood quantity and magnitude need to identify through the modelling exercise. Flood model was developed using HEC-RAS to identify area at risk of flooding as a result of land use changes. Study found that the flooding event in Junjung River Basin is category as High and Extreme. This can be proven as the data shown in the Table 5. below.

Table 5: Flood Classification of Scenario 1 and 2

Scenario 1				Scenario 2			
Average Recurrence Interval (ARI)	**Maximum Flood Depth (m)**	**Flooded Area (km^2)**	**Classification**	**Average Recurrence Interval (ARI)**	**Maximum Flood Depth (m)**	**Flooded Area (km^2)**	**Classification**
50	4.75	20.86	High	50	4.86	22.12	High
100	5.12	22.52	Extreme	100	5.24	23.16	Extreme

Figure 3a shows the current flood occurrence, which primarily affected areas near the river outlet or in low-lying areas. The flood depth reached approximately 4.76 meters, and the total flooded area was 20.86 km^2. However, Figure 3b shows that the 100-year ARI flood resulted in a larger affected area compared to the current flood. The flood depth reached approximately 5.12 meters, and the total flooded area was 22.52 km^2.

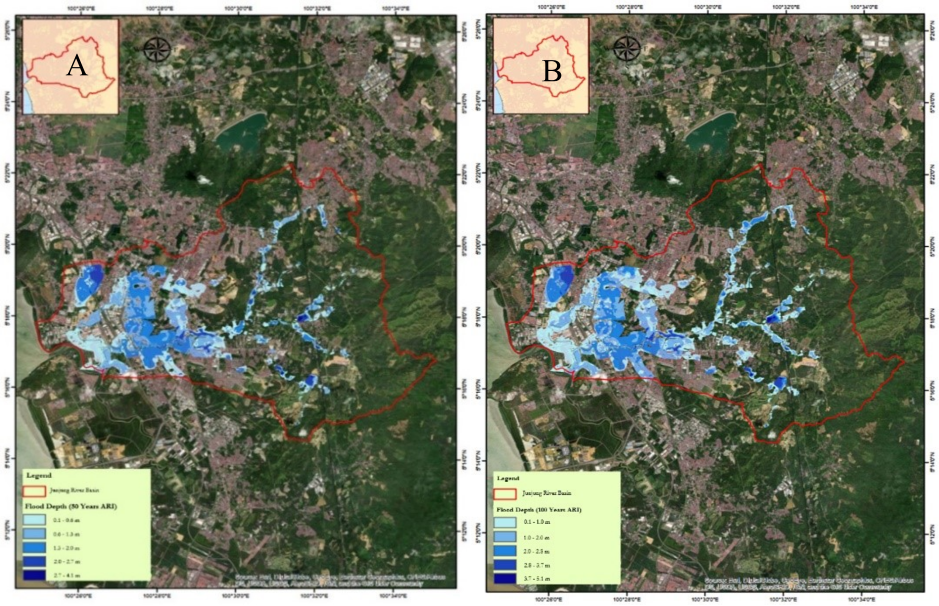

Figure 3 (a) and (b): Flood Depth for Scenrio 1 (50 and 100-years ARI & 12hours Critical Rain Period)

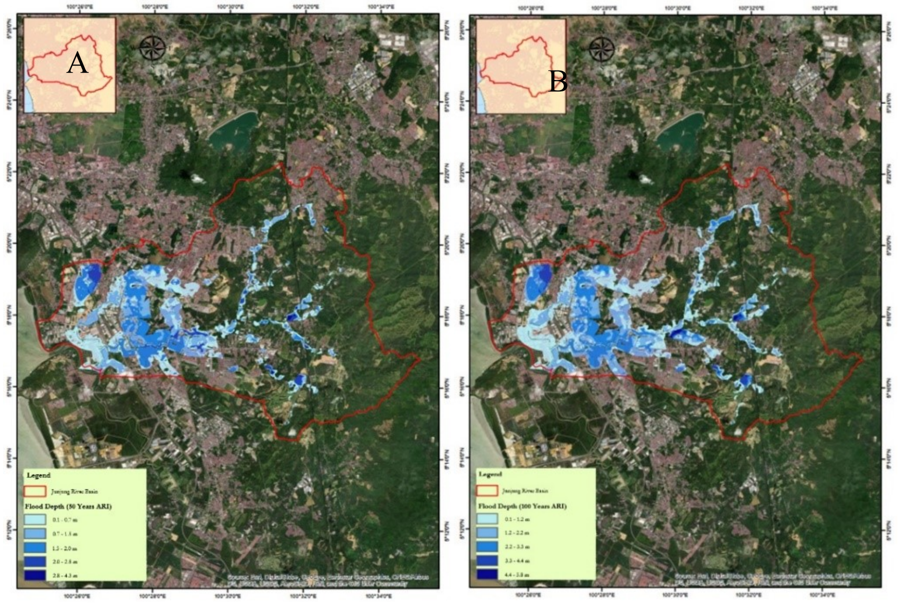

Figure 4 (a) and (b): Flood Depth for Scenrio 2 (50 and 100-years ARI & 12hours Critical Rain Period)

This study was conducted on the second scenario of 50-year and 100-year ARI floods to predict the potential impact of land use changes on previous flood situations in the research area. The 50-year ARI map shows that the total area that may be flooded would increase to a depth of 4.86 meters, with a total flooded area of 22.12 km^2 (Figure 4a). Figure 4b shows that the predicted flood occurrence in the Junjung River Basin has also increased due to changes in land use. Future land use changes are expected to further exacerbate the frequency and intensity of flooding, which could have a significant impact on local communities residing in these flood-prone areas. In the case of the 100-year ARI flood (as shown in Figure 4b), the estimated flood depth is 5.24 meters, and the total affected area is 23.16 km^2.

Millions of people are impacted by floods every year, making it one of the most destructive natural catastrophes. It's a regular occurrence in Malaysia, particularly during the rainy season, and it's responsible for a lot of destruction and tragedy. Predicting and reducing the effects of floods requires flood hazard mapping. Flood risk mapping using hydrological modelling is a common practise. In this study, we explore the evolution of hydrological modelling in the Junjung River watershed via the use of HEC-HMS and HEC-RAS for the purpose of flood hazard mapping. HEC-HMS and HEC-RAS are two extensively used hydrological modelling tools created by the Hydrologic Engineering Center (HEC) of the US Army Corps of Engineers. The watershed's hydrology may be modelled with the use of HEC-HMS, which then provides the input data for HEC-RAS. In order to calculate the river's hydraulics and predict how much water will flow and how deep it will rise during a flood, engineers turn to HEC-RAS. These two programmes work in tandem to provide a detailed depiction of flood risk in a specific region.

HEC-HMS was used to create the hydrological model for the Junjung River catchment. The model uses precipitation information collected from three stations within the catchment area. Precipitation information was gathered for the present period, and ARI forecasts for the next fifty-and-one hundred years. Discharge measurements were taken at the Junjung River gauge station to set the model's parameters. The hydrological model was able to mimic the runoff from the catchment region after a rainfall event with diverse land use changes. The hydraulic model took the artificial runoff as its starting point.

HEC-RAS was used to create the river's hydraulic model along the Junjung River. The gauge station readings from the Junjung River were used to properly adjust the model's parameters. The hydraulic model accurately reproduced the rate and height of flooding. The catchment area flood danger maps were then generated using the simulated water depth. The hydraulic model's simulated water depth was used to create the flood danger maps. Maps depicting the risk of flooding have been made for three distinct return periods: 50 years, 100 years, and two future projection scenarios. Areas most likely to be flooded within a specified return period have been pinpointed using flood hazard maps. The lowest region of the catchment area, close to the river mouth, was shown to be the most susceptible to flooding throughout all return periods in the flood hazard maps. Areas near the junction of the Junjung River and its tributaries are particularly at risk of flooding, as shown by the flood danger maps. HEC-RAS was used to create the river's hydraulic model along the Junjung River. The gauge station readings from the Junjung River were used to properly adjust the model's parameters.

The hydraulic model accurately reproduced the rate and height of flooding. The catchment area flood danger maps were then generated using the simulated water depth. The hydraulic model's simulated water depth was used to create the flood danger maps. Maps depicting the risk of flooding have been made for three distinct return periods: 50 years, 100 years, and two future projection scenarios. Areas most likely to be flooded within a specified return period have been pinpointed using flood hazard maps. The lowest region of the catchment area, close to the river mouth, was shown to be the most susceptible to flooding throughout all return periods in the flood hazard maps. Areas near the junction of the Junjung River and its tributaries are particularly at risk of flooding, as shown by the flood danger maps.

CONCLUSION

Developing hydrological models utilizing HEC-HMS and HEC-RAS for flood hazard mapping at the Junjung River basin has offered useful information for flood risk management in the region. The catchment area's runoff during a rainstorm event was successfully simulated by the hydrological model, and water flow was successfully simulated by the hydraulic model.

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DISCLOSURE STATEMENT

Following international publication policy and our ethical obligation as a researcher, we report that we have no conflict of interest.

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