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The Flood Inundation Mapping of Kampung Sungai Kertil in Kuala Muda, Kedah

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Abstract – This study focuses on using a geomatics-based flood modelling as a tool to visualise and communicate predicted flood levels in Kampung Sungai Kertil in Kuala Muda, Kedah. Flooding is a recurring problem in the area, causing significant damage and disruptions to human settlements, infrastructure, and the economy. This research aims to develop an effective flood model that enhances the accuracy of flood map preparation and facilitates a better understanding of flood risks. The research utilises a combination of hydrological modelling and geographic information systems (GIS) to analyse flood-prone areas in a case study region. In ArcGIS, the Hec-GeoRAS extension extracts geometric information from Digital Elevation Model (DEM) and imports data from HEC-RAS for flood inundation mapping. Data from the SRTM DEM is used in this case study. In order to accurately simulate floods and analyse water levels using the steady flow simulation approach, RAS layers that include crucial hydraulic parameters are created within HEC-RAS. The model results demonstrate that higher discharge scenarios (up to 150 m^3/s) produce substantially larger inundation extents, identifying seven settlements within the predicted flood-prone area. The study advances a thorough knowledge of regions vulnerable to flooding by creating maps of flood potential, which supports preventative flood management measures. The results underscore the importance of flood modelling in improving the precision of flood map creation and bolstering efficient flood control strategies.

Keywords *– Flood Modelling, Flood Velocity, Hydrology, River Analysis, Geomatics, GIS*

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1.0 Introduction

Flood modelling and simulation, as part of geovisualization approaches, are widely recognised as effective tools for improving public understanding and communication of flood inundation processes and impacts. By integrating hydrological modelling with Geographic Information Systems (GIS), complex spatial data can be translated into clear and accessible visual representations, allowing flood behaviour to be understood beyond technical audiences. This integration is particularly important in supporting risk communication, planning, and informed decision-making in flood-prone areas.

Previous studies on flood inundation mapping have shown its value in identifying areas at risk, estimating flood extent and depth, and supporting mitigation and emergency response planning (Vashist & Singh, 2023; Singh et al., 2021). Digital elevation data are commonly used in hydrologic and hydraulic models such as HEC-RAS to simulate water levels and flood spread under different flow conditions. The modelling results can then be visualised using GIS-based maps and interactive platforms, enabling users to explore spatial patterns of flooding and changes over time. Compared to static maps, interactive flood visualisations have been found to improve risk awareness and interpretation, particularly among non-expert users.

These geovisualization-based flood modelling tools are increasingly applied in planning, engineering, architecture, and disaster management, where understanding the interaction between flood dynamics, land use, and exposed communities is critical for effective decision-making (Al-Omari et al., 2024; Idris et al., 2025). In both urban and rural contexts, flood inundation maps are often used to communicate potential hazards, vulnerable locations, and response strategies to stakeholders. The use of visually intuitive flood maps has also been shown to encourage greater public engagement and more effective communication between authorities and local communities (Oubennaceur et al., 2021; Li et al., 2025).

This study examines the use of flood inundation modelling as a communication tool in Kampung Sungai Kertil, Kuala Muda, Kedah. The main aim is to support flood risk management efforts by enhancing public awareness and stakeholder engagement through geovisualization. Kampung Sungai Kertil is selected as the study area due to its frequent exposure to flood events and its proximity to river systems, making it highly vulnerable to recurring inundation impacts. The outcomes of this study are expected to contribute to improved flood vulnerability assessment, clearer communication for early warning purposes, and strengthened community preparedness and resilience in flood-prone areas such as Kampung Sungai Kertil.

2.0 Literature Review

Floods are among the most common and dangerous natural disasters in the world that happen almost anywhere, wreaking havoc on human settlements, infrastructure, the environment, and the economy (Gao et al., 2019; Guerreiro et al., 2018; Jongman et al., 2012; Winsemius et al., 2015). A flood is also defined as the overflow of areas normally submerged in water or a stream as a result of water rising significantly in a short period of time. According to the research, these occurrences are classified among the most catastrophic natural disasters globally, accounting for 40% of all events. Over the previous 20 years, these disasters have affected more than 4.2 billion people and caused over 2.97 trillion USD in economic damages. Meanwhile, flooding is expected to intensify in the years to come (Berndtsson et al., 2019; Costabile et al., 2021; Dottori et al., 2018; Gao et al., 2019).

Malaysia has approximately 189 river basins, including 89 in Peninsular Malaysia, 78 in Sabah, and 22 in Sarawak, most of which discharge into the South China Sea. Of these, about 85 basins are identified as vulnerable to recurring floods (PLANMalaysia, 2017).Thus, flooding events have become more frequent and intense in recent years, worsening the effects on vulnerable communities. Like many other countries, Malaysia is plagued by flooding, notably in areas such as Kelantan, Kedah, and Pahang, etc. These flood disasters have far-reaching repercussions for the communities affected, including disruptions to everyday operations, property destruction, and hazards to public safety.

These disasters may occur owing to climate change, poorly planned development, and urbanisation as a result of rapid population increase and a lack of efficient flood risk management strategies, particularly in low and middle-income nations. (Kaoje et al., 2020; Najibi & Devineni, 2018). Even though Malaysians are exposed to these threats on a regular basis, our country is unable to provide adequate early warning and management to the communities. This is due to a disparity in the amount of development and advancement in studying the various components of flood risk in Malaysia, where flood hazard and exposure assessment studies are more sophisticated and developed. In contrast, flood vulnerability models and assessments have made little progress (Kaoje et al., 2020; Karki, 2019; Zakaria et al., 2017). This study focuses on Kg. Sg Kertil in Kuala

Muda, Kedah, which is susceptible to flash floods during the monsoon season. In recent years, the region has seen catastrophic flooding, which has had a negative impact on both residents and the ecosystem. The repercussions of these floods show the importance of efficient flood risk management measures for mitigating losses and ensuring population safety.

Flood maps are currently regarded as a potentially beneficial tool for expanding this understanding (Costabile et al., 2021). Nonetheless, significant disadvantages of utilising flood maps for risk communication have been identified in the literature. Flood representations can provide an alternate method, so complementing flood maps with flood modelling approaches is increasingly viewed as a strong tool for engaging people with flood threats. The study examines the development of flood modeling, as well as the evaluation of its effectiveness as a communication tool for the general public.

3.0 Methodology

This research is based on the research methodology model that fits the project needs, which involves the data acquisition stage, data pre-processing stage, data analysis stage, and final results. Figure 1 shows the general methodology of this study.

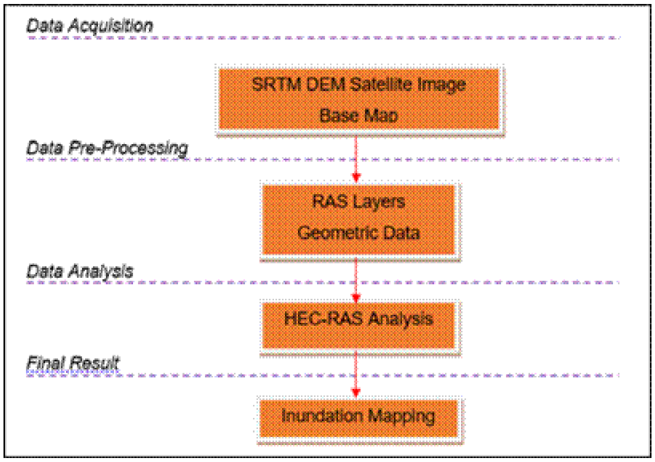


Figure 1: General flowchart of the study

3.1 Research Area

The study area focuses on Malaysia's Kedah state. In the past decades, Kedah has suffered several river floods, causing substantial damage to buildings, roads, and agricultural fields, almost every year (Department of Irrigation and Drainage Malaysia, 2017; National Disaster Management

Agency, 2022). Flooding frequently occurs in several areas of Kedah, particularly along major river systems such as Sungai Muda, Sungai Merbok, and Sungai Bongkok . The Muda River in the Kuala Muda district is identified as one of the many flood-prone regions in Malaysia, with high exposure to seasonal flooding (Department of Irrigation and Drainage Malaysia, 2017). The district is especially vulnerable to monsoon floods due to rapid urbanisation and unfavorable topographical conditions. The flood event of November 2021 was among the most significant natural disasters in recent years, severely impacting northern Peninsular Malaysia (Malaysian Meteorological Department, 2022). In 2021, Kedah recorded substantial flood-related losses, with a total of 88 flood incidents reported, including 85 flash floods and three coastal flooding events (National Disaster Management Agency, 2022).

3.2 Data Acquisition

This research relies on secondary data; notably hydrological data obtained from Malaysia's Department of Irrigation and Drainage (DID) for the year 2017. DID offers statistics on water level, discharge, flow, and other flood-related metrics. The website of the National Hydrological Network Management System provides hydrological data, which comprise both spatial and non-spatial data. The data is critical for advanced decision-making in GIS since it aids in resource management and analysis. Users can customize their data preferences, such as types, years, and states.

3.3 Data Processing

Data processing is an important phase in flood modelling since it allows for information analysis and display. Data processing is a crucial step that helps in further analysis and presentation.
Figure 2 below shows the flow of the phases.

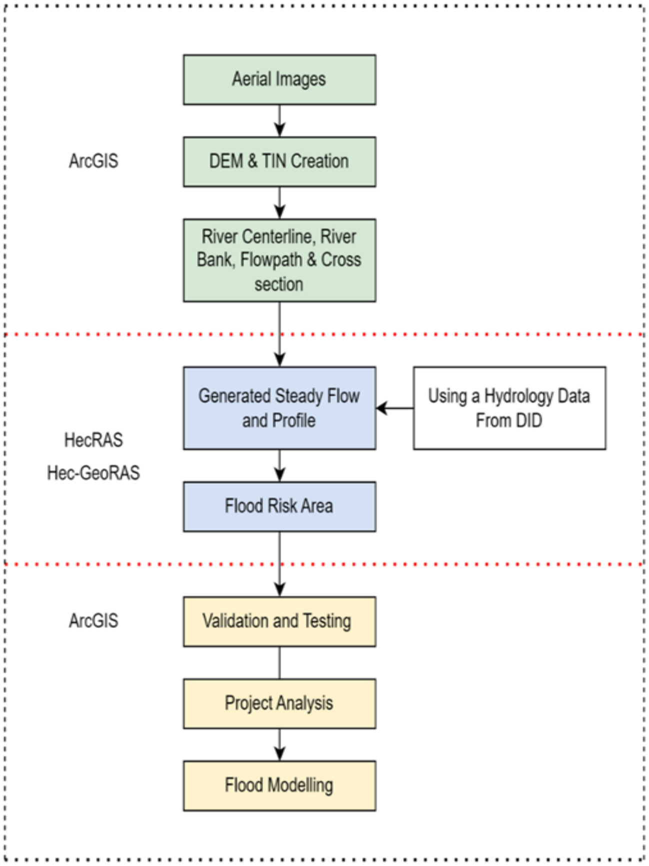


Figure 2: Processing flowchart of the study

3.4 SRTM Digital Elevation Model (DEM)

This study utilised the Shuttle Radar Topography Mission Digital Elevation Model (SRTM DEM), a global elevation dataset produced by NASA during the Space Shuttle Endeavour mission in February 2000. Captured using C-band radar, the SRTM DEM provides a 30-meter resolution digital elevation model of the Earth's surface. DEMs are essential for hydrological modeling, particularly for simulating water flow during flood events. For this study, SRTM data covering the Kedah region were downloaded from the US Geological Survey (USGS) in raster format.

HEC-RAS was employed to extract river channel geometry, generating cross-sectional profiles, delineating riverbanks, and estimating floodplain elevations directly from the DEM. Although higher-resolution data, such as LiDAR, would offer improved accuracy, access limitations necessitated the use of freely available SRTM data as a practical alternative.

Satellite imagery was also used to develop a topographic base map and to extract a subset image focused on the Kg. Sg. Kertil area. The river alignment was manually digitized using Google

Earth and saved as a shapefile. The subset emphasized residential zones to support subsequent flood monitoring and modelling efforts in the study area.

3.5 HEC-RAS Layer Creation

The HEC-RAS is a software program developed by the US Army Corps of Engineers that simulates the behaviour of rivers and water channels (Brunner, 2016). . It is used for hydrologic and hydraulic modelling, especially for simulating river and stream flooding. With the function tools that have been built in HEC-RAS, users can create models of water channels and simulate various hydraulic conditions, such as steady-state and unsteady flow, sediment transport, and water quality.

This study's approach is centered on flood modeling with the HEC-RAS program. Gathering and analyzing pertinent data, such as digital elevation models (DEMs), land use data, and streamflow data, is the first step in the process. After obtaining the data, it is imported into HEC-RAS, where the pertinent data parameters are entered and the study area is defined. The geometry of the river or stream channel is defined in HEC-RAS during the geometric data processing step that follows. The process includes the creation of geometric layers for culverts, bridges, riverbanks, cross-sections, and other constructions.

3.6 Stream Center Line Creation

One critical part of hydraulic modeling is the creation of stream centerlines in HEC-RAS, a popular hydraulic modeling software. Stream centerlines serve as a reference line for estimating the water surface profile and hydraulic grade line along the river reach. This data is vital for measuring the flow rate and velocity of water in the river, which is necessary for floodplain mapping, channel planning, and water resource management.

3.7 Riverbank Line Creation

Riverbanks define the river channel and play an important part in influencing the flow characteristics of the water. In HEC-RAS, riverbanks are created by describing their position and geometry, as well as assigning bank material qualities. Modeling riverbanks accurately can aid in assessing flood risks, designing flood control measures, and optimizing river management methods. Bank lines are the river channel's limits, which can be identified by tracing the channel's edge with GIS data. Each river reach might have its own set of bank lines. After specifying the bank lines, stationing is allocated to them. Stationing is a distance along the river channel that is used to reference the location of the bank lines. Stationing can be assigned manually or using the HEC-RAS automatic stationing tool.

3.8 Flow Path and Cross-Section Creation

Flow paths help to identify areas of the channel where the water is flowing and provide valuable information on the velocity and depth of the water. This flow path can be digitized from upstream to downstream. Thus, the flow boundary conditions must first be specified by defining a clear flow path.

The cross-sectional cut line will be used to present the cross-sectional data profile from the SRTM DEM data. Thus, this data needs to be digitized from the left overbank to the right overbank and needs to be perpendicular to the flow direction of the river. They also, should not be intersecting with each other because the process of creating the attribute will fail. According to El-Naqa and Jaber (2018), cross sections in hydraulic modelling must be extended sufficiently to capture the full extent of flood flow within the channel and floodplain. The procedure of constructing cross-sections in HEC-RAS can be time-consuming and tedious, but it is necessary to ensure correct hydraulic modelling results. Accurate cross-sections are required to accurately simulate various flow scenarios and identify locations prone to flooding or erosion. This data can be utilized to create effective flood control measures, channel stabilization initiatives, and stream restoration projects.

3.9 Estimation of Manning's n for Hydraulic Modelling

Manning's n Value calculates the water flow along the river network based on the surface roughness coefficient. In this study, the river network was supposed to be a grassy riverbank channel. Therefore, in this study, the river network was assumed as a grassy riverbank, Manning's n values in the range of 0.025 to 0.035 are commonly used to represent the roughness caused by grass. These values indicate a moderately rough surface due to grass cover. Thus, the value within the range was entered into the Manning's n table under Geometric Data.

3.10 Water Discharge and Boundary Condition

Accurate water discharge parameters must be entered to ensure reliable flood modeling and simulation in HEC-RAS. Water discharge represents the volume of water passing a specific point along a river or channel. By inputting the water discharge, the software can calculate flow velocity, water surface level, and other hydrological variables at various places along the river or channel. This information is critical for determining how floodwaters travel through the system. Consequently, to ensure the project produces reliable outcomes, the accuracy and consistency of the water discharge data must be verified.

Following this, the model's Reach Boundary Condition will be established. These boundary conditions are used to determine the behavior or characteristics of the borders of a system or domain. There is a total of four types of boundary conditions that must be chosen during these procedures. As a result, the normal depth was chosen. Consequently, to calculate the final outputs, a maximum water level value for both the upstream and downstream stages was required. The final stage involved conducting a Steady Flow Analysis to generate a simulation based on the established settings. Flow regimes are generally classified as subcritical, supercritical, or mixed. For this investigation, a subcritical setting was utilized as the default, after which the simulation was computed.

3.11 Inundation Mapping in ArcGIS

In the final stage after completing the HEC-RAS, inundation mapping in ArcGIS is performed. By converting the HEC-RAS procedure into operational maps, flood inundation mapping aids in communicating flood hazards and impacts to individuals, communities, and authorities. It helps with emergency planning, risk assessment, and decision-making by providing vital information on the extent and depth of flooding, allowing for better knowledge and control of flood hazards. Consequently, the final step involves exporting the modeling results, including water levels at multiple locations along the river. These data are then utilized within ArcGIS to generate inundation maps. To portray the areas that will be inundated, an appropriate mapping technique comprises converting the water level data into flood extent polygons or raster grids.

4.0 Result and Discussion

4.1 HEC-RAS Geometry Layer

Geometry Layers in HEC-RAS refer to the many graphical layers in the HEC-RAS software that can be used to display various types of information. These layers can be toggled on and off separately, allowing users to customize the information displayed on the HEC-RAS model. Several types of Geometry Layers were produced in HEC-RAS throughout this investigation, including:

(i) The Stream Center Line
(ii) The Riverbank Line
(iii) River Flow Path Line
(iv) River Cross-Section

4.1.1 The Stream Center Line and Riverbank Line

The path along which the main flow of water occurs within the river channel is represented by the centerline. The centerline layers were used as a flow path to identify the upstream and downstream points. The Stream Centre Line layer was created in the setting of Sg Kuala Kertil to identify the river network from Kuala Kertil River in Kg Pada as shown in Figure 3.

The bank lines were digitized manually in HEC-RAS by visually identifying the transition from the river channel to the surrounding land. The left and right bank lines in each cross-section profile, which reflected the approximate riverbank bounds, had to be digitized as shown in Figure 3.

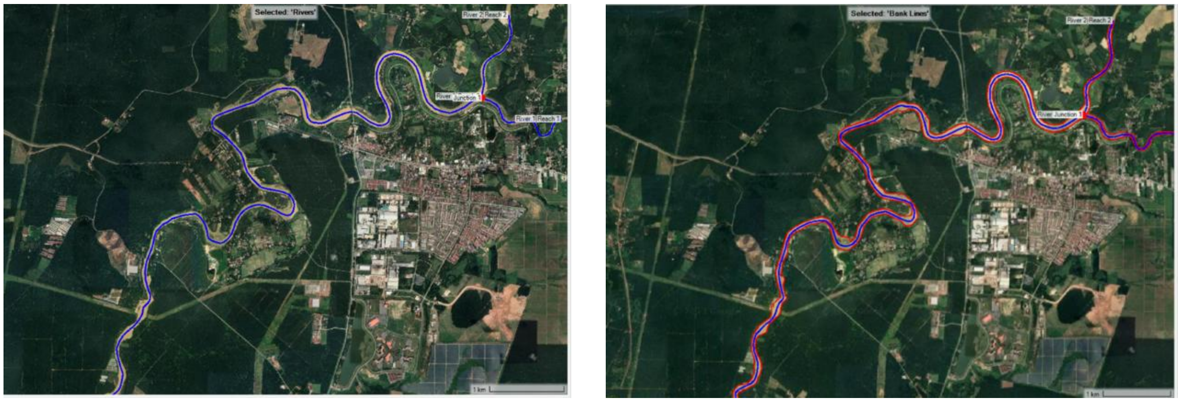


Figure 3: The River Network (Left) and The Riverbank Line (Right) From Kuala Kertil River to Kuala Muda River

4.1.2 The River Flow Path

Analyzing the flow path is an essential part of hydraulic modeling, as it helps in understanding how water moves through a river system and how it interacts with the surrounding areas. In order to create a flow path in HEC-RAS, the path's starting and ending points as shown in Figure 4 must be defined, and HEC-RAS computed the flow path based on the hydraulic model. This phase is critical for completing the simulation computation text.

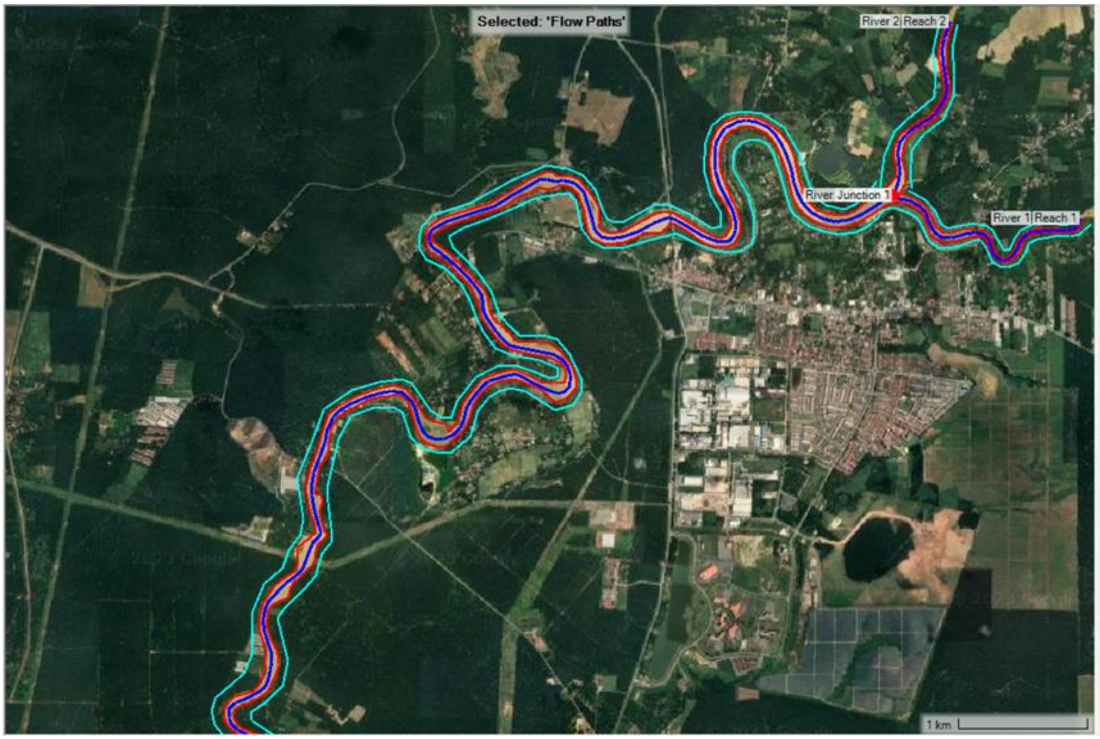


Figure 4: The Flow Path Line of The River from Kuala Kertil River to Kuala Muda River

4.1.3 The River Cross-Section

The cross-section is one of the key elements that we need to complete in the HEC-RAS software. The elevation data was extracted from the data sources using the crosssection. As a result, at least 251 cross-sections along the river have been produced in HEC-RAS, accurately capturing the river geometry and hydraulic behavior within the HEC-RAS model. The upstream point was the Kuala Kertil River in Kg Padang Kulim, and the downstream point was the Kuala Muda River in Kg Pantai Cicar. Figure 5 show the cross section creation in HEC-RAS software.

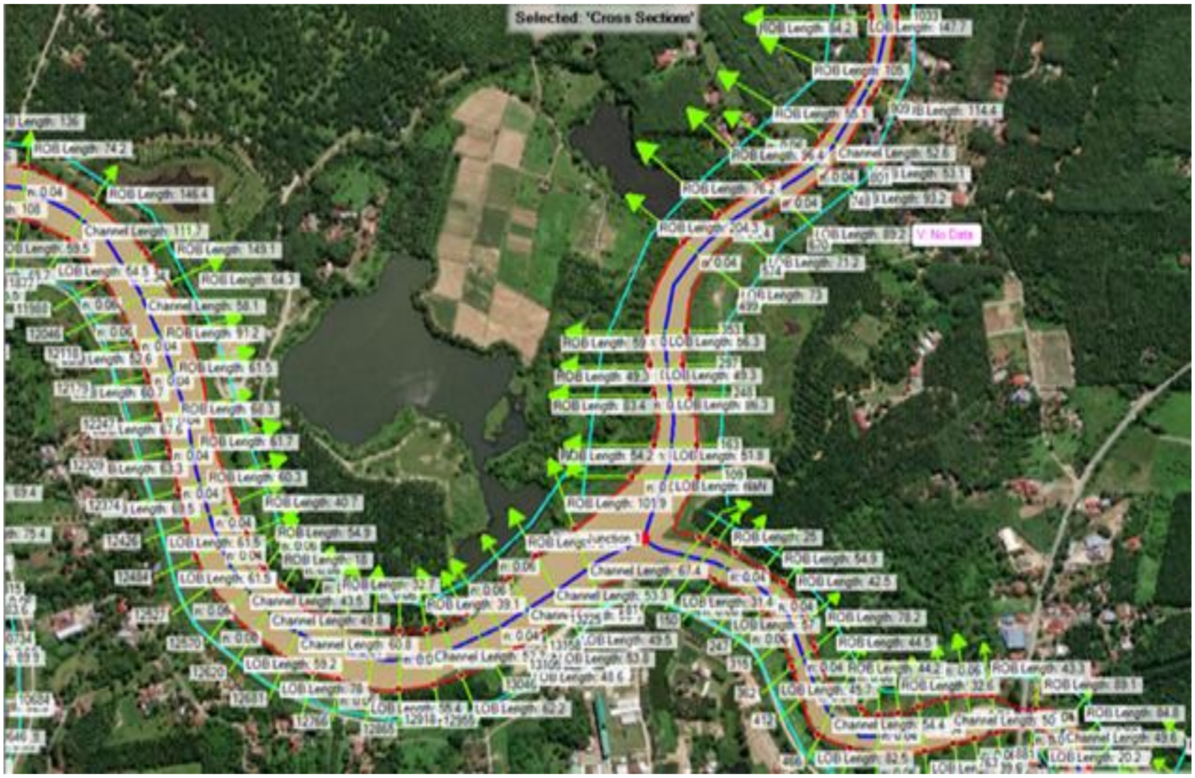


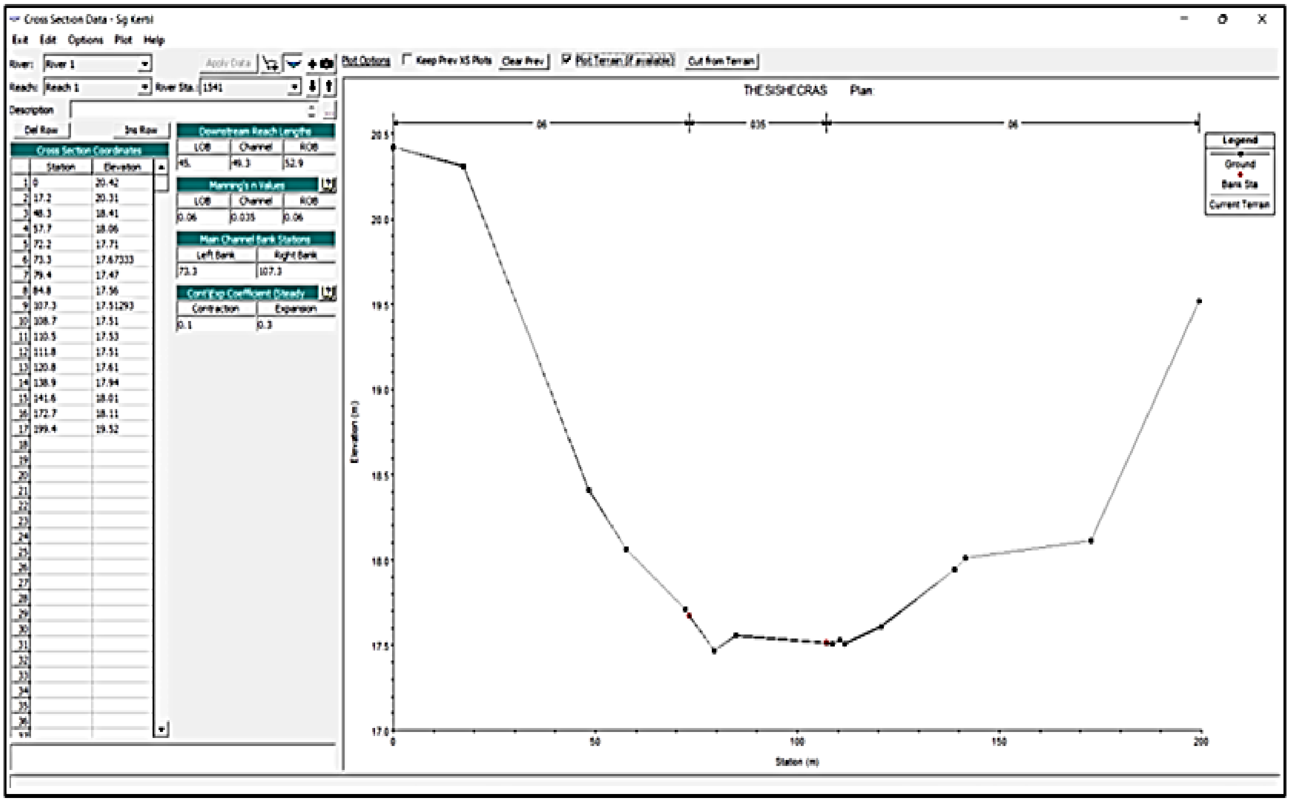
Figure 5: The Green Color Line Is the Cross-Section of the River

4.2 Channel Roughness based on Manning's n Value

Manning's n value is a parameter used in HEC-RAS analysis to represent channel roughness and resistance to flow. Variations in Manning's n directly affect flow velocity, water depth, and water surface elevation, which consequently influence the extent and pattern of flood inundation. Lower Manning's n values reduce flow resistance, resulting in higher velocities and deeper flow within the channel, while higher Manning's n values increase resistance, raise water levels, and promote wider lateral flooding into the floodplain.

The sensitivity analysis shows that changes in Manning's n led to noticeable differences in predicted flood extents, particularly in low-lying areas. Higher roughness values produce larger inundated areas and greater flood depths in the final flood maps, whereas lower roughness values tend to confine flooding closer to the river channel. This demonstrates that appropriate calibration of Manning's n is critical for producing reliable flood inundation outputs and accurate flood risk communication.

As a result (see Figure 6), the study emphasizes the need of choosing appropriate Manning's n values for accurate flood modelling. It emphasizes the significance of field measurements and calibration in increasing the dependability of the results.



River: River 1

Reach: Reach 1

River Sta.: 1541

Description:

Cross Section Coordinates

	Station	Elevation
1	0	20.42
2	17.2	20.31
3	48.3	18.41
4	57.7	18.06
5	72.2	17.71
6	73.3	17.67333
7	79.4	17.47
8	84.8	17.56
9	107.3	17.51293
10	108.7	17.51
11	110.5	17.53
12	111.8	17.51
13	120.8	17.61
14	138.9	17.94
15	141.6	18.01
16	172.7	18.11
17	199.4	19.52
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Downstream Reach Lengths

LOB	Channel	ROB
45.	49.3	52.9

Manning's n Values

LOB	Channel	ROB
0.06	0.035	0.06

Main Channel Bank Stations

Left Bank	Right Bank
73.3	107.3

Cont\Exp Coefficient (Steady)

Contraction	Expansion
0.1	0.3

Figure 6: Manning’s N value attribute table

4.3 Analysis by Water Discharge

Prior to conducting steady flow analysis, it is essential to define water discharge, which represents the volume of water flowing through a channel per unit time, typically measured in cubic meters per second (m^3/s). Based on established hydraulic modelling practices, a range of discharge values is commonly used to represent different flow scenarios in river systems (Brunner, 2016). In this study, discharge rates of 50, 100, and 150 m^3/s were selected to simulate varying flow conditions. Accurate input of these discharge values is crucial for obtaining reliable results from the steady flow analysis.

To evaluate how water flows within the Sg Kertil system under steady-state conditions, appropriate boundary conditions must be defined. In this study, the normal depth was selected as the downstream boundary condition. Normal depth, characterized by uniform flow with constant depth and velocity along the channel, serves as a quasi-steady state indicator governed by channel slope and roughness. It is widely adopted in hydraulic modeling of open channel flow and was used here to represent the river's water level determinant.

According to this study's limitation, the flood event was simulated using a Steady Flow Analysis. The result is analyzed in order to determine whether Steady Flow Analysis was suitable or out of the capability to give the best simulation.

4.4 The Flood Inundation Result

Flood inundation maps were produced for the subsequent flood scenarios. The generation flood inundation maps for Kg. Sg Kertil in Kuala Muda, Kedah based on flood hazard degree that has been produced during HEC-RAS processing. Figure 7 and Figure 8 visualize the resulted flood inundation mapping.

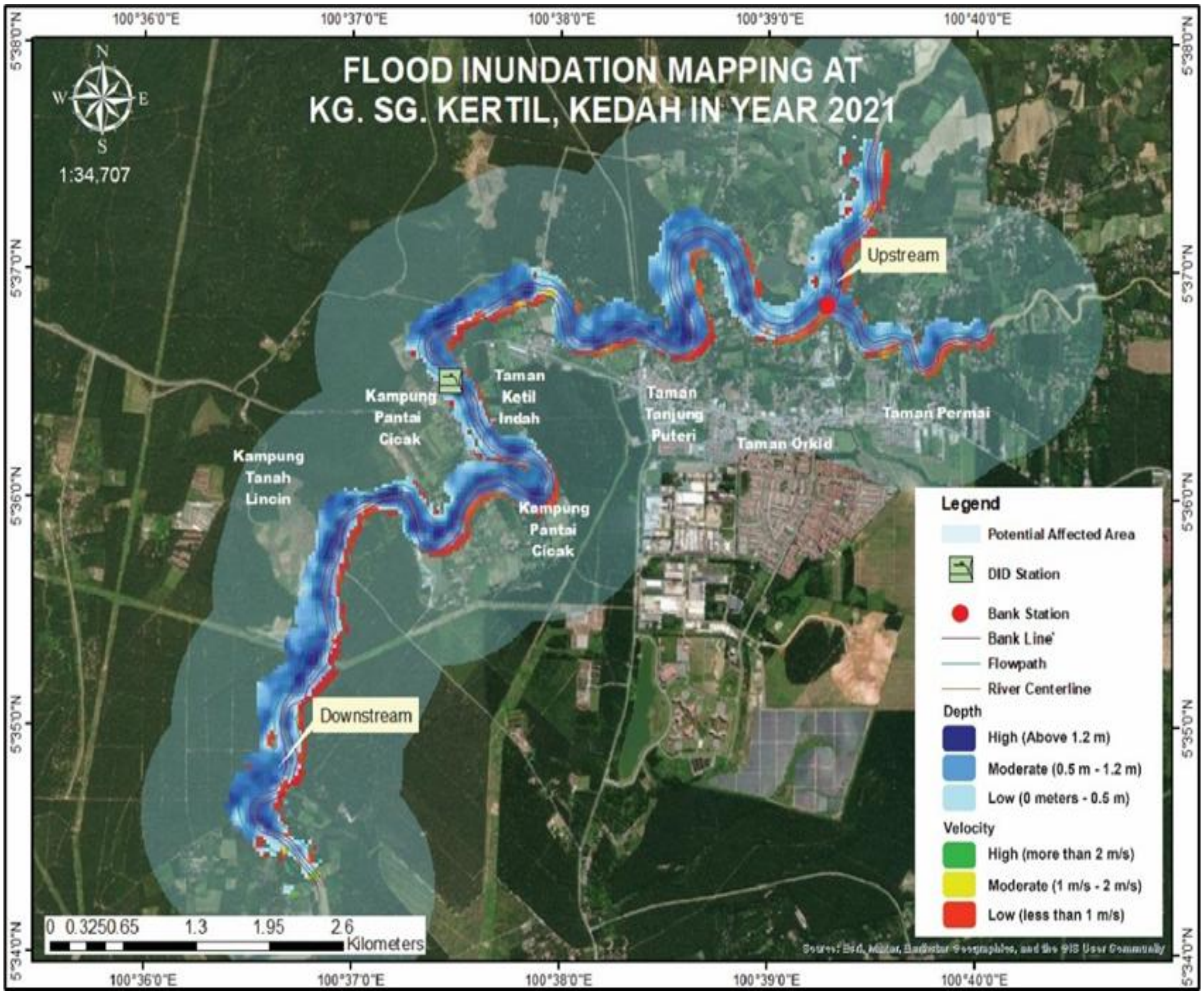

Figure 7: Flood inundation map (based on depth)

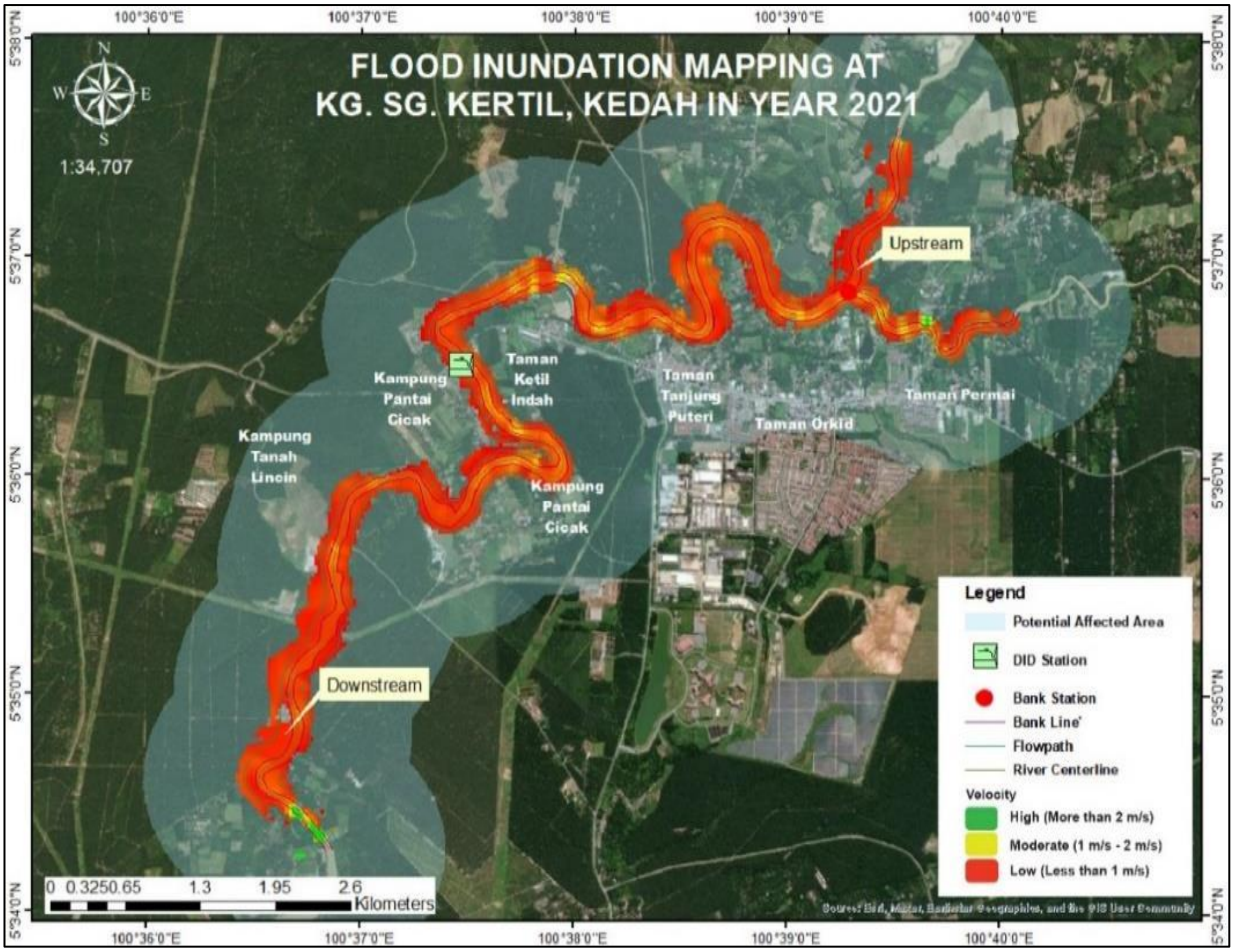

Figure 8: Flood inundation map (based on velocity)

4.5 Flooded Area Analysis

In analysing the potential flood region, the study concentrated on developing flood inundation maps forKg. Sg Kertil in Kuala Muda, Kedah. These maps provide helpful information regarding the extent of floods, depth classification, and river velocity. Flood depths and velocity were classified as low, moderate, or high using the flood danger degree categorization. This rating assists in identifying the severity of flooding and the appropriate steps to take. The project aims to improve understanding and readiness for flood events in Kg Sg Kertil by mapping flooded areas and facilitating efficient flood mitigation measures

Table 1: Degree of Flood Hazard (Adapted from UK Environment Agency, 2006)

Degree of Flood Hazard	Flood Range	Colour Coded	Description
Depth			
High Depth	(>1.5 meters)	🟦	Extreme Danger
Moderate	(0.50 meters – 1.50 meters)	🟦	Danger
Low Depth	(<0.50 meters)	🟦	Caution
Velocity			
High Velocity	(>2 m/s)	🟩	Extreme Danger
Moderate	(1 m/s – 2 m/s)	🟨	Danger
Low Velocity	(< 1 m/s)	🟥	Caution

Table 1 categorizes flood hazards based on water depth and velocity. Significant risks to life and property are posed by flood depths above 1.5 meters, which are categorized as Extreme Danger. The danger category, which indicates significant risk, applies to depths between 0.50 and 1.50 meters, while the caution category, which nevertheless warrants attention because of possible pain and damage, applies to depths below 0.50 meters. In a similar vein, floods exceeding 2 m/s are considered Extreme Danger because of their devastating power. Though even low-velocity flows can put individuals and infrastructure in danger, velocities between 1 m/s and 2 m/s are categorized as Danger, and those below 1 m/s are classified as Caution.

Comprehending the distribution of velocity in a river system is essential for managing flood risk effectively. By identifying regions vulnerable to silt deposition, backwater effects, erosion, or channel instability, steady flow analysis with HEC-RAS offers important insights into flow dynamics across river lengths. Delineating flood extents and assessing flood danger both depend on river depth. While shallower portions might suggest floodplain zones or silt deposition, deeper parts typically correlate with larger water volumes or main channels.

4.6 The Potential of Affected Area

The potential flood mapping was generated, as displayed in Figure 9, utilizing spatial analysis performed in ArcGIS. Consequently, towns and villages located within a one-kilometer radius of the projected flood zone are identified below:

(i) Taman Permai
(ii) Taman Orkid
(iii) Taman Tanjung Puteri
(iv) Taman Ketil Indah
(v) Kg Pantai Cicar
(vi) Kg Pantai Cicak
(vii) Kg Tanah Linci

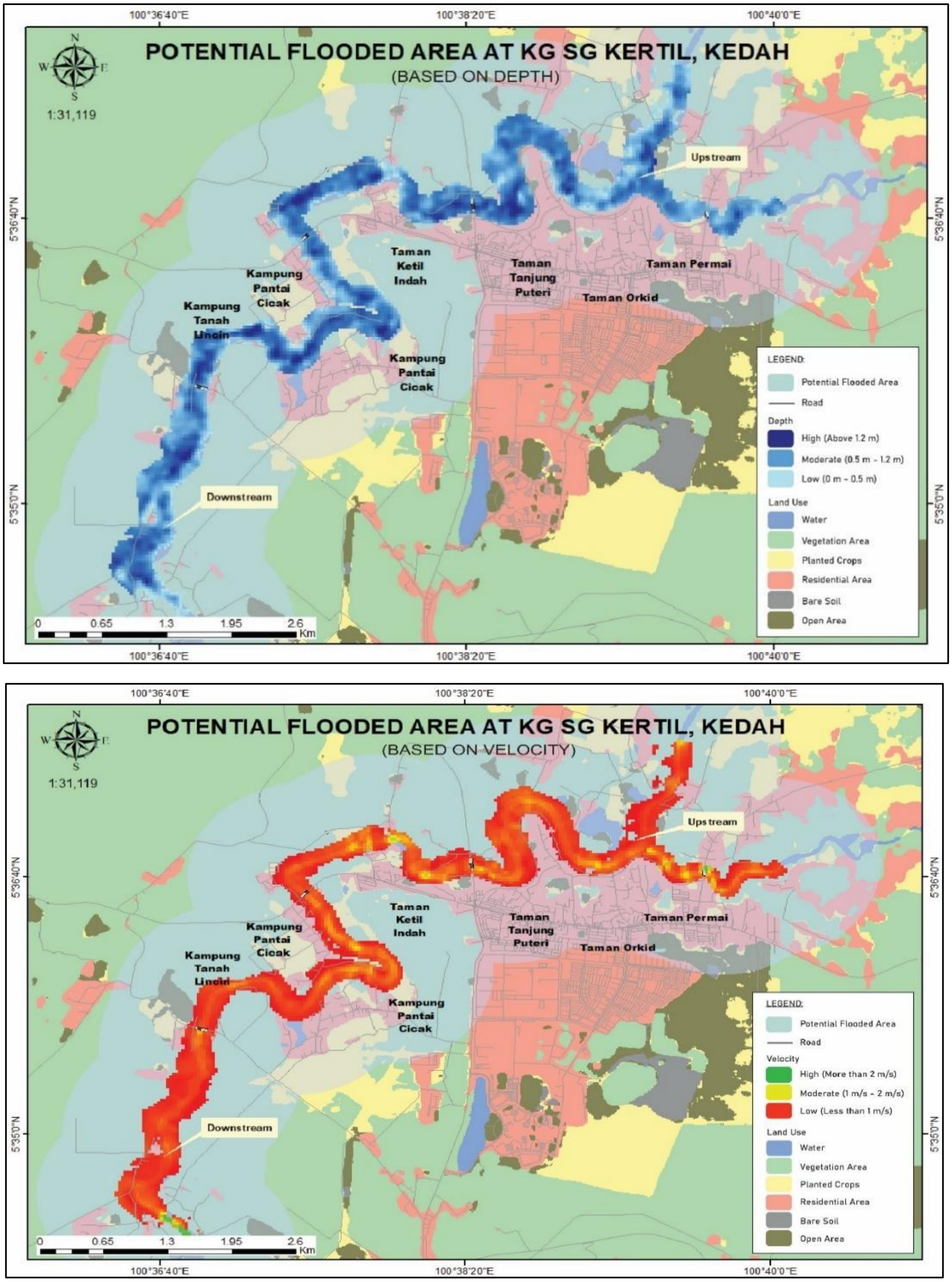

Figure 9: Possible flooded area according to velocity (top figure) and depth (bottom figure)

These results are subject to uncertainty due to model assumptions, input data resolution, and parameter selection, including Manning’s n and discharge values. The steady flow analysis provides an approximate estimate, so the exact flood extent should be interpreted as indicative rather than definitive.

5.0 Conclusion

The purpose of this study was to develop a flood modelling technique to effectively visualise anticipated flood levels in Kg. Sg Kertil, Kuala Muda, Kedah. In summary, the research successfully created a flood model using HEC-RAS to visualise local flood occurrences, providing insights into river behaviour and potential flood scenarios in the study area. However, it is important to interpret the results with caution, as the model has inherent limitations. These include uncertainties in input data accuracy, simplifications in representing complex hydraulic processes, assumptions in flow and roughness parameters, and the inability to fully account for extreme events or future climate variability. Such factors may lead to over- or under-estimation of flood extents and depths.

Overall, this research improves understanding of flood behaviour in Kg. Sg Kertil and demonstrates the utility of flood modelling and visualisation for local flood risk assessment. The findings highlight the importance of considering these limitations when using the results for decision-making. To enhance future flood modelling, the study recommends access to high-accuracy DEM data (e.g., LiDAR), historical and real-time meteo-hydrological data, uncertainty analysis, and scenario-based modelling that accounts for climate and land use changes. Implementing these recommendations would improve the reliability and applicability of flood models, supporting better flood management and mitigation strategies in the study area.

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Conflicts of Interest

The author declares that there is no conflict of interest regarding the publication of this paper.

References

Al-Omari, A. A., et al. (2024). Utilizing remote sensing and GIS techniques for flood hazard mapping and risk assessment. Civil Engineering Journal.

Berndtsson, R., Becker, P., Persson, A., Aspegren, H., Haghighatafshar, S., Jönsson, K., Larsson, R., Mobini, S., Mottaghi, M., Nilsson, J., Nordström, J., Pilesjö, P., Scholz, M., Sternudd, C., Sörensen, J., & Tussupova, K. (2019). Drivers of changing urban flood risk: A framework for action. Journal of Environmental Management, 240, 47–56. https://doi.org/10.1016/j.jenvman.2019.03.094

Brunner, G. W. (2021). HEC-RAS river analysis system user's manual (Version 6.0). Hydrologic Engineering Center, United States Army Corps of Engineers.

Costabile, P., Costanzo, C., De Lorenzo, G., De Santis, R., Penna, N., & Macchione, F. (2021). Terrestrial and airborne laser scanning and 2-D modelling for 3-D flood hazard maps in urban areas: New opportunities and perspectives. Environmental Modelling & Software, 135, 104889. https://doi.org/10.1016/j.envsoft.2020.104889

Department of Irrigation and Drainage Malaysia. (2017). National flood hazard mapping programme report. Ministry of Natural Resources and Environment Malaysia.

PLANMalaysia (Department of Town and Country Planning Malaysia). (2017). National physical plan 3 (NPP-3). Ministry of Housing and Local Government, Malaysia.

Dottori, F., Szewczyk, W., Ciscar, J. C., Zhao, F., Alfieri, L., Hirabayashi, Y., Bianchi, A., Mongelli, I., Frieler, K., Betts, R. A., & Feyen, L. (2018). Increased human and economic losses from river flooding with anthropogenic warming. Nature Climate Change, 8(9), 781–786. https://doi.org/10.1038/s41558-018-0257-z

El-Naqa, A., & Jaber, M. (2018). Floodplain analysis using ArcGIS, HEC-GeoRAS and HEC-RAS in Attarat Um Al-Ghudran oil shale concession area, Jordan. Journal of Civil & Environmental Engineering, 8, 323. https://doi.org/10.4172/2165-784X.1000323

Gao, L., Tao, B., Miao, Y., Zhang, L., Song, X., Ren, W., He, L., & Xu, X. (2019). A global data set for economic losses of extreme hydrological events during 1960–2014. Water Resources Research, 55(6), 5165–5175. https://doi.org/10.1029/2019WR025135

Guerreiro, S. B., Dawson, R. J., Kilsby, C., Lewis, E., & Ford, A. (2018). Future heat waves, droughts, and floods in 571 European cities. Environmental Research Letters, 13(3). https://doi.org/10.1088/1748-9326/aaaad3

Idris, R., et al. (2025). Catastrophic flood mapping: A geospatial analysis for strategic urban planning. Journal of Design and Built Environment.

Jongman, B., Ward, P. J., & Aerts, J. C. J. H. (2012). Global exposure to river and coastal flooding: Long-term trends and changes. Global Environmental Change, 22(4), 823–835. https://doi.org/10.1016/j.gloenvcha.2012.07.004

Karki, T. K. (2020). Flood resilience in Malaysian cities: A case study of two towns in Johor state. International Journal of Disaster Resilience in the Built Environment, 11(3), 329–342. https://doi.org/10.1108/IJDRBE-06-2019-0037

Kaoje, I. U., Abdul Rahman, M. Z., Idris, N. H., Tam, T. H., & Mohd Salleh, M. R. (2020). Physical flood vulnerability assessment of buildings in Kota Bharu, Malaysia: An indicator-based approach. International Journal of Disaster Resilience in the Built Environment, 12(4), 413–424. https://doi.org/10.1108/IJDRBE-05-2020-0046

Li, W., et al. (2025). 3D virtual geographic environment for flood risk communication.

Malaysian Meteorological Department. (2022). Climate and flood-related reports for Malaysia.

Najibi, N., & Devineni, N. (2018). Recent trends in the frequency and duration of global floods. Earth System Dynamics, 9(2), 757–783. https://doi.org/10.5194/esd-9-757-2018

National Disaster Management Agency. (2022). Annual disaster report 2021. Prime Minister's Department, Malaysia.

Oubennaceur, K., et al. (2021). Flood risk communication using ArcGIS StoryMaps. Hydrology, 8(4), 152.

Singh, S. K., et al. (2021). Flood risk modeling using HEC-RAS and geospatial techniques.

UK Environment Agency. (2006). Flood risks to people: Phase 2 (FD2321/TR2). Department for Environment, Food and Rural Affairs (DEFRA).

Vashist, K., & Singh, K. K. (2023). HEC-RAS 2D modeling for flood inundation mapping. Water Practice & Technology.

Winsemius, H. C., Aerts, J. C. J. H., Van Beek, L. P. H., Bierkens, M. F. P., Bouwman, A., Jongman, B., Kwadijk, J. C. J., Ligtvoet, W., Lucas, P. L., Van Vuuren, D. P., & Ward, P. J. (2016). Global drivers of future river flood risk. Nature Climate Change, 6(4), 381–385. https://doi.org/10.1038/nclimate2893

Zakaria, S. F., Zin, R. M., Mohamad, I., Balubaid, S., Mydin, S. H., & Mdr, E. M. R. (2017). The development of flood maps in Malaysia. AIP Conference Proceedings, 1903. https://doi.org/10.1063/1.5011632

Zischg, A. P., Hofer, P., Mosimann, M., Röthlisberger, V., Ramirez, J. A., Keiler, M., & Weingartner, R. (2018). Flood risk (d)evolution: Disentangling key drivers of flood risk change with a retro-model experiment. Science of the Total Environment, 639, 195–207.