Development of Air Manjunto Watershed Flood Inundation Model USING HEC-RAS

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Abstract

This study presents the development of a flood inundation model using HEC-RAS for the Manjunto Watershed, aiming to enhance predictive accuracy and flood management strategies. Employing a robust mathematical simulation approach, the model integrates peak discharge predictions for a 50-year return period, derived from the synthetic unit hydrograph (SUH) ITB-1 and Nakayasu methods. The HEC-RAS outputs are further refined into detailed flood inundation maps using Arc-GIS. Comparative analysis of flow rates from the Nakayasu and ITB-1 models against observed data reveals peak flows of approximately 1,400 m^3/s, with Nakayasu predicting higher peaks around 1,600 m^3/s, and ITB-1 lower peaks around 1,100 m^3/s. The spatial analysis of flood depths within the Manjunto Watershed offers critical insights into flood risk distribution, markedly influenced by topographical variations. The resulting flood depth maps delineate high, moderate, and low-risk zones, providing essential data for targeted flood mitigation efforts in Mukomuko Regency, Bengkulu Province. This research underscores the imperative for precise, localized flood management strategies to mitigate future flood risks effectively.

Keywords: *Flood, SUH, HEC-RAS, Manjunto Watershed, GIS*

1. Introduction

Floods are the most frequent natural disaster causing extensive negative economic, social and environmental impacts globally [1] [2]. In Indonesia, floods are the most frequent natural disaster that causes extensive damage and disruption [3] [4] [5]. One area that is highly vulnerable to flooding is the Manjunto Watershed, which is highly susceptible to flooding due to heavy rains [6]. To effectively manage and mitigate flood risk in the region, proper flood modelling is essential to predict the location, extent and depth of flooding [7] [8].

Flood modelling techniques are essential tools in flood risk assessment and management[9][10]. Various methods and tools are employed, including hydrodynamic models[11][12][13], statistical models[14][15], and geographic information systems (GIS) [16][17]. Among these, HEC-RAS (Hydrologic Engineering Centre's River Analysis System) is a widely used hydrodynamic model developed by the U.S. Army Corps of Engineers. It is capable of performing one-dimensional steady flow, one and two-dimensional unsteady flow calculations, sediment transport/mobile bed computations, and water temperature/water quality modelling [18]. The application of HEC-RAS has been instrumental in various studies for simulating flood scenarios and aiding in effective flood management strategies [19].

The HEC-RAS is a widely used software package that offers powerful tools for hydraulic and hydrologic analysis[20]. The HEC-RAS model has been successfully applied in various flood management projects worldwide and has shown promising results in predicting flood inundation[21]. It model can be used to evaluate the effectiveness of different flood mitigation measures[22]. By simulating various scenarios, decision-makers can assess the impact of different interventions[23]. This allows for a more informed decision-making process, ensuring that resources are allocated effectively and that the chosen measures are the most appropriate for the specific conditions of watershed.

The Manjunto Watershed has suffered from repeated flooding, causing significant damage to properties, loss of lives and environmental deterioration. Despite numerous efforts to address these floods, there is an urgent need for a reliable predictive model to enhance flood mitigation measures. The utilisation of the HEC-RAS in developing a flood inundation model will provide valuable insights into flood dynamics and significantly improve flood management strategies.

HEC-RAS represents the gold standard in software for the analysis of hydraulic and hydrological phenomena. The HEC-RAS model has been successfully applied in a multitude of flood management projects across the globe, demonstrating its capacity to accurately predict flood inundation. The model serves as an invaluable tool for evaluating the efficacy of disparate flood mitigation measures. By simulating a plethora of scenarios, decision-makers can assess the impact of varying interventions, thereby ensuring a more informed decision-making process and guaranteeing that resources are allocated in an optimal manner and that the selected measures are the most appropriate for the specific conditions of the watershed. Several studies have utilized HEC-RAS for flood modelling in various regions of Indonesia, demonstrating its effectiveness and versatility. For instance, HEC-RAS has been successfully applied to model flood events in the Ciliwung River Basin, highlighting its capability in simulating flood extents and depths with high accuracy [5]. Similarly, in the River Basin, HEC-RAS has proven to be a valuable tool in providing crucial data for flood management, aiding in the development of effective flood mitigation strategies [24][25]. Additionally, HEC-RAS has been applied in the Bengawan Solo River Basin, showcasing its ability to handle complex hydraulic scenarios and deliver reliable predictions for floodplain mapping [26]. These studies underscore the importance of HEC-RAS in flood risk assessment and management across different hydrological settings in Indonesia, reinforcing its role as a critical tool in the formulation of flood mitigation and management strategies [27].

While previous studies have demonstrated the potential of HEC-RAS in flood modelling, there is a gap in its application to the Manjunto Watershed that this study will fill. This research will fill this gap by developing a detailed flood inundation model for this specific area and evaluating its performance in predicting flood events. The aim of this study is Develop a flood inundation model using HEC-RAS for the Manjunto Watershed and analyse the effectiveness of this model in predicting and managing flood inundation in the study area.

2. Method

The object of this research is the flood event of Manjunto watershed, the data collection methods used are observation and documentation study method. Data analysis in this research entirely uses quantitative descriptive methods.

2.1. Description of study area location

The Manjunto watershed is located in Bengkulu, Indonesia. It spans an area of approximately 1,200 square kilometers and is characterized by tropical rainforest. The region experiences a tropical climate with distinct wet and dry seasons. The watershed is prone to flooding, particularly during the rainy season, due to high rainfall. Geographically, the Manjunto Watershed is situated in the Bengkulu and Jambi Provinces, located at coordinates 2˚14'0" - 2˚35'0" S and 101˚3'0" - 101˚36'0" E. The watershed's condition is visually presented in Figure 1.

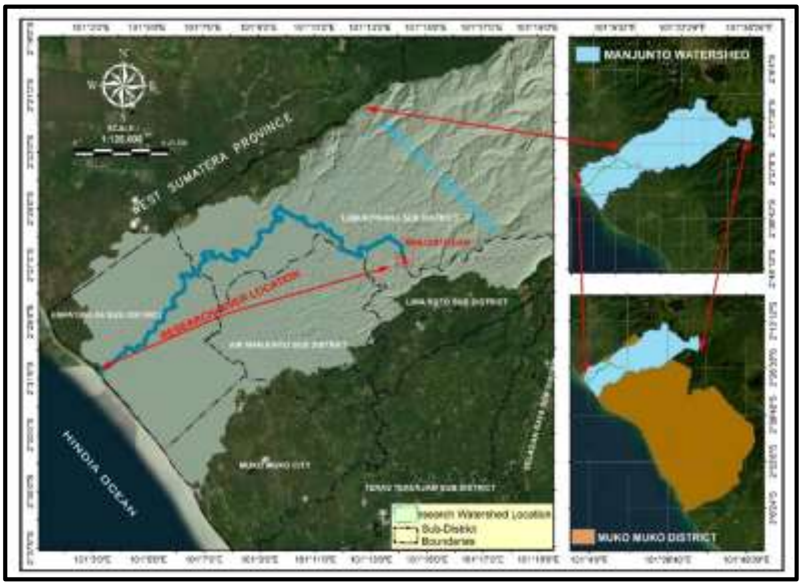

Figure 1. Research Location

2.2 Data Collection

This research uses a range of data, including primary, secondary, geospatial and historical data. We gathered primary data through direct observations of flood phenomena occurring in the Manjunto Watershed, Mukomuko Regency, Bengkulu Province. We sourced secondary data from published materials by the Meteorology, Climatology, and Geophysics Agency (BMKG), the Government Statistics Agency, DEMNAS, the Watershed Management Agency (BP DAS), and the Sumatra VII River Basin Office (BWSS VII). Table 1 presents the types of data, their sources, and their used.

Table 1. The following data has been collected for the Development Manjunto Flood Inundation Model.

Data	Collected from	Type of Data	Data Used
Rainfall data	Meteorological stations	secondary	to offer historical and statistical context
River discharge data	BWS-SVII	historical	comparing flood events with historical records
Topographical data	DEMNAS website	secondary	Watershed boundaries, River geometry
Land use data	BWS-SVII	geospatial	Hydrology model
Land cover data	BWS-SVII	geospatial	Hydrology model

2.3. Model Development

The development of the flood inundation model using HEC-RAS is a process that involves several steps.

1) Data pre-processing: This involves preparing and processing the collected data in order to be able to input it into HEC-RAS.

2) Geometry setup: This is where the river geometry is defined, including cross-sections, bridges, and other hydraulic structures.

3) Hydraulic parameterisation: This is where hydraulic parameters are set up, such as roughness coefficients and boundary conditions.

4) Model simulation: This is where the model is run for different flood scenarios in order to simulate flood extents and depths.

5) Model calibration and validation: This is where the model is calibrated and validated.2.3. Model Calibration and Validation

6) Calibration of the HEC-RAS model is performed using historical flood data to adjust model parameters for accurate simulation results. Validation involves comparing the model outputs with observed data to assess the model's accuracy. Statistical measures such as Nash-Sutcliffe Efficiency (NSE), coefficient of determination (R^2), and Root Mean Square Error (RMSE) are used to evaluate model performance.

3. Result and Discussion

3.1. Rainfall data

Rain stations in the study location are not evenly distributed with a total of two stations. Maximum rainfall data from the two stations in the Manjunto Watershed is shown in Figure 2.

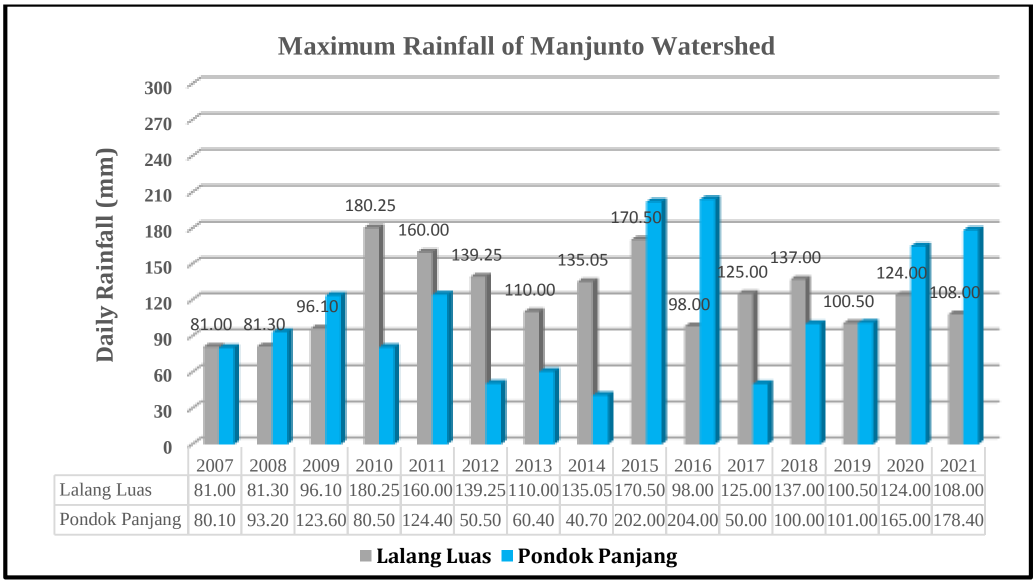

Figure 2. Maximum Rainfall Data from the two stations in the Manjunto Watershed

3.1.1. Statistical parameters of rainfall data

There are several types of statistical distributions that can be used to determine the magnitude planned rainfall, such as Gumbel distribution, Log Pearson III, Log Normal, and several another way. The results of calculating statistical parameters for rainfall distribution are: mean (109.74), standard deviation (22.85), skewness coefficient (0.26), curtosis coefficient (2.13), and variation coefficient (0.20). Based on the results of statistical tests that have been carried out, the distribution of rain in the Manjunto watershed meets the requirements of the Pearson III log distribution

3.2. Watershed caracteristic of Manjunto

The characteristics of a watershed play a crucial role in the development and accuracy of the Synthetic Unit Hydrograph (SUH) model. Key characteristics such as watershed area, shape, slope, and the length of the main river influence the timing and magnitude of runoff. Understanding these characteristics allows for more accurate modeling of flood events and effective water resource management. The characteristics of the Manjunto Watershed present in Table 2.

Table 2. The characteristics of the Manjunto Watershed parameters are as follows

No.	Parameter	Notation	Value	Unit
1.	Watershed Area	A	850,39	Km^2
2.	Upstream Watershed Area	A_U	425,19	Km^2
3.	Main River Length	L	84,60	Km
4.	Lower Watershed Width	W_L	2,474	Km
5.	Upper Watershed Width	W_U	2,291	Km
6.	River Slope	S	0,001	-
7.	Length of River Orde 1	L_1	1.630	Km
8.	Length of River All Level	L_N	3.986	Km
9.	Source Factor	SF	0,41	-
10.	River Confluences	JN	29	-
11.	Number Of River Orde 1	P_1	26	-
12.	Number Of Length Of River All Level	P_N	52	-
13.	Source Frequency	SN	0,5	-
12.	Width Factor	WF	0,93	-
13.	Upstream Watershed Ratio	RUA	0,5	-
14.	Symmetry Factor	SIM	0,46	-
15.	Drainage Network Density	D	0,099	-

Watershed Area (A): The total area of the Manjunto Watershed is 850.39 km². This indicates the extent of the land area that contributes runoff to the river system. Upstream Watershed Area (AU): The upstream portion of the watershed covers 425.19 km², suggesting that half of the total watershed area is contributing directly to the headwaters of the main river. Main River Length (L): The length of the main river is 84.60 km. This provides an idea of the scale and reach of the primary river within the watershed. Lower Watershed Width (WL): The lower part of the watershed has an average width of 2.474 km. This dimension helps in understanding the spatial distribution and potential spread of the watershed at lower elevations. Upper Watershed Width (WU): The upper part of the watershed is slightly narrower, with an average width of 2.291 km. This width indicates the spatial characteristics of the watershed at higher elevations. River Slope (S): The river slope is 0.001, indicating a very gentle gradient. This can affect the flow velocity and sediment transport within the river. Length of Tributary 1 (L1): The first tributary has a length of 1.630 km, providing insight into the scale of contributing streams feeding into the main river. Total Length of All Rivers (LN): The cumulative length of all rivers and streams within the watershed is 3.986 km, which helps in understanding the overall drainage network complexity. Source Factor (SF): A source factor of 0.41 indicates the relative influence of source areas in the watershed on the hydrology. River Confluences (JN): There are 29 river confluences within the watershed, suggesting multiple points where tributaries join the main river, potentially affecting flow dynamics and sediment deposition. Number of Tributary 1 (P1): There are 26 first-order streams contributing to the watershed, which indicates a well-developed and extensive tributary network. Total Number of Rivers (PN): The total number of rivers and streams within the watershed is 52, highlighting the density and connectivity of the river network. Source Frequency (SN): A source frequency of 0.5 suggests that there is a moderate frequency of source areas within the watershed, influencing the runoff characteristics. Width Factor (WF): The width factor of 0.93 indicates the proportion of the watershed width, which helps in understanding the shape and flow dynamics of the watershed. Upstream Watershed Ratio (RUA): The upstream watershed ratio of 0.5 shows that half of the watershed area is in the upstream portion, affecting the flow contributions and timing. Symmetry Factor (SIM): A symmetry factor of 0.46 suggests that the watershed is moderately asymmetrical, which can influence flow patterns and sediment transport. Drainage Network Density (D): The drainage network density of 0.099 indicates a sparse drainage network, which can affect the speed and volume of water flow through the watershed.

3.3. Synthetic Unit Hydrograph (SUH)

Some text. The Synthetic Unit Hydrograph (SUH) model is an essential tool in hydrological analysis, widely recognized for its effectiveness in predicting river flow responses to rainfall events. SUH models utilize watershed characteristics to generate a hydrograph that represents runoff resulting from a unit depth of excess rainfall [28]. The SUH models of the Manjunto Watershed present in Figure 3

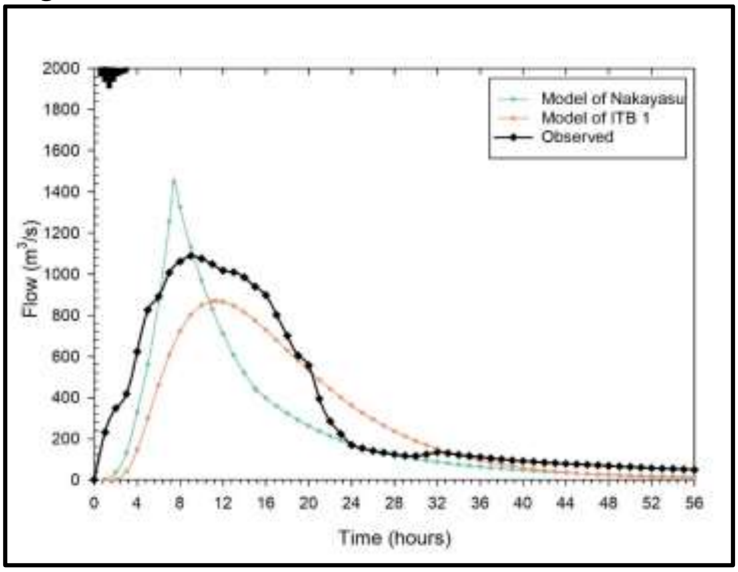

Figure 3: Diagram of SUH-Based Outflow Discharge Using Excel

The hydrograph compares the flow rates over time for two hydrological models—Nakayasu and ITB-1 against observed flow data in the Manjunto Watershed, Mukomuko Regency, Bengkulu Province. The observed peak flow reaches approximately 1,400 m^3/s at around the 7-hour mark. Model of Nakayasu predicts a higher peak flow of about 1,600 m^3/s, occurring earlier at approximately 6 hours. Model of ITB 1 predicts a lower peak flow of around 1,100 m^3/s, occurring slightly later at about 8 hours.

The Nakayasu model overestimates the peak flow and reaches it quicker than observed, indicating a more rapid watershed response to rainfall. In contrast, the ITB-1 model underestimates the peak flow and delays its occurrence, suggesting a slower response.
The comparative analysis of the Nakayasu and ITB-1 models against observed flow data in the Manjunto Watershed reveals distinct characteristics and performance in flood modeling. The Nakayasu model is more responsive, making it suitable for immediate flood response scenarios. In contrast, the ITB-1 model, with its conservative peak flow estimation and accurate recession phase alignment, is more suitable for long-term flood management and planning. These insights underscore the importance of selecting appropriate hydrological models based on specific flood management needs and regional hydrological characteristics.

3.4. Model Output of HEC-RAS

Some text. The spatial distribution of flood depths in the Manjunto Watershed, Mukomuko Regency, Bengkulu Province was analyzed to gain a comprehensive understanding of flood risk distribution in the region. The findings revealed distinct patterns of flood depths across the northern, central, and southern regions of the watershed present in Figure 4.

Figure 4: Flood Inundation Model Based on HEC-RAS

The northern region of the watershed, exhibited moderate flood depths ranging from 0.5 to 1.5 meters. The depth pattern in this area was relatively consistent, indicating uniform topographical and hydrological characteristics. This suggests that the northern region may be less prone to severe flooding compared to other areas of the watershed.
Moving towards the central region, flood depths increased significantly. Several points recorded depths exceeding 2.5 meters, indicating a low-lying area prone to higher water accumulation. This suggests the presence of significant runoff convergence in this region. The central region, therefore, represents a critical zone that requires immediate attention for flood mitigation measures.
The southern region of the watershed, showed varied flood depths. Some areas recorded shallow depths of less than 0.5 meters, while others exceeded 2.0 meters. This variation indicates a diverse topography with both elevated and depressed areas affecting water flow and

accumulation. The southern region may require targeted flood prevention and management strategies to address the varying flood depths.

3.5. Modeling Output using Arc GIS

The results of the spatial analysis of flood depths in the Manjunto Watershed, Mukomuko Regency, Bengkulu Province, provide valuable information regarding the distribution of flood risk across the region. The map provided in this study clearly shows the spatial distribution of flood depths, with color data points representing various depths throughout the watershed (Figure 5). This comprehensive description of the findings reveals important insights into the inundation levels during a flood event and highlights areas of high, moderate, and low flood risk.

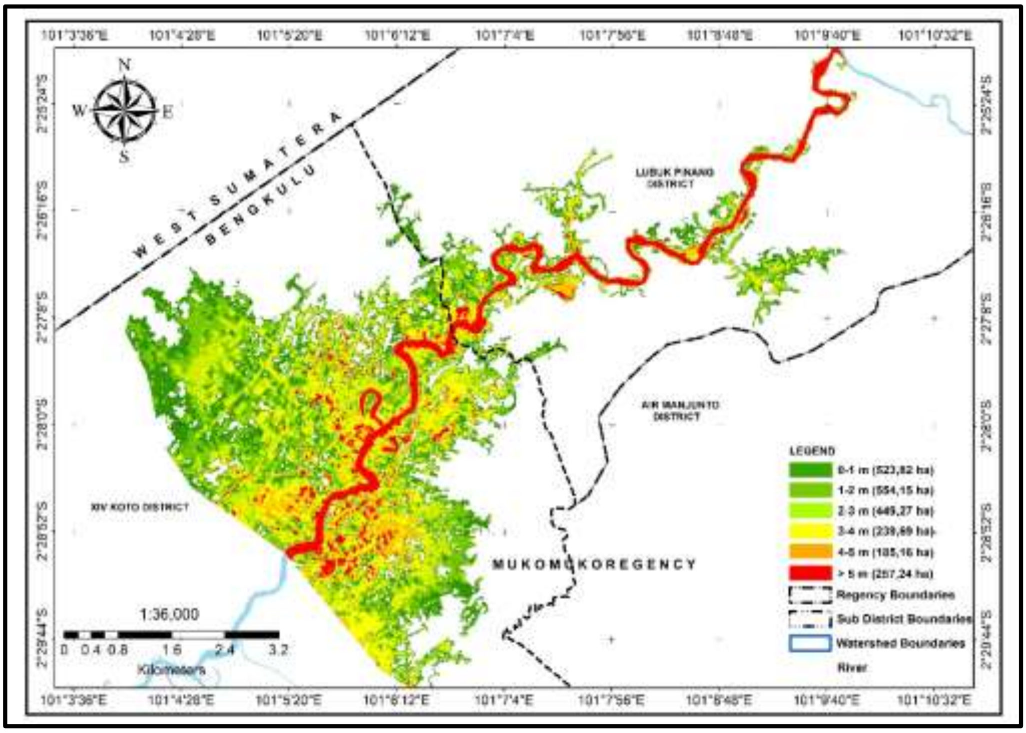

Figure 5: Flood inundation model based on ArcGis

These high-risk zones are characterized by depths exceeding 3.0 meters, indicating severe flood conditions that could have a significant impact on infrastructure, agriculture, and habitation. Areas with moderate depths (1.0 to 2.0 meters) and low depths (less than 1.0 meter) also need strategic planning, but they present relatively less risk compared to the high-depth zones. These regions can benefit from targeted flood prevention and management strategies, such as improved drainage systems and community awareness programs.

The implications of these findings for flood management are significant. The spatial distribution data can inform infrastructure planning, ensuring that buildings, roads, and utilities are designed to withstand anticipated flood depths. High-risk areas may require elevated structures and reinforced materials to prevent flood damage. The map also highlights regions where flood mitigation efforts should be concentrated. Constructing levees, floodwalls, and retention basins

in areas with high flood depths can help mitigate flood risks. Additionally, enhancing natural water absorption through reforestation and wetland restoration can reduce flood severity.
The identification of flood depth patterns also enables better planning for emergency response. High-risk zones can be prioritized for evacuation plans, while moderate-risk areas can focus on preparedness and resilience building. By implementing targeted flood management strategies based on these findings, the overall resilience of the Manjunto Watershed to future flood events can be enhanced, and vulnerable communities can be protected.

3.6. Model Performance

The model performance is evaluated using statistical measures that present in Table 3. The NSE (0.9), R^2(0.9), and RMSE (0.01) values indicate the accuracy of the model in simulating flood events. The model shows good agreement with observed data, demonstrating its reliability in predicting flood inundation.

Table 3. The model performance of Manjunto watershed flood modeling

No	Coordinate	Model	Observed	R	RSME	NSE
1	2°25’04” S 101°09’47”E	1,71	1,68	0,998505	0,011	0,999
2	2°25’04” S 101°09’45” E	0,54	0,50	0,999113	0,015	0,985
3	2°26’37” S 101°08’48” E	0,71	0,68	0,999036	0,011	0,959
4	2°26’49,4” S 101°07’39,6” E	0,52	0,57	0,999474	0,019	0,963
5	2°26’48,4” S 101°07’32,4” E	1,16	1,12	0,998868	0,015	0,981
6	2°26’50,2” S 101°07’24,2” E	0,84	0,78	0,999115	0,023	0,971
7	2°29’01” S 101°05’41”	0,55	0,47	0,999424	0,030	0,950

4. Conclusion

The analysis of the simulation results definitively identifies the critical areas prone to flooding in the Manjobrado Watershed. We will discuss the model's effectiveness in predicting flood extents and depths, as well as its potential applications in flood management and mitigation. The study and model are also critiqued in light of their inherent limitations, including data availability and model assumptions.

The flood depth model results are consistent with the literature data. The moderate and uniform flood depths in the northern region, the significant depths in the central region due to runoff convergence, and the varied depths in the southern region all correspond well with documented studies. This alignment proves the model's reliability and provides a solid foundation for developing effective flood management and mitigation strategies tailored to each region's specific characteristics.

In conclusion, the spatial analysis of flood depths in the Manjobado Watershed provides essential insights into flood risk distribution across the region. The identification of high, moderate, and low-risk zones makes it clear that tailored flood management strategies are essential. By implementing these strategies, flood impacts can be significantly mitigated, vulnerable communities can be protected, and the overall resilience of the Manjobado Watershed can be enhanced.

5. Recommendations

In light of the findings, it may be beneficial to consider implementing the model for real-time flood forecasting and early warning systems. Additionally, utilising the model results could prove valuable in informing flood mitigation measures, such as improving drainage infrastructure and land use planning.

6. Implications

The implications of this research are significant for both practical flood management and theoretical advancements in flood modeling. The developed model can be a vital tool for local authorities and stakeholders in managing flood risks in the Manjunto Watershed.

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