Geographia Technica, Vol. 18, Issue 2, 2023, pp 1 to 13

2D SIMULATION OF DESIGN DISCHARGE IN FLOOD HAZARD SPATIAL ANALYSIS USING HEC-RAS, (CASE STUDY MATA ALLO SUB-WATERSHED, ENREKANG, INDONESIA)

Uca SIDENG[1*], Hamzah UPU[2], Nurul Afdal HARIS[1], Dwi RAHMAYANA[1]

DOI: 10.21163/GT_2023.182.01

ABSTRACT:
Indonesia is one of the countries frequently hit by hydrometeorological disasters. Flood is one of the disasters that often occurs in Indonesia. Especially for the Enrekang area which is traversed by the Mata Allo River. With topographical characteristics and land use that has the potential to cause flooding and high rainfall. It will harm activities in the watershed area. In reducing the impact that occurs, it is necessary to identify and map flood-prone areas as initial information on flood control. This study aims to determine the distribution and level of vulnerability to flooding in the Mata Allo sub-watershed using 2D HEC-RAS simulations. By utilizing annual rainfall data, the Nakayasu HSU method is applied to generate design discharge values to be used in flood simulations. The simulation results show that there are five classes of flood hazard levels which show the uniformity of flood vulnerability levels in each return period. The average level of vulnerability is in the very low range of ±9.60 Ha, in the low range of ±8.8 Ha, medium vulnerability is in the range of ±13.63 Ha, high vulnerability is ±23.58 Ha, and extreme vulnerability is ± 25.71 Ha. The area that is mapped is an area that is often affected when a flood occurs. As a result, the use of this approach can provide an overview of the distribution of flood-prone areas.

Key-words: *spatial analysis, flood, Nakayasu HSU, discharge, simulation.*

1. INTRODUCTION

Natural disasters are phenomena significantly impacting either the natural environment or human, with a high chance of damage (Popescu and Bărbulescu, 2023). Indonesia is a country with high potential for natural disasters, influenced by geological conditions and climatic factors (Rauf, 2021). Indonesia's National Disaster Management Agency noted throughout 2022 that natural disasters in Indonesia had occurred ± 2,111 times, be it extreme weather, landslides, drought, earthquakes, fires, tidal waves, abrasion, and floods. In the period of natural disasters that occurred, it was also explained that floods were the most dominant of the other natural disasters that occurred (BNPB, 2022).

Flooding is a condition where a land is submerged because the amount of surface runoff exceeds the capacity of the drainage system (Kodoatie, 2013), often occurring in several areas every rainy season (Pratiwi and Santosa, 2021). Through this situation, it also causes huge losses and even casualties. South Sulawesi Province is an area in Indonesia with a high risk of flood vulnerability, which has a disaster index of 154.87 (BNPB, 2022). Of the several districts/cities that Included in the list of flood-prone areas in the high vulnerability level, Enrekang Regency is one of those that has a high risk of flood vulnerability during 2020-2021. This is based on the convergence of the main sub-watersheds of the Saddang watershed, namely the Saddang sub-watershed and the Mata Allo sub-watershed. These two sub-watersheds meet in the capital of Enrekang Regency and flooding often occurs (Uca *et al.*, 2021). In responding to an area that is prone to a disaster, Flood disaster management efforts need to be made. One of the efforts in flood disaster management is the provision of information about flood risk hazards, especially related to the potential distribution of floods that are expected to occur in an area.

[1] *Geography Department, Faculty of Mathematics and Natural Science, State University of Makassar, Makassar, Indonesia, corresponding author ucasideng@unm.ac.id, nurul.afdal.haris@mail.ugm.ac.id, 200110500007@student.unm.ac.id*
[2] *Mathematic Department, Faculty of Mathematics and Natural Science, State University of Makassar, Makassar, Indonesia, hamzahupu@gmail.com*

The level of regional vulnerability to flooding can be determined by spatial modeling of floods through a review or determined from the prone aspects of flood disasters (Rauf, 2021). The flood prone index is then used to determine the level of disaster vulnerability, which consists of 2 main components, namely the likelihood of a disaster occurring and the magnitude of the disaster impact that occurs.

Geographic Information System (GIS) is one of the evidences or results of the increasing advancement of information and computer technology in supporting spatial analysis (Rajeev and Singh, 2016). The use of this technology has been widely used in modeling hydrological mechanisms (Avinash, Jayappa and Deepika, 2011) such as the level of vulnerability of a disaster and prediction of watershed overflow through hydraulics modeling. The capacity to simulate flood hazard maps is particularly strong when GIS and HEC-RAS (Hydrologic Engineering Center-River Analysis System) are combined. HEC-RAS was created for the management of floodplains and studies evaluating flood inundation, and it can analyze changes to river water and channel profiles (US Army Coprs of Engineers, 2016). The assessment of hydrological issues, including flooding, as well as modeling watershed-related issues can both be aided by this application (Sabău and Şerban, 2018; Kim, Tantanee and Suparta, 2020). Over the past decades, many hydraulics models have been developed (Lea, Yeonsu and Hyunuk, 2019). Hydraulic modeling takes into account the prediction of peak discharge and the shape of the flood hydrograph on the river water surface (Bomers *et al.*, 2019). The use of several software such as HEC-RAS is one form of hydraulic model development to address hydraulic problems in detail (Bomers, Schielen and Hulscher, 2019). HEC-RAS is intended for processing geospatial data, and makes it easy for users to create files containing geometric data, and the results of the formed water surface profile can be used and interpreted in determining the depth and extent of flooding (Ahmad *et al.*, 2022). Hydraulic modeling through HEC-RAS can be interpreted into 2-D modeling, the resulting simulation also provides a more accurate average depth value (Ngo *et al.*, 2023).

Efforts to visualize flood events, integration between 2D HEC-RAS simulations and Geographic Information Systems (GIS) have been applied almost all over the world in an effort to develop mitigation strategies (Liu, Merwade and Jafarzadegan, 2019), also applicable to the Saddang watershed area (Mata Allo sub-watershed). Previous research that also applies hydrological modeling such as in surface flow calculations (Haidu and Ivan, 2016), flood simulation (Popescu and Bărbulescu, 2023) and curve number calculation (Khaddor and Alaoui, 2014). This study's aim is to figure out the distribution of flooded areas using simulation results and design discharge analysis in view of the background information. to gather information on the spatial distribution of flood hazard. This is crucial to do as a first step in providing details or an overview of places that are vulnerable to floods and at high risk. As an additional early warning system for the surrounding community.

2. STUDY AREA

This research is located in the Saddang River basin, Mata Allo Sub-watershed located in Enrekang District, Enrekang Regency, South Sulawesi Province (**Fig. 1**). Enrekang regency is located between 3°14'–3°50'S and 119°40'-120°06'E. The Mata Allo sub-watershed is 4.81 km long from upstream (H1) to downstream (H2) as can be seen in Figure 1 below. The location of this study was determined because the area often experiences flooding. One of the causes is a change in land use in the upstream area which causes the rapid concentration of surface runoff into the river area. as well as a confluence with the Saddang river in the downstream area, thus enabling an increase in water volume in the area.

3. DATA AND METHODS

To achieve the objectives of this research, data is needed that can be formed to present a river cross-section model. As well as rainfall data within a period of 10 years to produce river discharge data. The data used to obtain the data are described as follows (a) and (b):

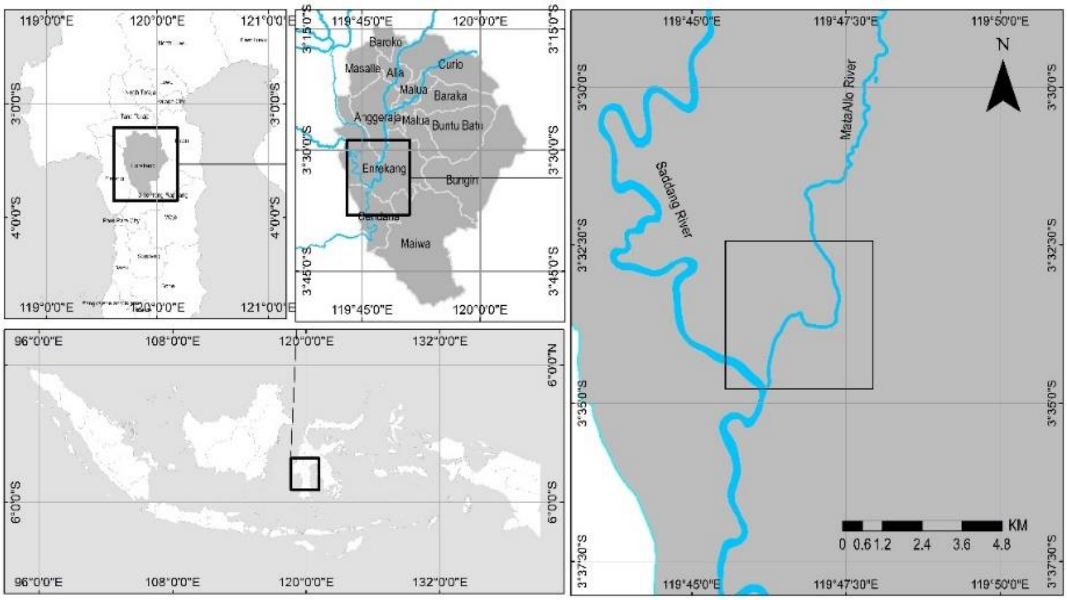

Fig. 1. Map of the Study Area.

a) DEM (Digital Elevation Model) data with 8.2m resolution, obtained from the Geospatial Information Agency (https://tanahair.indonesia.go.id/) was used as the basis for river geometry (Pathan and Agnihotri, 2020). With this resolution DEM data will be able to provide a more detailed formation for the scale of mapping used. So that the results given are close to the real conditions in the field.
b) Rainfall data (2012 to 2021) was obtained from the Climate Hazards Group InfraRed Precipitation with Station (CHIRPS) through the Google Earth Engine (GEE) platform (https://earthengine.google.com/). CHIRPS itself provides daily rainfall data at 0.05° spatial resolution since 1981 to the present, and users can use it for free. CHIRPS data shows good potential accuracy for use in meteorological studies and research related to water resources (Geleta and Deressa, 2021). The rainfall data used has gone through an interpolation process in GEE to cover the study area. In addition, CHIRPS rainfall data can improve the accuracy of runoff and river flow simulations for hydrological modeling (Le and Pricope, 2017)

The data that has been collected is then processed using ArcGIS, HEC-RAS, Matlab Aprob_41, Microsoft Office software.

The stages of data processing and analysis are described as follows (1), (2), (3) and (4):

1) The design rainfall was analyzed according to Triatmodjo (2013) which includes the calculation of standard deviation (s), coefficient of variation (Cv), slope coefficient (Cs), and kurtosis coefficient (Ck). The precipitation period uses return periods of 2, 10, 25, 50 and 100 years. The Gumbel, Normal, Normal Log, , and Pearson III methods were used in analyzing the frequency distribution (Harahap, Jeumpa and Hadibroto, 2018). Distribution matching includes analysis of Chi-Square test and Smirnov-Kolmogorov test using Matlab AProb_41 software. From the results of the frequency analysis and the Chi-Square and Smirnov-Kolmogorov tests, the distribution type with the lowest Smirnov-Kolmogorov test value and passing the Chi-Square test was selected for use in further analysis (Steele, Chaseline and Hurst, 2006).
2) The calculation of the unit hydrograph is to determine the peak flow based on the maximum rainfall data that occurs in the study area. The Nakayasu HSU (Hydrograf Synthetic Unit) method was used in this study to analyze the peak flow as input from the river flow simulation using the HEC-RAS software. Because the Nakayasu HSU method, in calculating the total

flood discharge also considers the effective rainfall and baseflow discharge (Harahap, Jeumpa and Hadibroto, 2018; Prastica and Fanani, 2021). Thus, the return period flood discharge is the result of the total discharge from multiplying the ordinate of the Nakayasu HSU unit to the effective rainfall distribution which is then summed up with the base flow discharge.
We present below the formulas that are the basis of the study.

Nakayasu HSU formula:

$$Q_p = \frac{1}{3{,}6}\left(\frac{A\,Ro}{0{,}3T_p + T_{0,3}}\right) \tag{1}$$

$$T_p = t_g + 0{,}8T_r \tag{2}$$

$$t_g = 0{,}4 + 0{,}058L \text{ (for L>15km)} \tag{3}$$

$$t_g = 0{,}2L^{0,7} \text{ (for L<15km)} \tag{4}$$

$$T_{0,3} = \alpha t_g \tag{5}$$

$$t_r = 0{,}5t_g \text{ to } t_g \tag{6}$$

where:

- Qp - peak flood discharge
- A - watershed area (km^2)
- Ro - effective rainfall (1mm)
- Tp - time from the beginning of the flood to the peak of the hydrograph (hours)
- $T_{0,3}$ - time from the flood peak to 0.3 times to peak discharge (hours)
- t_g - time of concentration (hours)
- t_r - time unit of rainfall (hours)
- α - watershed characteristic coefficient (between 1,5 – 3)
- L - main river length (km)

Nakayasu HSU Unit Ordinate Formula:

The curve rises when $0 < t < T_p$

$$Q_a = Q_P \times \left(\frac{t}{T_P}\right)^{2,4} \tag{7}$$

Descending curve $T_P < t < T_{0,3}+T_P$

$$Q_{d1} = Q_P \times (0{,}3)^{\frac{(t-T_P)}{T_{0,3}}} \tag{8}$$

$$Q_{d2} = Q_P \times (0{,}3)^{\frac{(t-T_P)+(0{,}5T_{0,3})}{1{,}5T_{0,3}}} \tag{9}$$

$$Q_{d3} = Q_P \times (0{,}3)^{\frac{(t-T_P)+(1{,}5T_{0,3})}{2{,}0T_{0,3}}} \tag{10}$$

Effective rainfall formula:

$$R_e = R_h \times C \tag{11}$$

where:

- Re - Effective rainfall
- Rh - Probability of daily rainfall from Log Pearson III plan rainfall calculation analysis
- C - Flow coefficient total

Flood discharge formula:

$$Q_T = (\sum_{t=1}^{n} U_t \times Re) + Q_B \quad (12)$$

where:

Q_T - total flood discharge
Ut - hydrograph ordinate (Qa, Qd1, Qd2, Qd3)
Re - effective rainfall
QB - base flow discharge

3) Hydrological modeling is carried out using the HEC-RAS application with a 2D model. The 2D hydraulic modeling in question is a model that has two flow directions consisting of flow directions along the main channel and flow directions around the main stream (Indrawan and Siregar, 2018). The continuity equation is used as an unsteady flow simulation using the assumption that the water flow varies with time. The continuity equation (conservation of mass principle) can be written in the form of a partial differential equation.

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} - ql = 0 \quad (13)$$

where:

A - total cross-sectional area of the stream
Q - flow discharge
ql - lateral discharge of unity length
x - distance measured in the direction of flow
t - time

In the simulation on the HEC-RAS program, the Manning roughness coefficient data is needed to provide the influence of the channel bed surface conditions. The determination of the Manning's roughness coefficient is based on field observations of the characteristics of the Mata Allo sub-watershed study site. The river has a rocky bottom along the flow, especially in the lower reaches of the river and there is little vegetation. The Manning coefficient value is adjusted to the value issued by Gray, 1973. So that the Manning roughness coefficient used based on the characteristics of the study area is 0.05 (Gray, 1973; Liu, Merwade and Jafarzadegan, 2019).

4) The 2D simulation data in the form of inundation depth values is then used to identify flood hazards. The discharge results obtained from the calculation of the design discharge are then used as input to the HEC-RAS program in simulating river flow or flooding at certain return times (**Fig. 2**). Using the previous DEM data, river geometry data in the study area can be generated. This is then used as the basis for the river discharge flow analysis model. The simulation is carried out on the Unsteady Flow model because the inputted discharge is not a fixed flow (Gray, 1973; US Army Coprs of Engineers, 2016; Albo-Salih, Mays and Che, 2022). **Table 1** below presents the depth class in the spatial analysis of flood hazard.

Table 1.

Classification of Flood Hazard Levels Based on Depth.

No	Depth Interval (m)	Hazard Level
1	< 0,50	Very Low
2	0,50 – 1,00	Low
3	1,00 – 2,00	Medium
4	2,00 – 5,00	High
5	>5,00	Extreme

Source: (Ahmad et al., 2022)

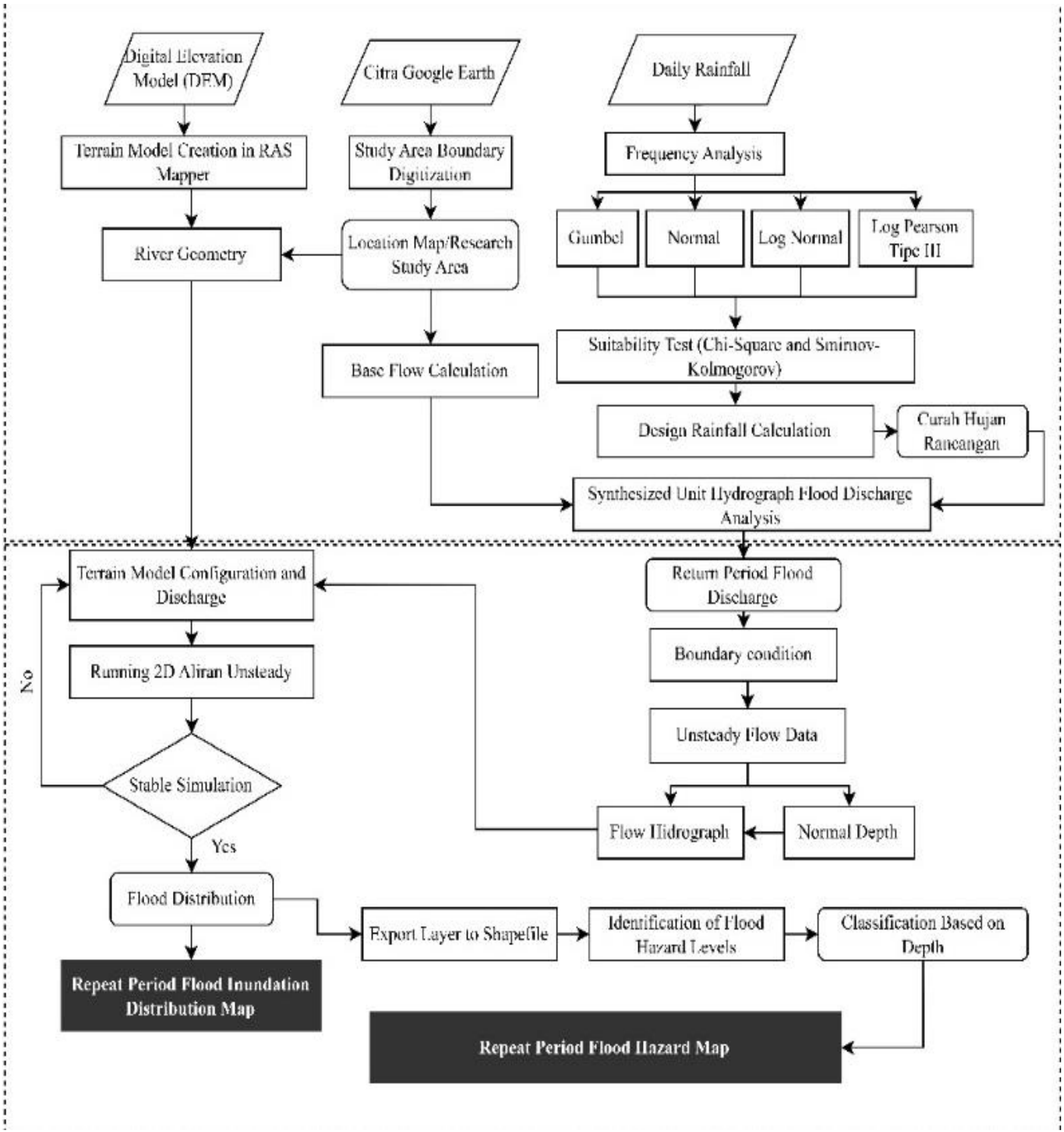

Fig. 2. Flow Chart of 2D Flow Modelling Simulation.

4. RESULTS AND DISCUSSIONS

4.1 Frequency of Rainfall

Calculation of the frequency of rainfall using maximum daily rainfall data in units of 24 hours/mm, as the design rain value (**Fig. 3**). From this data, statistical parameter calculations are carried out in calculating the dispersion value (Amin, Izwan and Alazba, 2016).

In measuring dispersion to obtain statistical parameters, the Normal Distribution, Gumbel, Normal Log, and Log Pearson III were calculated (Ben Khalfallah and Saidi, 2018; Rauf, 2021). It was found that the Log Pearson III meets the requirements in the calculation of the statistical parameter dispersion and will be used for further analysis. Seen in **Fig. 4**, it is found that the skewness value for Log Pearson III is 0.416 with the condition that the value must not be equal to zero (≠0) (Ben Khalfallah and Saidi, 2018).

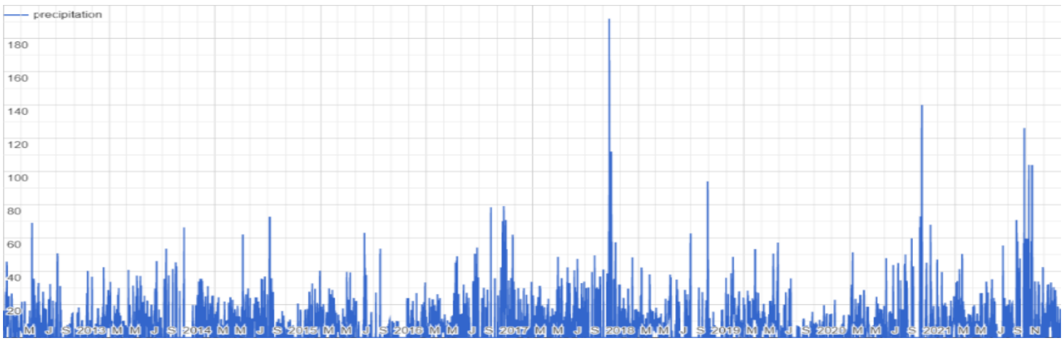

Fig. 3 Daily Rainfall of the Mata Allo Sub-watershed for 2012-2021

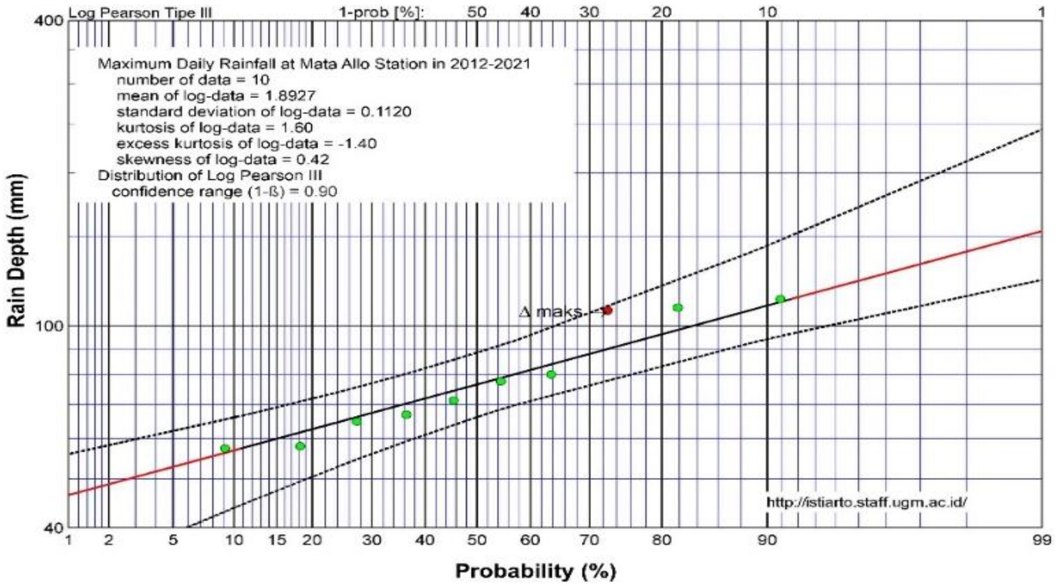

Fig. 4. Probability Distribution of Maximum Rainfall using the Log Pearson III Method

Based on the requirements for selecting the type of distribution and the data distribution suitability test shows that the Log Pearson III method is suitable for use. The results of the calculation of rainfall return periods using the Log Pearson III method can be seen in full in **Table 2** below.

Tabel 2.

Results of rainfall calculation plan

Return Period (year)	Rainfall (mm)
2	76,51
5	96,38
10	109,73
25	127,00
50	140,23
100	153,77

Source: Results of calculations and data processing, 2022.

4.2 Discharge Analysis

By using the planned rainfall value, a flood discharge analysis is obtained using the Nakayasu HSU method. The calculation results show, the peak time (Tp) for the Mata Allo Sub-watershed is 1 hour with a hydrograph shape that can be seen in **Fig. 5**. In addition, the magnitude of the peak flood discharge obtained at the return period of 2 to 100 years is 137,05 m^3/det; 148,83 m^3/det; 156,75 m^3/det; 167,0 m^3/det; 174,84 m^3/det; 182,87 m^3/det.

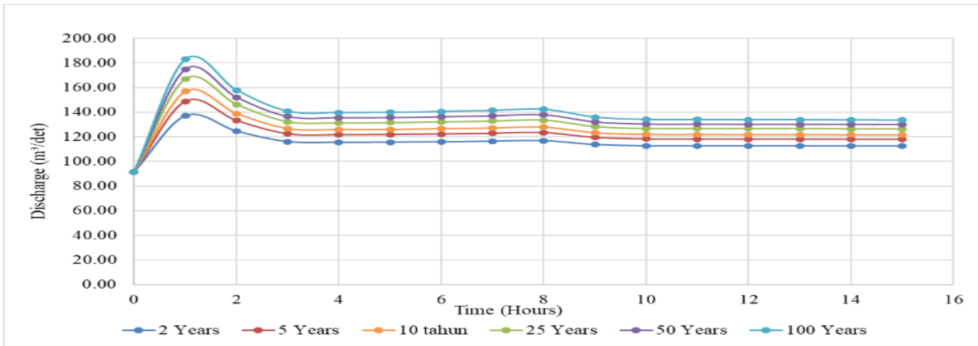

Fig. 5. Flood Hydrograph of Mata Allo Sub-watershed using Nakayasu HSU Method.

The simulated flood inundation area shows 54.9266 Ha at the 2-year return period, 59.3351 Ha at the 5-year return period, 62.1189 Ha at the 10-year return period, 64.8449 Ha at the 25- year return period, 68.734 Ha at the 50-year return period and 69.734 Ha at the 100-year return period. From all simulations of the return period that have been carried out, it can be seen that the areas that experience inundation include Lewaja District, Galonta District, Puserren District, Juppandang District, and Ranga Village (**Fig. 6**).

Fig. 6. Flood inundation distribution map of the Mata Allo Sub-watershed at the Q100 year return period.

In addition, the depth value from the simulation results also shows the uniformity of the location of the flood vulnerability level at each return period. The average level of vulnerability in the very low range is ±9.60 Ha, low range is ±8.8 Ha, moderate vulnerability range is ±13.63 Ha, high vulnerability level is ±23.58 Ha, and the level of vulnerability in the extreme range is ±25.71 Ha. As for urban villages with a level of flood hazard based on spatial analysis carried out which have high to extreme vulnerability are Lewaja Village and Galonta Village. For clarity, it can be seen in **Fig. 7.**

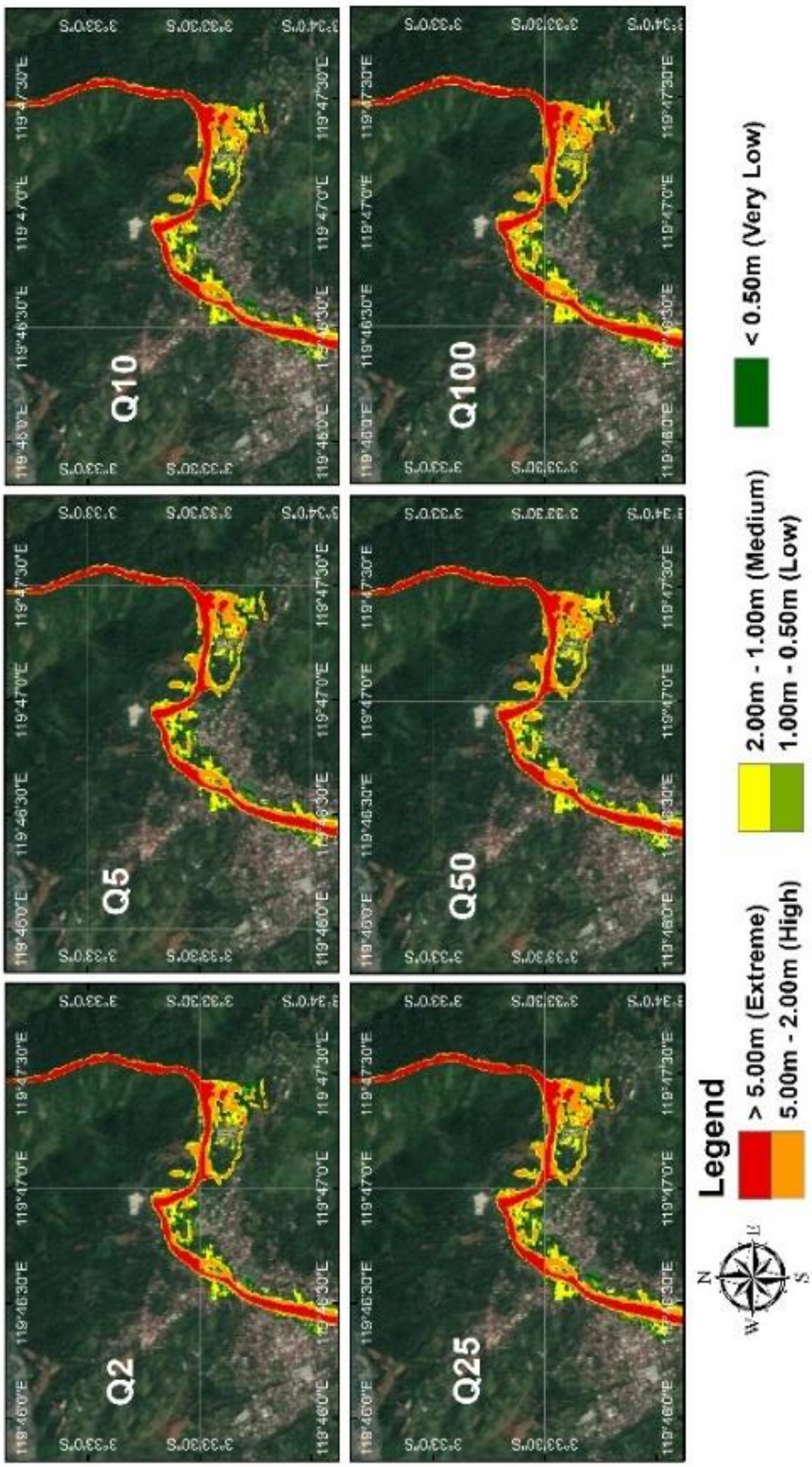

Fig. 7. Flood hazard level of the study area.

4.3 Discussion

Vojtek and Vojteková (2019) explained that the flood phenomenon is influenced by 4 main factors which include hydrography, hydrology, morphometry and permeability that compose an area. The flood phenomenon that occurs at the Mata Allo Sub-watershed research location based on the results of the analysis that has been carried out shows that flood events tend to be influenced by hydrological and morphometric factors of the region.

The hydrological aspect is closely related to river problems, especially the rain that will flow into the river system (Harahap, Jeumpa and Hadibroto, 2018). The amount of rainwater flowed determines the increase in flood runoff (Kang et al., 2013). The design flood analysis uses the maximum value of the planned rainfall (Harahap, Jeumpa and Hadibroto, 2018). The results of the calculation of the rainfall value at the study location for the return period of 2 to 100 years respectively are 76.51mm, 96.51mm, 109.73mm, 127.00mm, 140.23mm, and 153.77mm respectively. The calculation of this rainfall plan uses the distribution of the Log Pearson III. So that the estimated amount of flood discharge for a certain period of the estimated flood discharge does not deviate far from the actual flood event (Harahap, Jeumpa and Hadibroto, 2018). Meanwhile, the peak flood discharge at the return period obtained is 137,05 m^3/s; 148,83 m^3/s; 156,75 m^3/s; 167,0 m^3/s; 174,84 m^3/s; 182,87 m^3/s.

Physical and hydrological characteristics are the main factors that influence the frequency of flooding for different return periods. However, it is known that the slope has a greater influence on the intensity and frequency of flood events (Ben Khalfallah and Saidi, 2018). The morphometric aspect is illustrated from the results of DEM data processing, the topographic conditions of the Mata Allo Sub-watershed area are low relief and gentle slopes which are in line with the research of Uca et al., (2021). Mata Allo watershed has a rounded or elongated rounding ratio where the time required by river water is getting shorter so that river flood fluctuations will be higher and the ratio of low relief and gentle slopes (Uca et al., 2021).

Modeling the distribution of flood inundation that occurs at the research site using 2D HEC-RAS simulation. The simulation results obtained through the HEC-RAS application are given to produce inundation maps to determine the estimated flood hazard areas (Bharath et al., 2021). Determination of the inundation area limit that occurs due to peak flood discharge is carried out with the assumption that the flow is in the form of unsteady flow in the state of the river at the study location. In addition, knowing the flood hazard assessment requires flood propagation that changes over time. This is the basis that steady flow simulations can illustrate how flood hazards through water surface elevations (Albo-Salih, Mays and Che, 2022) and become part of an early warning information system against flooding. Based on the simulation results, the simulated flood inundation area shows 54.9266 Ha at the 2-year return period, 59.3351 Ha at the 5-year return period, 62.1189 Ha at the 10-year return period, 64.8449 Ha at the 25-year return period, 68.734 Ha at the 50-year return period and 69.734 Ha at the 100-year return period. The depth value shows the uniformity of the location of the flood vulnerability level between return periods. Based on the classification of Ahmad *et al.* (2022) to the depth of flood. The average level of vulnerability in the very low range is ±9.60 Ha, low range is ±8.8 Ha, moderate vulnerability range is ±13.63 Ha, high vulnerability level is ±23.58 Ha, and the level of vulnerability in the extreme range is ±25.71 Ha. These results indicate that areas in the Mata Allo Sub-watershed are in the high to extreme range with inundation depths of 2 meters to above 5 meters. This result also includes the value of river depth during flooding according to the HEC-RAS simulation that has been carried out (Ahmad et al., 2022).

6. CONCLUSIONS

This research produced flood inundation maps in the area around the Mata Allo Sub-watershed study site using a hydraulics and Geographic Information System approach, with the help of HEC-RAS software. Based on the results of the research, it was found that flood mapping using 2D HEC-RAS can provide a visualization of the distribution of inundation and the potential level of flood vulnerability that may occur as a result of flood recurrence. This is based on the results of spatial analysis of the height and flood inundation of the Mata Allo Sub-watershed, which shows that the Lewaja Village and Galonta Village areas are at the highest level of inundation of potential floods and are affected by flood events. In addition, given that the simulations in this flood modeling incorporate peak discharge data obtained from the last 10 years of maximum rainfall data, as well as river geometry data that has a resolution of 8.2 meters, the maps resulting from this modeling may not always represent annual routine events in the Mata Allo Sub-watershed study area.

The use of annual rainfall data in an effort to obtain river discharge data using the Nakayasu HSU method is very helpful in obtaining discharge data. The actual data discharge for rivers in Indonesia is still lacking, especially for rivers in Enrekang (Mata Allo Sub-watershed). With this debit data, the use of the HEC-RAS program can be done by inputting the existing debit data. The results can then describe flood-prone areas by classifying flood areas based on their depth level. But keep in mind, the resolution of the DEM data used is only 8.2m which cannot fully describe the cross-sectional model in detail. So, the results of this study are only limited to an overview in anticipation of floods that often occur in the study area.

REFERENCES

Ahmad, I., Wang, X., Waseem, M., Zaman, M., Aziz, F., Khan, R.Z.N. and Ashraf, M. (2022) "Flood Management, Characterization and Vulnerability Analysis Using an Integrated RS-GIS and 2D Hydrodynamic Modelling Approach: The Case of Deg Nullah, Pakistan," *Remote Sensing*, 14(9). Available at: https://doi.org/10.3390/rs14092138.

Albo-Salih, H., Mays, L.W. and Che, D. (2022) "Application of an Optimization/Simulation Model for the Real-Time Flood Operation of River-Reservoir Systems with One-and Two-Dimensional Unsteady Flow Modeling," *Water (Switzerland)*, 14(1). Available at: https://doi.org/10.3390/w14010087.

Amin, M.T., Izwan, M. and Alazba, A.A. (2016) "A best-fit probability distribution for the estimation of rainfall in northern regions of Pakistan," *Open Life Sciences*, 11(1), pp. 432–440. Available at: https://doi.org/10.1515/biol-2016-0057.

Avinash, K., Jayappa, K.S. and Deepika, B. (2011) "Prioritization of sub-basins based on geomorphology and morphometricanalysis using remote sensing and geographic informationsystem (GIS) techniques," *Geocarto International*, 26(7), pp. 569–592. Available at: https://doi.org/10.1080/10106049.2011.606925.

Bharath, A., Shivapur, A. V., Hiremath, C.G. and Maddamsetty, R. (2021) "Dam break analysis using HEC-RAS and HEC-GeoRAS: A case study of Hidkal dam, Karnataka state, India," *Environmental Challenges*, 5(November), p. 100401. Available at: https://doi.org/10.1016/j.envc.2021.100401.

BNPB (2022) *Kejadian Bencana per Provinsi Tahun 2022*. Available at: https://gis.bnpb.go.id/ (Accessed: September 7, 2022).

Bomers, A., Meulen, B. van der, Schielen, R.M.J. and Hulscher, S.J.M.H. (2019) "Historic Flood Reconstruction With the Use of an Artificial Neural Network," *Water Resources Research*, pp. 73–88. Available at: https://doi.org/10.1029/2019WR025656.

Bomers, A., Schielen, R.M.J. and Hulscher, S.J.M.H. (2019) "Decreasing uncertainty in flood frequency analyses by including historic flood events in an efficient bootstrap approach," *Hazards Earth Syst*, pp. 1–23. Available at: https://doi.org/https://doi.org/10.5194/nhess-19-1895-2019, 2019.

Geleta, C.D. and Deressa, T.A. (2021) "Evaluation of Climate Hazards Group InfraRed Precipitation Station (CHIRPS) satellite-based rainfall estimates over Finchaa and Neshe Watersheds, Ethiopia," *Engineering Reports*, 3(6), pp. 1–16. Available at: https://doi.org/10.1002/eng2.12338.

Gray, D.M. (1973) *Handbook on the Principles of Hydrology: With Special Emphasis Directed to Canadian Conditions in the Discussions, Applications, and Presentation of Data*. Water Information Center, Incorporated (A Water Information Center publication). Available at: https://books.google.co.id/books?id=5P1OAAAAMAAJ.

Haidu, I. and Ivan, K. (2016) "Urban runoff pathways and surface water volumes evolution. Case study: Bordeaux 1984-2014, France," *Houille Blanche*, 2016-Octob(5), pp. 51–56. Available at: https://doi.org/10.1051/lhb/2016050.

Harahap, R., Jeumpa, K. and Hadibroto, B. (2018) “Flood Discharge Analysis with Nakayasu Method Using Combination of HEC-RAS Method on Deli River in Medan City,” *Journal of Physics: Conference Series*, 970(1). Available at: https://doi.org/10.1088/1742-6596/970/1/012011.

Indrawan, I. and Siregar, R.I. (2018) “Analysis of flood vulnerability in urban area; A case study in deli watershed,” *Journal of Physics: Conference Series*, 978(1). Available at: https://doi.org/10.1088/1742-6596/978/1/012036.

Kang, M.S., Goo, J.H., Song, I., Chun, J.A., Her, Y.G., Hwang, S.W. and Park, S.W. (2013) “Estimating design floods based on the critical storm duration for small watersheds,” *Journal of Hydro-Environment Research*, 7(3), pp. 209–218. Available at: https://doi.org/10.1016/j.jher.2013.01.003.

Khaddor, I. and Alaoui, A.H. (2014) “Production of a Curve Number map for Hydrological simulation -Case study: Kalaya Watershed located in Northern Morocco,” *International Journal of Innovation and Applied Studies ISSN*, 9(4), pp. 2028–9324. Available at: http://www.ijias.issr-journals.org/.

Ben Khalfallah, C. and Saidi, S. (2018) “Spatiotemporal floodplain mapping and prediction using HEC-RAS - GIS tools: Case of the Mejerda river, Tunisia,” *Journal of African Earth Sciences*, 142, pp. 44–51. Available at: https://doi.org/10.1016/j.jafrearsci.2018.03.004.

Kim, V., Tantanee, S. and Suparta, W. (2020) “GIS-Based Flood Hazard Mapping Using HEC_RAS Model: A Case Study of Lower Mekong River, Cambodia,” 15(1), pp. 16–26. Available at: https://doi.org/10.21163/GT_2020.151.02.

Kodoatie, R.J. (2013) *Rekayasa dan Manajemen Banjir Kota*. Yogjakarta: ANDI OFFSET.

Le, A.M. and Pricope, N.G. (2017) “Increasing the accuracy of runoffand streamflow simulation in the Nzoia Basin, Western Kenya, through the incorporation of satellite-derived CHIRPS data,” *Water (Switzerland)*, 9(2). Available at: https://doi.org/10.3390/w9020114.

Lea, D., Yeonsu, K. and Hyunuk, A. (2019) “Case study of HEC-RAS 1D-2D coupling simulation: 2002 Baeksan flood event in Korea,” *Water (Switzerland)*, 11(10), pp. 1–14. Available at: https://doi.org/10.3390/w11102048.

Liu, Z., Merwade, V. and Jafarzadegan, K. (2019) “Investigating the role of model structure and surface roughness in generating flood inundation extents using one- and two-dimensional hydraulic models,” *Journal of Flood Risk Management*, 12(1). Available at: https://doi.org/10.1111/jfr3.12347.

Ngo, H., Bomers, A., Augustijn, D.C.M., Ranasinghe, R., Filatova, T., van der Meulen, B., Herget, J. and Hulscher, S.J.M.H. (2023) “Reconstruction of the 1374 Rhine river flood event around Cologne region using 1D-2D coupled hydraulic modelling approach,” *Journal of Hydrology*, 617(PC), p. 129039. Available at: https://doi.org/10.1016/j.jhydrol.2022.129039.

Pathan, A.K.I. and Agnihotri, P.G. (2020) “2-D unsteady flow modelling and inundation mapping for lower region of Purna basin using HEC-RAS,” *Nature Environment and Pollution Technology*, 19(1), pp. 277–285.

Popescu, C. and Bărbulescu, A. (2023) “Floods Simulation on the Vedea River (Romania) Using Hydraulic Modeling and GIS Software: A Case Study,” *Water*, 15(3), p. 483. Available at: https://doi.org/10.3390/w15030483.

Prastica, R.M.S. and Fanani, A.J. (2021) “What causes Ngancar River in Wiroko Temon sub-watershed vulnerable to flooding?,” *IOP Conference Series: Earth and Environmental Science*, 847(1). Available at: https://doi.org/10.1088/1755-1315/847/1/012003.

Pratiwi, Z. and Santosa, B. (2021) “Journal of Geospatial Information Science and Engineering,” *Journal of Geospatial Information Science and Engineering*, 4(1), pp. 81–86.

Rajeev and Singh, S. (2016) “Watershed Management - A GIS Approach,” *IMPACT: International Journal of Research in Applied, Natural and Social Sciences*, 4(6), pp. 109–116. Available at: https://oaji.net/articles/2016/491-1468576163.pdf.

Rauf, I. (2021) “Analisis Spasial Tingkat Bahaya Banjir Desa Amasing Kali Dengan HEC-RAS 2D,” *Jurnal Teknik*, 19(2), pp. 107–119. Available at: https://doi.org/10.37031/jt.v19i2.188.

Sabău, D., and Șerban, G. (2018). Arch dam failure preliminary analysis using HEC-RAS and HEC-GEO RAS modeling. Case study Someșul Rece 1 reservoir. *Forum Geografic*, XVII (1), 44-55. doi:10.5775/fg.2018.058.i

Steele, M., Chaseline, J. and Hurst, C. (2006) *A comparison of the powers of the Chi-Square test statistic with the discrete Kolmogorov-Smirnov and Cramér-von Mises test statistics.*, *COMPSTAT Proceedings in Computational Statistics*. Available at: http://eprints.jcu.edu.au/281/.

Triatmodjo, B. (2013) *Hidrologi Terapan*. Keempat. Yogyakarta: Beta Offset.

Uca, Amal, Tabbu, M.A.S., Yusuf, M., Jeddayanti and Sriwahyuni (2021) "Karakteristik Morfometri Sub DAS Saddang dan Mata Allo Provinsi Sulawesi Selatan," *Indonesian Journal Of Fundamental Sciences*, 7(2), pp. 52–66. Available at: https://doi.org/https://doi.org/10.26858/ijfs.v7i2.26151.

US Army Coprs of Engineers (2016) "HEC-RAS River Analysis System: User Manual 1D and 2D Version 5.0," *US Army Corps of Engineers*. US ACE IWR Hydrologic Engineering Center, pp. 1–790. Available at: www.hec.usace.army.mil.

Vojtek, M. and Vojteková, J. (2019) "Flood susceptibility mapping on a national scale in Slovakia using the analytical hierarchy process," *Water (Switzerland)*, 11(2). Available at: https://doi.org/10.3390/w11020364.