Flood Analysis Based on the Influence of Geomorphology and Rainfall Patterns in the Tallo River Flow Area, Makassar City, South Sulawesi Province, Indonesia

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Abstract

The South Sulawesi region is one of the regions in Indonesia that is often affected by flood disasters. The aim of this research is to determine the extent of inundation and flood discharge which is influenced by rainfall and geological characteristics. The research method is data collection, spatial analysis using HEC-RAS, and statistical analysis of rainfall data in the research watershed. Based on flood analysis, the rate of soil infiltration is influenced by layers of rock and soil in the form of clay, silt and sand, as a determinant of the runoff coefficient in the research area there are tufa and materials ranging from fine sand to clay and in general it is a pond area with water conditions. very shallow ground. In the research area, it was found that the geomorphological data consisted of flat alluvial units and sloping alluvial wavy units with flat topography and land cover dominated by dense settlements, ponds and open land, so that very high surface runoff could cause rapid flooding in the research watershed. Based on discharge calculations and flood simulation results, the annual planned flood inundation area for the research area has increased with the percentage of discharge and inundation area, namely Q2 with a discharge of 1994.5 m3/second and an inundation area of 30.49 km2, Q5 with a discharge of 2799.30 m3/second. and inundation area 32.97 km2, Q10 with discharge 3332.1 m3/second and inundation area 34.29 km2, Q50 with discharge 4504.9 m3/second and inundation area 36.64 km2, Q100 with discharge 5000.7 m3/ seconds and the inundation area is 37.46 km2.

Keywords: flooding analysis, south sulawesi, HEC-RAS, geomorphology

1. Introduction

South Sulawesi, an area of Indonesia, is frequently impacted by floods. The geographical features of South Sulawesi, situated in a coastal region with substantial precipitation, render it susceptible to flooding. Moreover, unregulated growth and deteriorating environmental conditions are primary contributors to flooding in the region. One event transpired in Makassar City, namely inside the Tallo River Basin, including an area of 432.21 km² and a river length of 77.90 km (Suarni et al., 2021). BNPB data indicates that Makassar City experienced its highest day rainfall on February 13, 2023, resulting in the evacuation of 2,293 individuals and considerable material damage. Utilizing the above indicated facts, the author undertook a study to ascertain the sources of floods, inundated regions, and flood discharge within the research area. This study utilized spatial analysis and statistics, including climatic variables and geological aspects like topography, geomorphology, and land use within the research watershed. There are various perspectives from which to examine the problem's background. Examples include: the influence of rock and soil types on the flood runoff coefficient of the Tallo River's surface area; the impact of geomorphology on the topographic runoff coefficient and vegetation land use within the Tallo Watershed; the determination of annual flood discharge and inundation area over the past decade, from 2014 to 2023; and the projection of annual flood discharge and inundation area for the forthcoming two, five, ten, fifty, and one hundred years. This study seeks to evaluate the flood risk in the Tallo River watershed in Makassar City, including the effects of geomorphology and precipitation patterns. It also seeks to generate simulations to ascertain the inundation area and flood depth inside the Tallo River watershed with HEC-RAS. This research offers proposals and recommendations for future developmental requirements for the Tallo River Basin.

Geomorphology and precipitation patterns substantially affect the complex problem of flooding in the Tallo River basin of Makassar City, South Sulawesi Province. The city's topography, marked by low-lying coastal regions and closeness to significant rivers, intensifies its susceptibility to floods, especially during the peak rainfall period from December to February. Seasonal flooding is predominantly driven by intense rainfall events, which correlate with the region's geomorphological features (Muzakir et al., 2023).

The geomorphology of the Tallo River watershed is essential in influencing the conversion of rainfall into flood occurrences. Musliadi et al. conducted a study analyzing the characteristics of the Tallo watershed, demonstrating that its elevation gradient and river morphology greatly affect flood dynamics (Musliadi et al., 2021). The research emphasized that the watershed's dimensions and expanse influence water buildup and flow, impacting both the inundation area and flood depth. The study highlighted the interplay between tidal variations and flood flow, underscoring the necessity of incorporating geomorphological elements in flood risk assessments for the region.

Rainfall patterns, especially their strength and length, are essential for flood events. Didiharyono et al. noted that alterations in precipitation patterns have resulted in more frequent and severe rainstorm events in Makassar, exacerbating the city's flooding problems (Didiharyono et al., 2022). The study indicated that a reduced overall rainfall, coupled with a heightened frequency of intense precipitation, can result in considerable flooding hazards. Luo et al. further substantiate this claim, indicating that urban flooding is profoundly affected by the attributes of rainfall events, such as intensity and length, which are anticipated to intensify owing to climate change (Luo et al., 2018).

Antecedent moisture conditions are crucial in understanding the correlation between precipitation patterns and flood risk. A model by Cea and Fraga integrates rainfall intensity and soil moisture for flood discharge predictions. Hydrological modeling and precipitation data are essential for efficient flood risk management, with IDF curves aiding in forecasting hydrological responses during extreme events.

2. Geological Setting

Sukamto (1982) categorized the regional geomorphology of the research area into the Pangkajene and Watampone sheets in the western portion of Sulawesi (Figure 3). The Majene-Palopo Sheet delineates the northern boundary of this map sheet, while the Ujung Pandang, Benteng, and Sinjai Sheets define its southern boundary, the Makassar Strait marks the western boundary, and Bone Bay constitutes the eastern boundary. Volcanic rocks and alluvial deposits predominate in the geological formations of the studied region. The Tmc Formation has marine sedimentary rocks intermingled with volcanic rocks, tuff sandstone, siltstone, mudstone, conglomerate, and volcanic breccia. Qac: Alluvial, lacustrine, and coastal deposits; comprising clay, silt, mud, sand, and gravel next to major rivers and shorelines. The regional configuration of the research area is marked by comparatively minor folding and faulting in the western

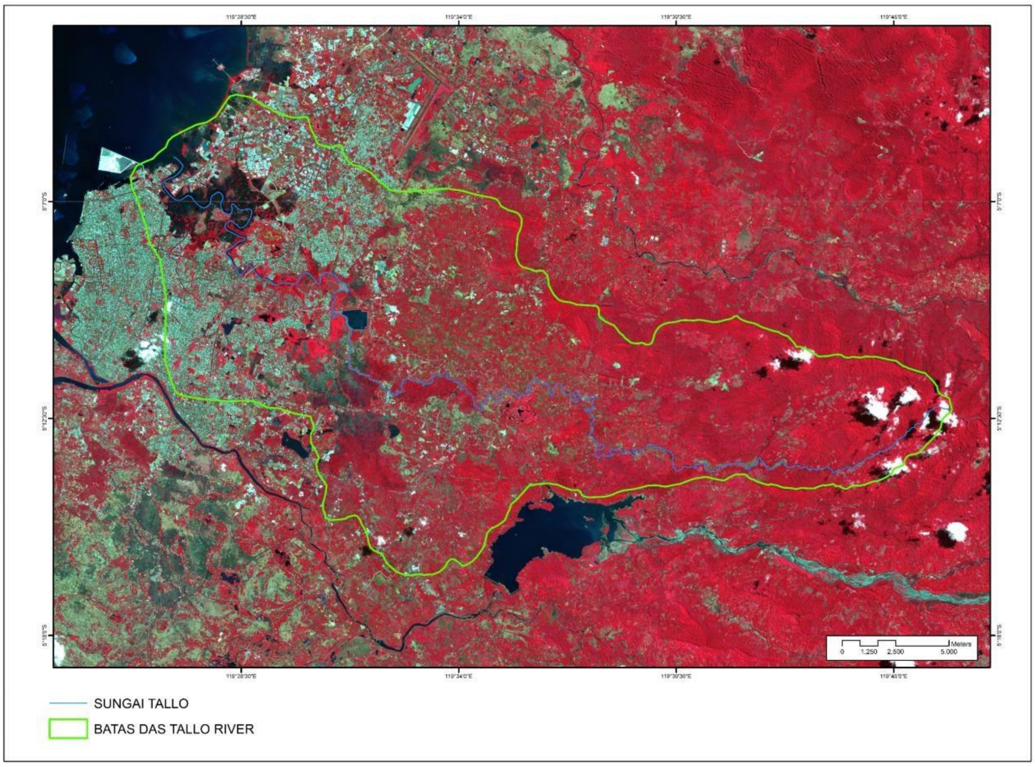

Figure 1. Study area on Tallo River Basin, South Sulawesi, Indonesia

mountains, which are oriented northwest-southeast and concave, likely resulting from right-lateral horizontal displacement along a significant fault. Sukamto, 1982. The orientation of the rocks in the research region, exhibiting a southeast-northwest striking direction and a southwest dip with a comparable slope angle, indicates the presence of folds. (Compilation by Asnawi, 2008; Anas, 2008).

3. Data and Methods

The methods of this research are conducting by literature evaluation, encompassing the examination of pertinent literature, prior studies, and the research domain to acquire an understanding of the existing conditions within the field (Figure 2). The data collection phase comprises two types of data: primary and secondary. Primary data involves conducting field observations or direct data collection in the research area, including assessments of the physical conditions, river locations, validation of previously occurred flood points, measurements of flood heights, river water discharge, delineation of flood positions and boundaries, and identification of factors influencing flood occurrences. The secondary data utilized in this study was obtained indirectly from various sources, including satellite imagery from Land Viewer, precipitation data from the Makassar Meteorology, Climatology, and Geophysics Agency, and the Pompengan-Jeneberang River Basin Centre (BBWS) of South Sulawesi Province, geological information from the Regional Geological Map of Ujung Pandang, Benteng, and Sinjai sheets by Rab. Sukamto and S. Supriatna (1982), as well as the Digital Elevation Model (DEM). Demnas supplied the data, whilst Government of South Sulawesi documented the flood event point data and the historical flood records. The subsequent phase of data processing

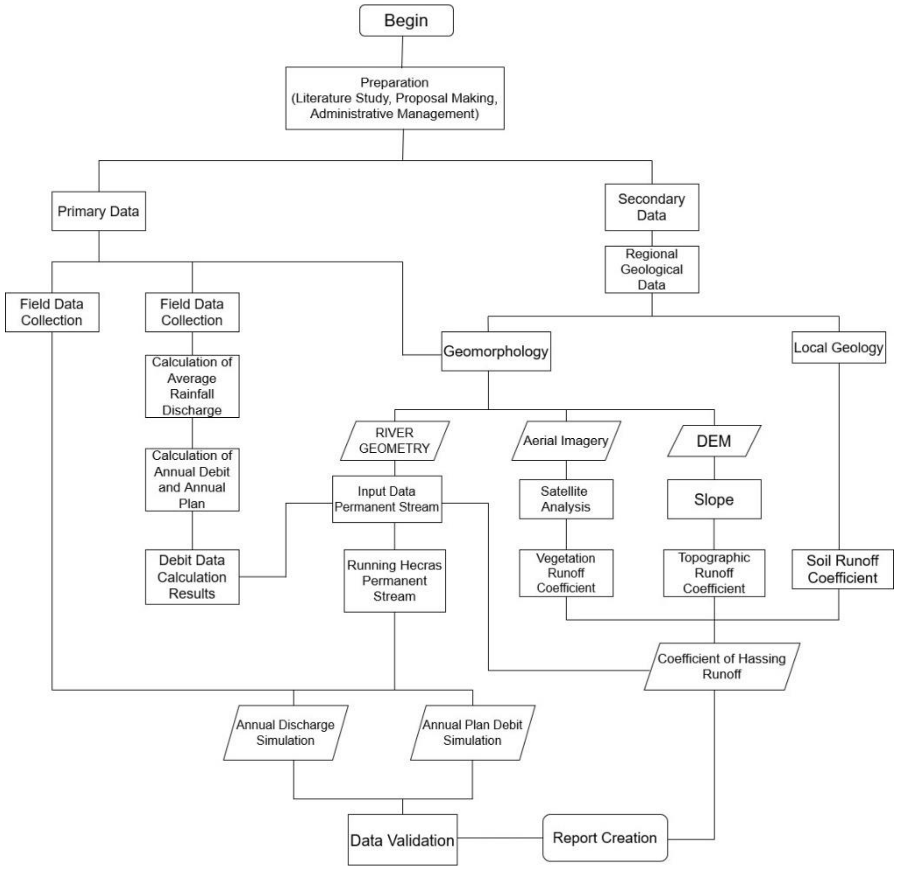

Figure 2. Research flow of Flooding analysis in the Tallo River basin

entails the digitization of the map, succeeded by the digitization of river geometry and land use for the runoff coefficient using aerial images and digital elevation models (DEM).

Subsequently, we employ the Hassing method from 1995 to compute the runoff coefficient utilizing the topography derived from the DEM data source. Demnas, Land derived from geological data Geological Cartography Regional Geological Map sheets Ujung Pandang, Benteng, and Sinjai by Rab. Sukamto and S. Supriatna (1982), rock samples collected from the research area, and vegetation analyzed from Sentinel 2 imagery and field observations.

Simultaneously, during the analysis of rainfall pattern data, calculations for annual discharge and annual planning are conducted. The computation of average rainfall commences with the establishment of average regional rainfall via the Thiessen polygon method, followed by the assessment of rainfall distribution and the calculation of peak discharge to ascertain annual discharge and planning, subsequently executed in HEC-RAS. Phase of data analysis: Currently, data analysis is conducted to assess the accuracy of the flood source analysis derived from the annual discharge pool and the anticipated annual discharge pool by validating the outcomes of prior river discharge measurements in the field. The final phase involves the compilation of a research report. This report must encompass all information acquired throughout the research, including the employed technique, the outcomes of data analysis, and the conclusions derived. The last stage involves compiling a report that includes research findings, conclusions, and suggestions aimed at mitigating the risk of flood disasters in the study area.

4. Results and Analysis

Primary data is obtained directly from the field, specifically validating flood data, which encompasses flood position, flood height, and the geomorphology of the flood site at that moment.

Collection of River Data

The Tallo River discharge data was collected during the rainy season, with one data collection location utilizing the jergen method. We want to validate the field discharge measurements by juxtaposing the measured discharge value with the outcomes of annual discharge calculations and the projected discharge. The discharge of the Tallo River was recorded on Saturday, May 20, 2023, in the Kera-Kera region at coordinates 119º28'41" LS - 5º07'33" BT, yielding the subsequent findings. The measurement results indicate that the average current velocity is 0.068043682 m/s, with a river width of 99 m, an average depth of 5.4 m, a river cross-sectional area of 534.6 m^2, a wet area of 356.45 m^2, a wet circumference of 75.98 m, a hydraulic radius of 4.691 m, and an average river discharge of 36.37 m^3/s.

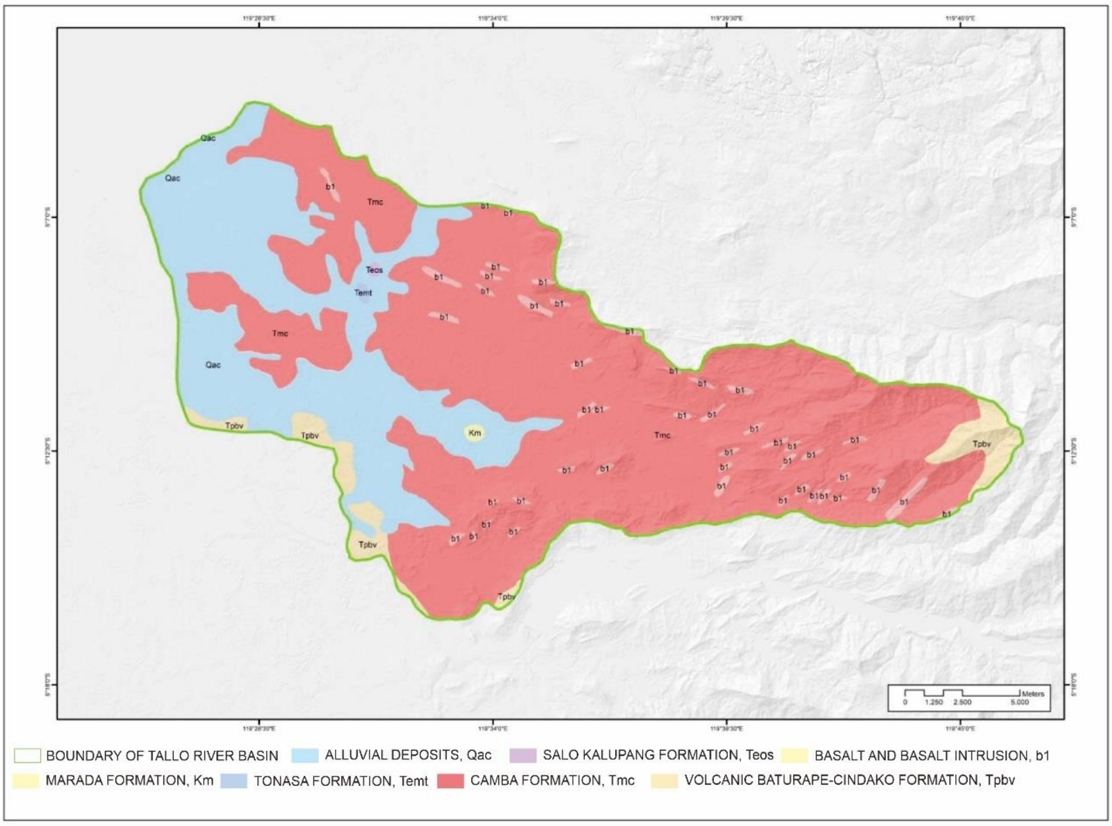

Figure 3. Geology of the Tallo River Basin Area, South Sulawesi Indonesia (Sukamto and Supriatna, 1982)

Collection of flood point data.

The procedure for gathering flood point data is modified based on diverse documentation sources and subsequently validated in the field, encompassing multiple points as follows:

*Precipitation Data.*This research utilizes maximum monthly rainfall data per year from the rainfall station in the Tallo River basin, obtained from BMKG Paotere, BMKG Gowa, BMKG Hasanuddin, BMKG Maros, and BBWS Pompengan Jeneberang.

*Secondary Data.*The utilized secondary data comprises DEM data, aerial pictures, geomorphological data, and geological data, detailed as follows:

*Topographical Data of the Research Watershed.*The topography data was processed to determine the topographic runoff coefficient of the Research Watershed, employing DEM (Digital Elevation Model) data from the Indonesian Geospatial Agency.

Geological Information of the Research Watershed. The geological data for the research area is sourced from the regional geology of the Ujungpandang, Benteng, and Sinjai sheets by Rab. Sukamto and S. Supriatna (1982).

Aerial Photograph. Aerial photographs obtained from Sentinel 2 imagery, featuring a resolution of 10 meters. For the composite band vegetation analysis, we utilized bands 8, 4, and 3, whereas for natural photos, we employed bands 4, 3, and 2.

Table 1. Results of Analysis of Missing Rainfall Data Using the Inversed Square Distance Method in the research area.

Rainfall Data based on station location (mm/tahun)					
Year	Paotere	Senre	Gowa	Hasanuddin	Pucak
2014	668	602	637	350	620
2015	595	810	673	617	742
2016	839	764	690	617	787
2017	789	784	646	810	790
2018	677	981	810	726	936
2019	523	524	524	524	577
2020	647	943	771	668	960
2021	948	1716	1314	1215	1493
2022	816	1029	942	1004	991
2023	544	610	590	674	620

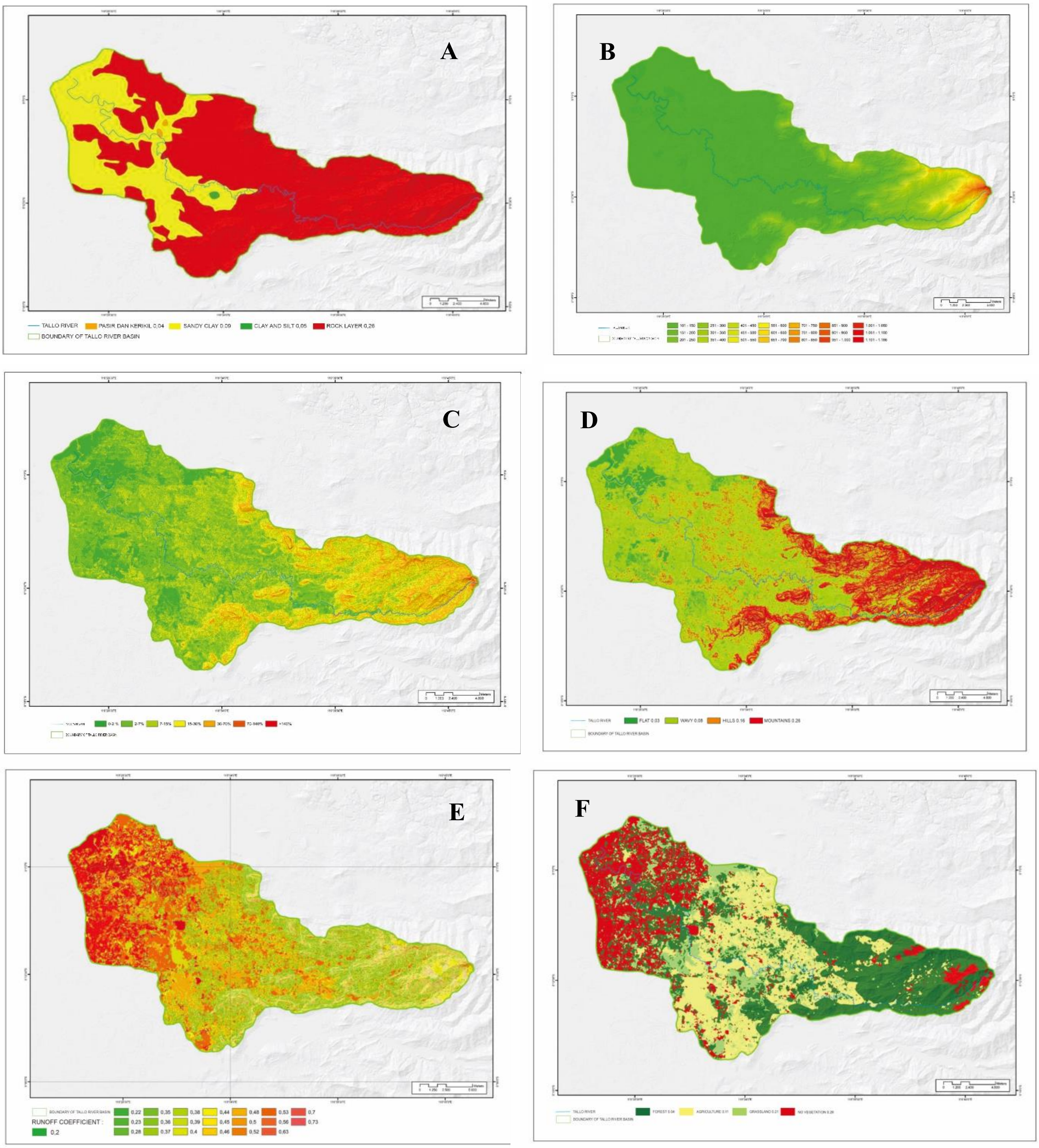

Figure 3. Data input and processing by spatial format on HEC-RAS tool simulations. A. Run off coefficient of soil and rock layer, B. Digital Elevation Model (DEM) of Tallo River basin, C. Slope angle of Tallo River basin, D. Topographic run off coefficient of Tallo River basin, E. Run of coefficient of watershed, and F. Vegetation run off coefficient by data processing.

5. Discussions

5.1 Investigate the Soil Runoff Coefficient and Geological layer of the Watershed

The soil runoff coefficient and rock layer of the study area are analyzed utilizing regional geological data from the Ujungpandang, Benteng, and Sinjai sheets as compiled by Rab. Sukamto and S. Supriatna (1982). Hassing's (1995) calculation of the topographic runoff coefficient in the Tallo river basin indicates that the runoff coefficient in the research watershed is primarily influenced by sandy clay in the downstream region and rock layers in the upstream region, yielding a coefficient of Cs = 0.21 (Table 7).

The stratification of rock and soil, including clay, silt, and sand, affects the runoff coefficient of soil and rock in the study region. The strata vary from fine sand to clay, and typically, the downstream section of the research watershed in the pond region exhibits very shallow groundwater conditions. Under these circumstances, when precipitation occurs and causes overflow, previously stagnant water will see a volume increase due to the sluggish rate of soil infiltration, resulting in an expanded inundation region and subsequent floods.

5.2 The geomorphology of the research area

Employing the slope class classification by Van Zuidam (1985) and Bermana (2006), the analysis of a 1:32,000 scale topographic map, featuring a 25-meter contour interval interpolated to a 1-meter interval, categorizes the geomorphological units of the study area into two classifications: the plains geomorphological unit and the undulating oblique geomorphological unit.

5.2.1 Fluvial Plain Geomorphological Unit

This geomorphological unit encompasses approximately 71.1% of the study area, equating to roughly 54.13 km², situated in the center region and extending from the northeast to the southwest. This geomorphological unit is situated on both the left and right banks of the Tallo River, encompassing the Tallo, Tamalanrea, Rappocini, Makassar, Bontoala, and Ujungtanah regions. The morphometric examination of this geomorphological unit indicates a slope gradient of roughly 0-2% and a height differential of less than 3 m. The direct observation in the area indicates a topographical configuration resembling a river plain.

The primary genetic process that creates this geomorphological unit is the deposition of unconsolidated material as river deposits along the Tallo River. This external process generates a relatively expansive alluvial plain, with deposits ranging from clay to sand-sized particles throughout the river's course. This material originates from river transportation and constitutes river deposits in the form of floodplains. This unit utilizes tuff as its lithology. Land utilization comprises ponds, rice paddies, and habitations.

5.2.1 Fluvial Oblique Wavy Geomorphological Unit

The oblique wavy geomorphological unit constitutes around 28.9% of the overall research area, including around 21.99 km². This unit extends from the eastern to the southern region of the research area, encompassing the Biringkanaya, Manggala, and Panakukang locales. The morphometric investigation of this geomorphological unit indicates a slope gradient of roughly 2.5–3%, a height differential of less than 15 m, and an undulating relief.

This unit comprises tuff and agglomerate lithology. Land usage encompasses urban areas, rice paddies, plantations, and undeveloped terrain.

5.3 Rivers Characterictics

Rivers can be classified based on various factors, including the characteristics of the river flow, the circumstances within the river body, and the geological and tectonic framework of the region. Rivers in the research region can be categorized into permanent rivers according to their water discharge or volume of flow. The flow pattern of the river in the research area is dendritic. The genetic type of the Tallo River is classified as insequential, as it traverses a rather expansive fluvial plain and exhibits only deposits ranging from clay to sand-sized materials along its course, with no rock outcrops present. The river cross-section exhibits a U-shape, and the channel pattern is characterized by meandering. The Tallo River experiences considerable sedimentation, characterized by sediment materials that vary from fine sand to clay. It is situated at a depth of 5.4 m and attains a width of 99 m. As sedimentation in the river escalates over time, the water undergoes pressure and flows from the Tallo River. The expanding breadth of the Tallo River signifies the prevalence of lateral erosion over vertical erosion over its course. The aforementioned description suggests that this phase of the river is an antiquated one.

The research region exhibits a somewhat "U"-shaped valley morphology characterized by flat and undulating alluvial slopes. Erosion in the research region results in the degradation of the river valley, creating a river with a "U"-shaped cross-sectional profile. This indicates that erosion transpires in both lateral and vertical orientations along the river's course. The occurrence of sediment components, varying from clay to sand, along the river in the study region, which constitutes a floodplain, illustrates the sedimentation process. The river in the study region is a perennial river. The research region undergoes physical deterioration, with soil thickness varying from several centimeters to one meter. Vegetation is moderately sparse, characterized by plantations, rice fields, open terrain, ponds, and habitations. The detected traits indicate that the study area is in a mature stage, approaching old stage.

5.4 Topography Topography analysis

We analyzed topographic data to ascertain the topographic runoff coefficient of the Research Watershed, utilizing DEM (Digital Elevation Model) data with an elevation range of 0-25 meter above sea level in the downstream area and 1.186 meter above sea level in the upstream area, sourced from the Indonesian Geospatial Agency (BIG) website with a resolution of 5-10 meters. The data was subsequently transformed into slope data categorized by percentages of 0-2% and 2-7%, which predominate in the Research Watershed. Hassing's (1995) computation of the topographic runoff coefficient for the Tallo River basin resulted in a value of Ct = 0.13 (Table 7).

5.5 Image Analysis processing as data input HEC-RAS simulation

We perform image analysis to assess land cover or vegetation in the research area, encompassing composite bands, segmentation, training classification, and accuracy evaluation. A composite band refers to the amalgamation of multiple bands. Segmentation is the process of transforming picture pixel data with contiguous values and locations into a uniform value. Generate Train refers to the process of producing shapefiles derived from segmentation data as a classification example, specifically generating caru pictures with the requisite classification specified by the author. Accuracy involves computing the precision of image data by utilizing sample points for each segmentation class and subsequently comparing the pixel values in the segmentation shapefile with those in the raster classification.

5.6 The Impact of Geomorphology on the Topographic Runoff Coefficient and Vegetation Land Use in the Study Watershed

The geomorphology of the study area consists of river plain units and undulating fluvial slope units. The deposition process of unconsolidated material, specifically river silt, varies in size from fine sand to clay. Lateral erosion predominates in this process along the Tallo River. The primary watershed runoff coefficient of this study is classified as low, influenced by topography and vegetation, marked by dense towns, ponds, open land, and very shallow groundwater conditions. During rainfall, the river inundates, resulting in a surge of volume in the previously stagnant water due to elevated runoff, hence expanding the region of stagnant water and inducing flooding.

5.6.1 Runoff Coefficient of the Research Watershed

Hassing (1995) calculated the runoff coefficient, yielding a value of C = 0.45 (Table 7). The characteristics of soil and rock layers are the primary determinants of the runoff coefficient in the Hassing technique, with a value of Cs = 0.21. The upstream section of the Research Watershed is characterized by camba formations comprising sandstone, tuff, siltstone, claystone, conglomerate, and volcanic breccia, whereas the downstream section is predominantly composed of alluvial deposits, including clay, silt, mud, sand, and gravel. The Research Watershed, or Tallo Watershed, possesses a runoff coefficient of 0.45, signifying that 45% of the precipitation is categorized as surface flow, which denotes a substantial flow rate.

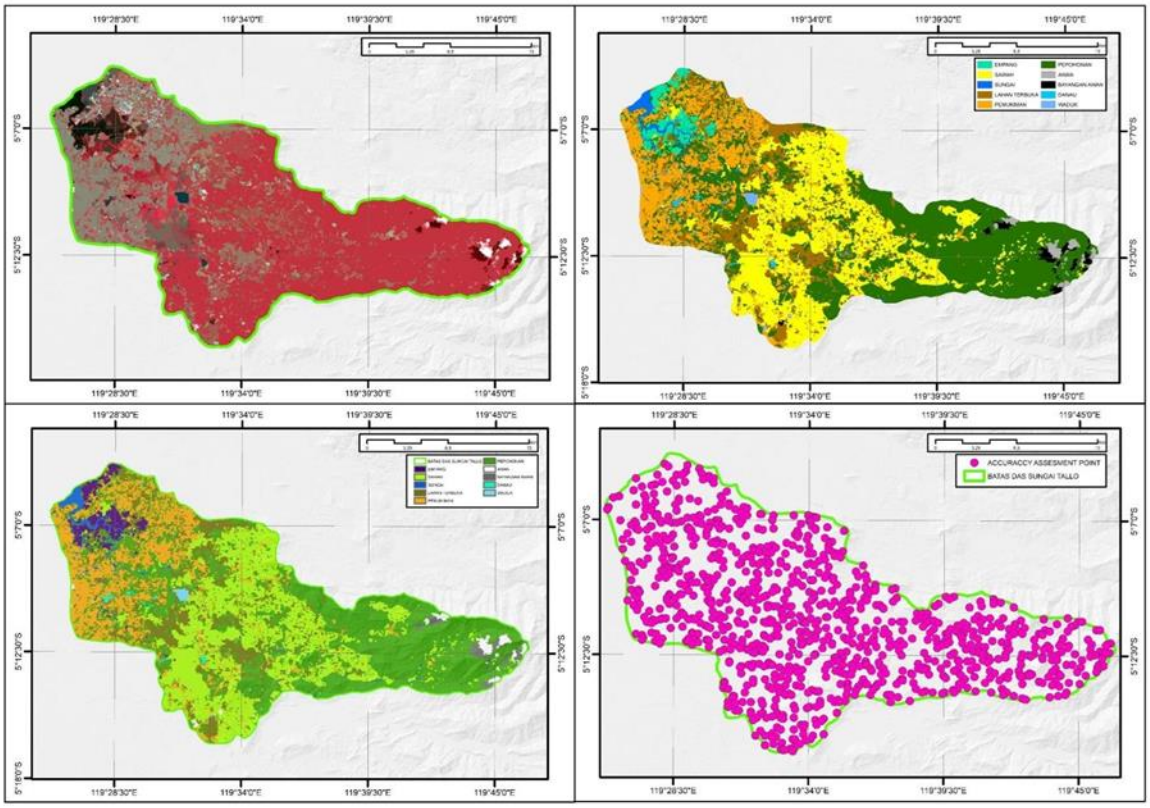

Figure 4. Image processing of Study area. (A) Segmentasi Citra, (B) *Generate Train*, (C) *Classify* Citra, (D) Points of validation data

5.6.2 Calculation of Discharge

a. Computation of Absolut Precipitation Data

Employ the inverse square distance approach to compute absent rainfall data. (Harto, 1993 as cited in Fahmi, 2015).

b. Precipitation Frequency

The Gumbel frequency, which assesses rainfall frequency according to distribution criteria, produces the subsequent outcomes for the annual rainfall data:

c. Results of Debit Calculation

The debit values produced in this study comprise two categories: annual debit from 2014 to 2023 and annual projected debit.

d. Running of simulations on HEC-RAS tools

The procedure for executing data input on HEC-RAS entails initially pinpointing the flood points within the study area, succeeded by the acquisition of field data at these sites (Figure 23). Subsequently, input the DEM data for the research region, integrating the flood spots identified by the HEC-RAS software.

The assessment of river geometry utilizes aerial images to derive elevation values from DEM data and establishes the runoff coefficient for land use based on the runoff coefficient data from the Hassing technique, 1995. Digitize geometric representations within the primary interface of HEC-RAS, particularly in the RAS Mapper. Subsequently, insert topographical data from the Digital Elevation Model (DEM) that includes flood locations inside the study area. Ultimately, digitize the Digital Elevation Model (DEM) of the study area, as illustrated in Figure 24. This encompasses the digitization of river data (dark blue), bank line data (red) on both the right and left banks, flowpath data (light blue), and cross-section line data (green), which delineate the river's cross section. To assess flood inundation, see land use as the runoff coefficient that affects infiltration within the watershed of the study area.

Table 2.Debit analysis on annual plan in Tallo river basin area on period 2014 -2023 year

Year	Maximun rainfall, Average (mm)	Rainfall intensity (mm/jam)	Area (Km^2)	Run off Coefficient (C)	Debit(m^3/detik)
2014	580,3467295	29,97429518	398,890776	0,45	1495,75438
2015	720,5204101	37,21411762	398,890776	0,45	1857,030469
2016	743,2954874	38,39042629	398,890776	0,45	1915,729726
2017	767,9308813	39,66281835	398,890776	0,45	1979,223662
2018	870,7803526	44,97488484	398,890776	0,45	2244,302346
2019	534,4728682	27,60495873	398,890776	0,45	1377,521562
2020	843,1186025	43,54618468	398,890776	0,45	2173,008442
2021	1442,548077	74,50608346	398,890776	0,45	3717,94566
2022	979,1749354	50,57335047	398,890776	0,45	2523,672701
2023	610,9829739	31,55662482	398,890776	0,45	1574,714585

Table 3. Debit analysis on annual plan by period on 2 to 100 year

Year	Rainfall (mm)	Rainfall intensity (mm/hour)	Area (Km^2)	runoff coefficient (C)	Debit(m^3/second)
2	773,8621036	39,96915971	398,890776	0,45	1994,510475
5	1086,119267	56,09691218	398,890776	0,45	2799,305258
10	1292,879194	66,77584388	398,890776	0,45	3332,19715
50	1747,898706	90,27712072	398,890776	0,45	4504,939913
100	1940,260624	100,2124105	398,890776	0,45	5000,723153

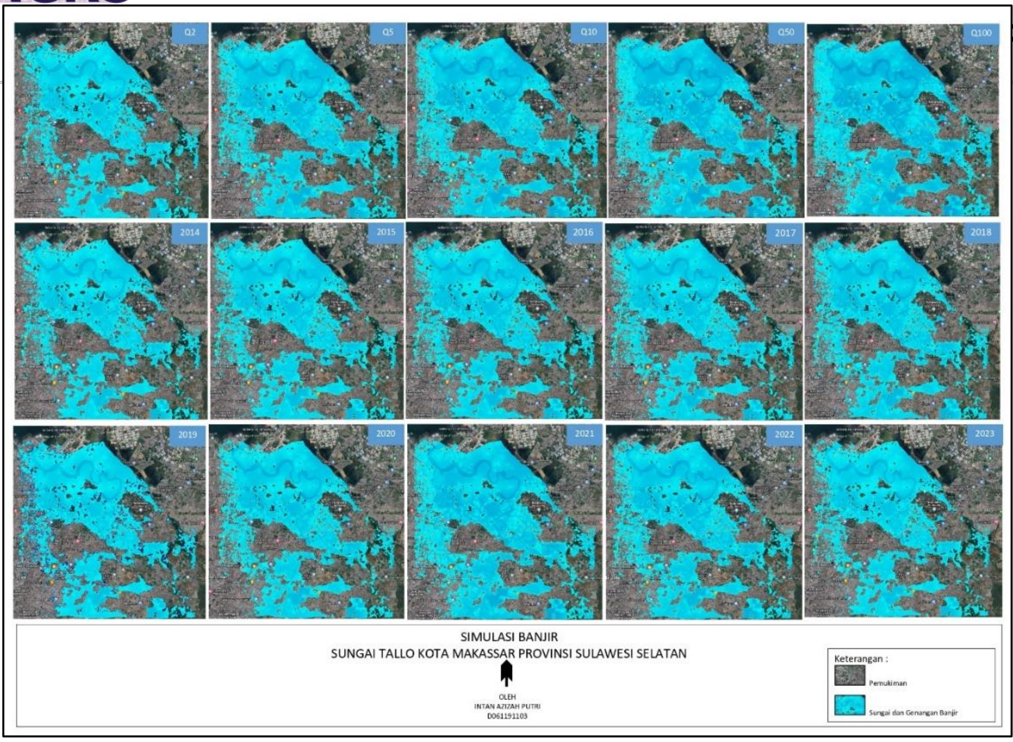

Figure 5. Flooding simulation by HEC-RAS tool in the Tallo River basin

5.7 Flood Simulation

Upon digitizing river geometry, we utilize HEC-RAS software to do flood modeling. Subsequently, we entered data from the calculations of annual discharge and annual anticipated discharge at steady flow into the HEC-RAS software. The HEC-RAS program findings indicate the following values for the Flood Inundation Area, as recorded in both the yearly simulation and the annual plan simulation.

5.8 Data Validation

Arun Goel (2011) states that two error level criteria are employed for data validation: the correlation coefficient (R) and the root mean square error (RMSE). These are applied to the inundation height data derived from simulations of annual discharge and plans, in conjunction with flood elevation values obtained from field interviews.

The correlation between simulation data and observational data is 97%, with a R value of 0.97489. The correlation is effective, with a coefficient value of $0.75 < R \leq 0.99$. The simulation results indicate that the flood event in 2021, which involved buildings, has the highest accuracy in relation to annual discharge statistics. The projected discharge for the second year nearly aligns with the precision of the annual planned flood.

Table 4. Innudation simulation on Tallo river basin by area per year.

No	Year	Area (Km^2)
1	2014	28,5206
2	2015	29,9636
3	2016	30,1809
4	2017	30,4394
5	2018	31,3253
6	2019	27,9684
7	2020	31,0897
8	2021	35,1579
9	2022	32,1888
10	2023	28,8553

Table 5. Discharge simulation for assessment of inundation area on annual plan.

No	Period	Area (Km^2)
1	Q2	30,4997
2	Q5	32,9704
3	Q10	34,2996
4	Q50	36,6417
5	Q100	37,4612

6. Conclussions

The research region is influenced by various rock and soil types, including tuff and agglomerate layers, and elements ranging from fine sand to clay. This affects the runoff coefficient, which can lead to flooding when rivers exceed their capacity. The region's geomorphology, including fluvial plain units and fluvial systems, also contributes to the runoff coefficient.

The Tallo River, with significant sediment and the Hassing method, has elevated the runoff coefficient. The study area experienced varying discharge distribution from 2014 to 2023, with an increase in discharge and flood inundation area between 2014 and 2018. The most significant flood in 2021 was recorded at 3717.9 m^3/second, inundating an area of 35.15 km^2. The projected annual flood inundation area for the region has increased, with regions susceptible to flooding increasing by percentages. The study concludes that the region's geomorphology and the application of the Hassing method contribute to the region's flood risk.

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