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Morphometry and Topographic Wetness Index Analysis for flood inundation mapping in Mata Allo watershed (South Sulawesi, Indonesia)

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Abstract

Lorem Along with climate change, natural disasters will occur more frequently such as floods. Floods that occur in watersheds which include various human activities, such as Mata Allo (Indonesia) will especially cause a large enough impact. The elongated shape of the watershed has a slow response to peak discharge and time lag. The Mata Allo watershed is dominated by slopes above 25%→45% (65%) and agricultural land use which accounts for 53% of the area, which has an obvious impact on the amount of runoff and erosion that occurs. The eroded soil will be carried away by surface runoff and deposited in the plains between mountains and river floodplains. Based on the results of the study, the Topographic Wetness Index (TWI) map indicates that the part between the mountains and the floodplain around the Mata Allo river had a high TWI value. A high TWI value indicates a high vulnerability to anticipate flooding in the event of overflowing from the Mata Allo River. River morphometry, land use, and hydrological behavior in a watershed are closely related to the TWI value in the Mata Allo watershed.

Keywords: *modelling, hydrodynamics, mitigation, flood, watershed, morphometry*

Rezumat. Analiza morfometriei și a indicelui topografic de umiditate pentru cartarea inundațiilor în bazinul Mata Allo (sudul insulei Sulawesi, Indonesia)

Datorită schimbărilor climatice, dezastrele naturale, precum inundațiile, se vor produce cu o frecvență mai mare. Inundațiile din cadrul bazinelor hidrografice unde se desfășoară diverse activități antropice, cum este cazul bazinului Mata Allo, vor avea în mod particular un impact considerabil. Ca urmare a formei alungite a bazinului, propagarea debitului maxim se face lent ceea ce duce la un decalaj și a timpul de producere. În cadrul bazinul Mata Allo predomină pantele cu o înclinare de 25-45% (65%) și terenurile agricole care reprezintă 53% din suprafața totală, ceea ce are un impact evident asupra cantității de apă scursă pe versant și eroziunii. Solul erodat este transportat o dată cu scurgerea de suprafață și apoi depus în zonele mai plane dintre munți și luncile râurilor. Pe baza rezultatelor acestui studiu, harta indicelui topografic de umiditate (ITU) indică faptul că zona situată între munți și luncile râurilor din Mata Allo prezintă o valoare ridicată a acestui indice, ceea ce indică o vulnerabilitate ridicată pentru anticiparea inundațiilor în cazul unor precipitații abundente ce ar duce la revărsări ale râului Mata Allo. Morfometria râului, utilizarea terenurilor și comportamentul hidrologic din cadrul bazinului hidrografic sunt într-o strânsă relație cu valorile ITU.

Cuvinte-cheie: *modelare, hidrodinamică, atenuare, inundație, bazin de recepție, morfometrie*

Introduction

Global climate change causes extreme rains and floods. Floods have become a serious threat in several countries in the world, especially in Indonesia over the last few decades. The ratio of the occurrence of this disaster is increasing due to high urbanization and continuous development around the river (Chang et al., 2014). The Mata Allo watershed contains residential areas located on the banks of the river which are prone to be affected in the event of a flood. The Mata Allo watershed, which is dominated by hills and mountains with high rainfall, has the potential for flooding in the watershed area (Enrekang Regency Regional Disaster Management Agency, 2021). 57.18% of the Mata Allo watershed is agricultural land, this will trigger flooding during the rainy season, which in general agricultural land is located on a slope of 15-25%. All areas on the earth's surface close to settlements, agriculture, and industry, there is a need for future projections of flood risk to improve the possible mitigation actions (Tramblay et al., 2014).

Due to the concurrent effects of climate change, human activities, land use, and hydrological problems, it is unavoidable and must be addressed in flood risk evaluation (Zhang, 2014). The risk of flooding is defined as a function of both the probability of a flood happening and its impact (Fernández & Lutz, 2010). Floods can cause death and loss of property. High rainfall lasting for a long time can trigger major floods (Sholihah et al., 2020). High-strength floods can cause damage to settlements, agricultural land, road infrastructure, bridges, and human deaths (Carrivick, 2006; Kelley & Prabowo, 2019). The identification, mapping, and zoning of flood-prone areas are critical, becoming more challenging and pressing for our society (Grimaldi et al., 2013). Flood inundation modelling in watersheds and urban areas is important for mitigation and development planning (Chen et al., 2009; Cea & Costabile, 2022). Modeling inundation areas by utilizing Geographic Information Systems (GIS) will be easier to carry out. Flood analysis is due to utilizing spatial data that includes spatial, environmental or regional concepts (Mitchell et al., 2002). So that in estimating areas that have the potential to experience flooding will be easier. The use of GIS is very beneficial in modeling flood events because the input data entered is geographically oriented so that the model formed is not much different from the real model in the field (Vogiatzakis, 2003). Floods that occur in an area are strongly influenced by the duration of the rain, the distribution of rainfall, the topography of the watershed, and land use (Zoccatelli et al., 2010). Changes in the use of forest land to agricultural land will increase by 7% of surface runoff when it rains (Choi, 2007; Guzha et al., 2018). The Mata Allo Watershed (DAS) is an area that often experiences flooding. One of the efforts to anticipate future flood events can be done by identifying and mapping areas that are potentially affected by flooding. This study aims to identify potential flood hazards based on the Topographic Wetness Index (TWI) approach in the Mata Allo watershed. TWI can be used as an indicator to determine potential flood areas so that it can be used as a reference for further regional management.

Study Area

The Saddang and Mata Allo watersheds are located in the central part of South Sulawesi. The total area of the Mata Allo watershed is 923,090 km2. Located at 3° 14' 36″ S to 3° 50' 00″ S and 119° 40' 53″ E to 120° 06' 33″ E (Fig. 1). The area of Enrekang Regency has a tropical climate with air temperatures ranging from 21°–32°C. The relative humidity level ranges from 77% to 83%. Rainfall in the Mata Allo watershed tends to be high throughout the year, ranging from 2,300–2,900 mm/year with the number of rainy days ranging from 160 to 220 rainy days/year. Geomorphology in general, the Mata Allo watershed consists of hilly, mountainous, and karst topographic areas.

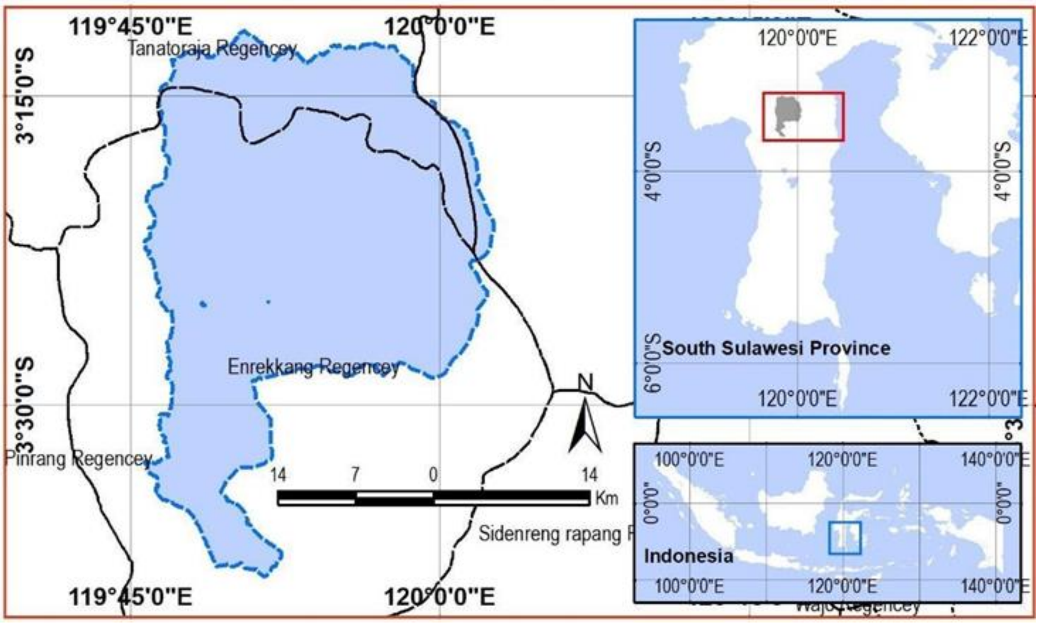

Fig. 1: Research Location Map

The hilly area extends from north to south, with an altitude between 200-1000 meters above sea level. The mountainous area is in the east with an altitude of more than 1000 meters above sea level. While the karst topography is in the middle of Mata Allo watershed. The geology of the study area is composed of a Latimojong formation consisting of shale, filling, chert, marble, quartzite, and quartz which is intruded by medium to alkaline igneous rocks with a formation thickness of more than 1000 meters, which is estimated to be limestone age. The western part consists of reef limestone, marl, conglomerate, shale which is part of the Toraja formation. The land use/land cover consists of settlements, shrubs, primary forest, secondary forest, dryland agriculture, savanna/grassland, rice fields, open land, mixed gardens. and forest. The Mata Allo watershed is dominated by hilly and mountainous topography. On the other hand, there are alluvial plains and flood plains along the edge of a river.

Method

Data used in this study consisted of land use/land cover, geological, geomorphology, slopes, soil types and watershed morphometry. Land use data were obtained from the Regional Development Agency of Enrekang Regency. Geological and Geomorphology data obtained from Geological and geomorphology maps with a scale of 1:50,000. For rainfall and soil type data obtained from the Department of Agriculture, Enrekang Regency.

All data is then processed in ArcGIS to make it a single data unit. To generate morphometric data, Digital Elevation Model (DEM) data is used, obtained from the official website of Indonesia: http://tides.big.go.id/DEMNAS. This DEM data has a resolution of 0.27 arcsecond or 8.3m, making it suitable for use for 50,000 scale map data after resampling. DEM data is used to create slope and elevation data and it is also used for defining sub-watershed boundaries, parameter areas, linear parameters, drainage network characteristics, and relief parameters. The collected data is then presented spatially for later analysis using a mapping application.

Topographic Wetness Index (TWI) is calculated using Digital Elevation Model data processed using ArcGIS 10.4 software. The Topographic Wetness Index is used to determine the condition of the groundwater table and was calculated using the following formula (Beven & Kirkby, 1979);

$$\mathrm{TWI} = \ln(\alpha/\tan\beta)$$

where α is the upslope contributing area per unit contour length and tan β is the slope. Then the TWI results are used to form a prone area inundation class based on the values formed. Formula for the calculation in obtaining TWI which is applied to the data that has been prepared can be seen in the following table (Table 1, 2, 3).

Table 1 Formula used for the computation of Areal Parameters

No.	Parameters	Formula	Definition	Units	References
1	Form Factor (S_b)	$R_f = \frac{A}{L^2b}$	A/Lb^2	Dimensionless	Horton (1945)
2	Shape Factor (S_b)	$S_b=L^2{}_{b/A}$	L=Basin Length (km), A=Area of the basin (km^2)	Dimensionless	Horton (1945)
4	Circulatory Index (I_c)	$I_c = \frac{A}{Ac} = \frac{4\pi A}{P^2}$	A = Area of the basin (km^2), A_c= Area of the circle having equal perimeters as that of drainage basin (km^2)	Dimensionless	Miller (1953), Strahler (1964)
5	Compactness Coefficient (C_c)	$C_c= \frac{P}{2\sqrt{\pi A}}$	Perimeter/Perimeter of Circle of Watershed	Dimensionless	Gravelius (1914)
6	Elongation Ratio (R_e)	$R_e=\left(\frac{Dc}{Lb}\right)=\left(\frac{2}{Lb}\right)\sqrt{\frac{A}{\pi}}$	D_c = Diameter of the circle having the same area as that of the basin (km), Lb = basin length (km)	Dimensionless	Schumm (1956)
7	Texture Ratio (R_t)	$R_t = \frac{N_2}{P}$	N_1 = number of first order streams and P = Basin Perimeter (km)	km^{-1}	Horton (1945)
8	Drainage Density (D_d)	Dd=(ΣLt)/A	ΣLt/A, where ΣLt is the total length of all the ordered streams 1/2Dd	Km/km^2	Horton (1932, 1945)
9	Stream Frequency (F_s)	$F_u = \left(\frac{N}{A}\right)$	N=total number of stream segments of all orders, A=basin area (km^2)	km^{-1}	Horton (1932, 1945)

Table 2 Formula used for the computation of Linear Parameters

No.	Parameters	Formula	Definition	Units	References
1	Stream Order	-	Hierarchical Rank	Dimensionless	Strahler (1964)
2	Basin Length (L_b)	-	Maximum Length Of The Basin measured from the outlet	km	Schumm (1956)
3	Average Basin Width (B)	$B = \left(\frac{A}{L_b}\right)$	A=basin area (km^2) and L_b=basin length	km	-
4	Bifurcation Ratio (R_b)	$R_b = \left(\frac{N_u}{N_{u+1}}\right)$	N_u=Number of stream segments of next higher order u+1	Dimensionless	Schumm (1956)
5	Stream Length (L_u)		Length of the stream	km	Horton (1945)
6	Stream Length Ratio (R_L)	$R_L = \frac{L_u}{L_{u-1}}$	L_u=average length of stream of order u L_{u-1}=average length of stream of order u-1	Dimensionless	Horton (1945)
7	Length of Overland Flow (L_o)	$L_o = \frac{1}{2D_d}$	L_o=length of overland flow D_d=drainage density (km/km^2)	Km	Horton (1945)

Table 3 Formula used for the Computation of Relief Parameters

No.	Parameters	Formula	Definition	Units	References
1	Watershed Relief (H)	$H = Hh - Hl$	The elevation difference between the highest and the lowest point	M	Strahler (1952)
2	Relative relief (R_R)	$= R_R \times 100$	R_R=Relative relief (%) H= Watershed relief (m) and L_p=Length of the perimeter (m)	%	Melton (1957)
3	Relief ratio (R_r)	$R_r = \left(\frac{H}{L_b}\right)$	H=Watershed relief (m) and L_b=basin length (m)	Dimensionless	Schumm (1956)
4	Ruggedness number (R_R)	$R_n = HxD_d$	H = Watershed relief (km) and D_d= drainage density (km/km^2)	Dimensionless	Schumm (1956)
5	Geometric number	Geometric number $= \frac{HxD_d}{S_g}$	H= watershed relief (km) D_d= drainage density (km/km^2) S_gSlope of ground surface (sg=2.H.Dd)	Dimensionless	Suresh (2012)

Overall analysis was carried out using ArcMap software by inputting data on each attribute table on each research variable. The flow of work and analysis carried out in this research can be briefly presented in the form of a research flow diagram as follows. Where a, is the local upslope area draining through a certain point per unit contour length and β is the local slope.

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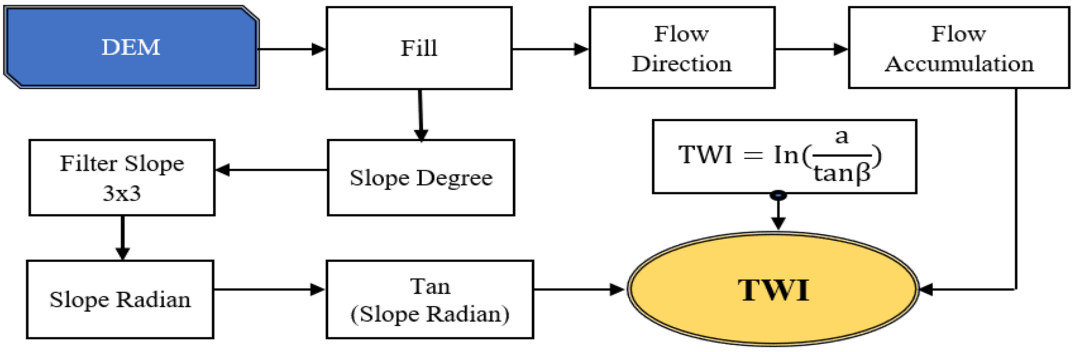

Fig. 2: Analysis Flow Chart

Results and Discussions

Basic Data Analysis

Figures 4, 5 and 6 show the basic maps used as the basis for data analysis. Spatial data used in the form of geological data, geomorphology, soil type, slope, land use land cover, and sub-watershed. Some data such as geological data, geomorphology, soil types are obtained from agencies such as the Ministry of Environment and Forestry and the Geospatial Information Agency. Other data such as slope and subdas data obtained from the results of DEM analysis (Cheah et al., 2019).

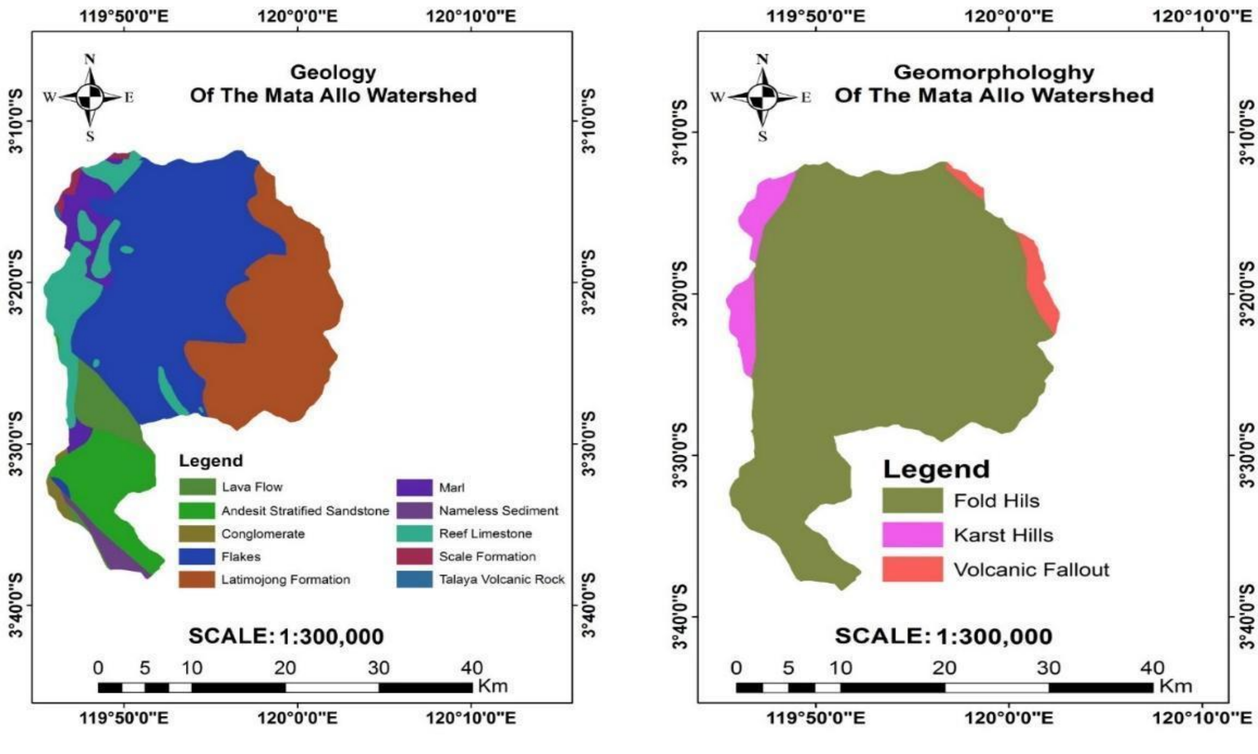

Fig. 3: Geology (left) and Geomorphology (right) map of Mata Allo Watershed

Watershed Area (A)

The area of the Mata Allo watershed is divided into 19 segments. The division of each sub-watershed (SW) is created using ArcGIS 10.4. The total area of the Mata Allo watershed is 923,090 km2, which is included in the large watershed category because it is more than 100 km2 (Horton, 1945). For the analysis of morphometric characteristics, the Mata Allo watershed is divided into 19 sub-watersheds. The area of each sub-basin is between 7,200 km2 – 179.579 km2. The area of the watershed based on slope and land use can be seen in the Table 4-5.

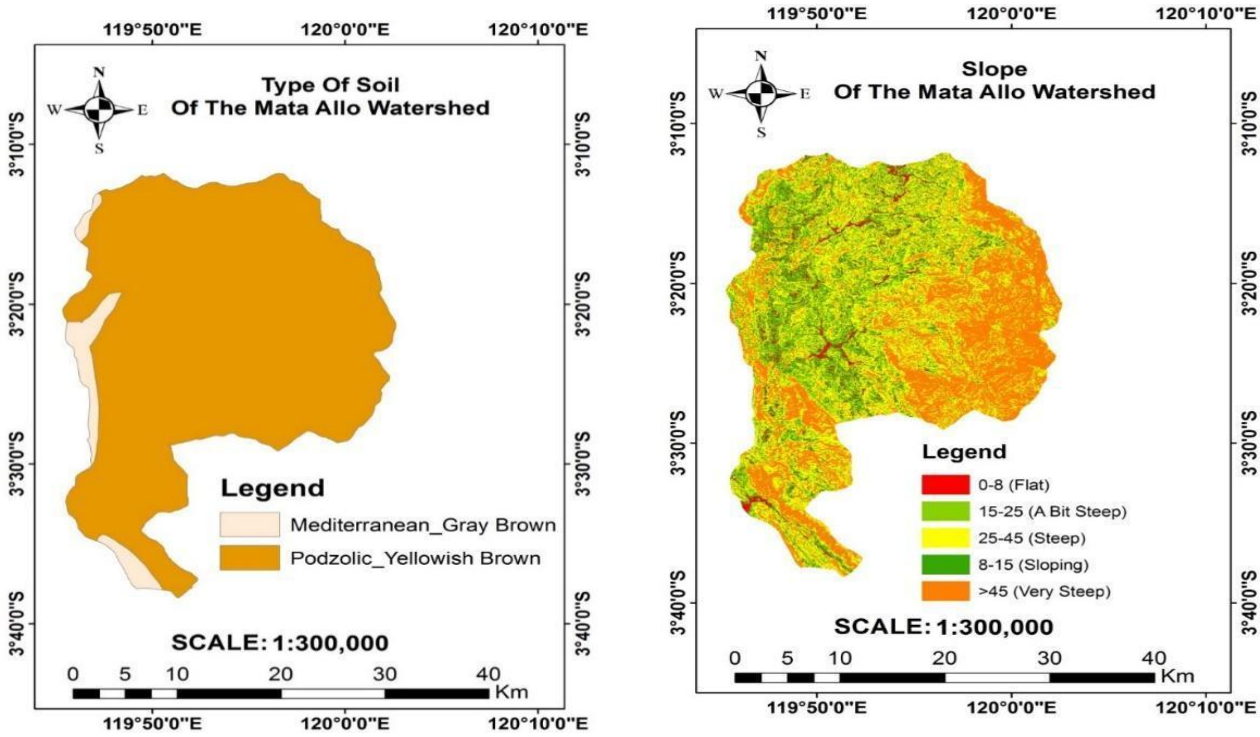

Fig. 4: Soil Type (left) and Slope Class (right) map of Matta Allo Watershed

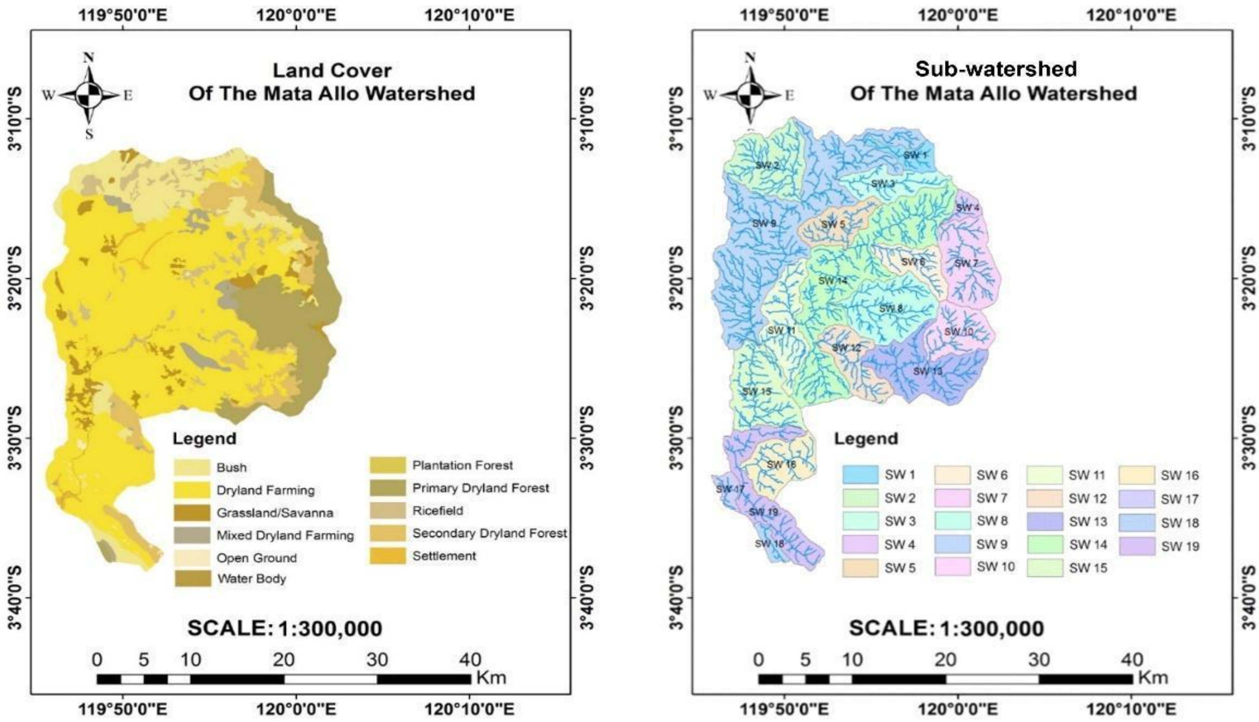

Fig. 5: LULC (left) and Sub-watershed (right) map of Matta Allo Watershed

Stream Length (Lu)

The stream length is hence an indicator of the relationship between vegetation, climate, physical properties of rock, and intensity of soil erosion (Bajabaa et al., 2013). The total length of order 1 to order five of the 19 sub-watersheds is 1460.11 km. Based on the data, the total length of each suborder is almost 2 times greater than the length of the order one level lower. Trendline analysis using logarithmic, between the order level and the total length of the suborder stream, the value of R2 (coefficient of determination) = 0.9784, r (coefficient of correlation) = 0.881.

Using y=-485 ln(x)+757.81 ……………………….… (1).

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The correlation coefficient value shows that the order level and the total length have a very significant relationship (0.88), with a coefficient of determination of 0.97. A complete table regarding the length of rivers can be seen in Appendix 5-6.

Table 4 The slope of Mata Allo Watershed

No.	Slope	Area (km2)	%
1	0-8	40.56	0.04
2	8-15	97.53	0.10
3	15-25	192.44	0.20
4	25-45	313.60	0.33
5	>45	302.03	0.32

Table 5. Landuse of Mata Allo Watershed

No.	Land Use	Area (ha)	%
1	Waterbody	205	0.21
2	Primary dryland forest	12,201	12.79
3	Secondary dryland forest	7,466	7.83
4	Plantation Forest	106	0.11
5	Settlement	711	0.75
6	Open ground	127	0.13
7	Savanna/grassland	3,712	3.89
8	Dryland farming	54,071	56.70
9	Mixed dry land farming	2,366	2.48
10	Scrub	10,961	11.49
11	Rice Field	3,439	3.61

Drainage Texture (Dt) and Drainage Density (Dd)

The distance between streams is an important geomorphological aspect. Drainage texture for the 19 Mata Allo subbasin is influenced by rock type, rock weathering level, rainfall, temperature, vegetation, soil type, relief, infiltration capacity, and weathering depth of rock and soil solum depth. Land use, its types, and density also play an important role in determining the drainage texture (Kale and Gupta, 2001; Kopecký et al., 2021).

For 19 sub-basin Mata Allo all values of drainage density are included in low (<2). Low drainage density in the Mata Allo watershed indicates highly permeable subsoil material. Based on geology, Mata Allo watershed is dominated by igneous rock and sediment. For more details on the characteristics of Drainage Texture and Drainage Density of watershed, see the table in the Table below.

Table 6. Classification drainage density and drainage texture Mata Allo Watershed

No.	Drainage density (Km/Km^2)	Drainage texture
1	< 2	Very course
2	2 - 4	Course
3	4 - 6	Moderate
4	6 – 8	Fine
5	>8	Very fine

Form Factors (f) and Shape Factors (Sf)

Form factor indicates the flood formation, degree of erosion, and transport capacities of sediment load in a watershed. The shape factor affects the time of increasing and decreasing peak discharge when it rains. The value of form factor for 19 sub-watershed the all between 0.154-0.569. It shows all basin shapes elongated to slightly rounded.

Mata Allo's subwatershed form factors which are very long are SW1, SW3, SW9, SW11, SW14 (very long). The hydrological response to this form is the peak discharge time and the long lag time. This also occurs in SW17 and SW18 (elongated) which have long peak discharge hydrological response characteristics. While SW2, SW7, SW10, and SW16 have a response time of reaching peak discharge and faster lag time. The response of the basin to overland flow, surface runoff, peak flow, lag time, flood during and after rainfall is influenced by the shape factor. The circular basin has the response after rainfall. The Complete table of Form factors and Shape Factors of Mata Allo watershed can be seen in Table below.

Table 7. Classification form factor and shape of Watershed

No.	Form Factor	Shape of Basin
1	< 0.22	Very long
2	0.22 – 0.30	Elongated
3	0.30 – 0.37	Slightly elongated
4	0.37 – 0.45	Neither elongated nor widened
5	0.45 – 0.60	Slightly widened
6	0.60 – 0.80	Widened
7	0.80 – 1.20	Very widened
8	>1.20	Surrounding the drain

Length Overland Flow (lo)

Form The length of overland flow can be defined as the length of the flow of water over the ground before it becomes concentrated in definite stream channels (Singh, 1989). The average length of overland flow ((Lo)) is approximately half the average distance between stream channels (Horton, 1932). The length overland flows its categorization into 3 groups namely: low (< 0.2), moderate (0.2 - 0.3) and high (> 0.3). All sub-basin of Mata Allo (SW1 – SW19) belong to the high category (0.61-0.91). This shows that the Mata Allo sub-basin has the characteristics of a gentle slope, long flow path, more infiltration, and reduced runoff. More details can be seen in the Appendix 1.

Circularity Ratio (Rc)

In Mata Allo's subwatershed, the Rc value varies between 0.149 – 0.717. Low values occur in SW9, SW14, and SW19 (0.149, 0.172, and 0.185), this indicates that the influence of geological and geomorphological structures is low. While high Rc values are found in SW7 and SW10 (Rc values are 0.717 and 0.681, respectively), this indicates that the area is strongly influenced by geological structures. Meanwhile, SW1, Sw2, SW3, SW4, Sw5, Sw6, SW8, SW11, SW12, and SW13 were only slightly influenced by geological and geomorphological structures (Strahler, 1964). More details can be seen in the Appendix 2.

Elongation Ratio (Re)

Schumm (1956), suggested that the shape of a drainage basin be described in the same manner as the shape of rock grain by using the Wadell sphericity ratio. The Re ratio generally varies between 0.60 to 1.0 (Singh, 1989). The ratio of all sub-watershed Mata All0 varies from 0.44 to 0.87. Based on Re Mata Allo Watershed of strong relief and steep ground slopes. The Re shows an increase in elongation with increasing drainage area. Smaller values mean the watershed is elongated. Shows more elongation and is more susceptible to erosion and sediment loads with a smaller infiltration capacity. This happened to SW3, SW9, SW14, and SW19. More details can be seen in the Appendix 2.

Ruggedness Number (Rn)

Rn values are low at SW17 and SW 18 (0.75 and 0.59). This shows a relatively flat basin area. In these areas, the drainage density is relatively lower and less susceptible to erosion, and tends to deposition. Rn values are moderate at SW5, SW11, and SW16 (1.04, 1.83, and 1.77). This subwatershed shows a hilly area with a moderate slope. Meanwhile, SW7, SW13, and SW14 have high scores (3.52, 3.86, and 3.64). This indicates an area whose topography is steep. Very susceptible to erosion, thin soil thickness, and low TWI value. More details can be seen in the Appendix 1.

Compactness Coefficient (Cc)

This is the ratio between the circumference of the basin with the circumference of a circle to the area of the same watershed (Horton, 1945). Cc is independent of watershed size and only depends on slope. The cohesiveness coefficient is directly proportional to the erosion risk assessment i.e. lower values imply less vulnerability to risk factors, while higher values indicate greater vulnerability and represent the need for implementing conservation measures. Lower values of this parameter indicate more basin elongation and less erosion, while higher values indicate less elongation and high erosion (Patel et al., 2012). More details can be seen in the Appendix 2.

Stream Frequency (Fs)

Stream Frequency may be directly related to the solum depth of soil, rock weathering rate, and intensity of soil erosion. It mainly depends upon the lithology of the watershed and reflects the texture of the drainage network. Horton (1945) states that the total number of stream segments of all orders per unit area is the stream frequency. The stream frequency for the all sub-watershed Mata Allo is 2.19 – 3.16, with an average of 2.67. The high Fs is 3.16 on SW5, due to the predominantly agricultural area. In agricultural land, the stream has a high frequency, because land processing activities facilitate erosion, as the initial process of channel formation. While in SW12 the lowest is 2.19 because the area is forest. In the subwatershed that has a high channel frequency, it will accelerate the accumulation of surface runoff into the channel, thereby accelerating the occurrence of peak discharge and vice versa. If the drainage density and relief are high and the slope is steep and long then the ruggedness number is also high (Strahler, 1956; Waikar & Nilawar, 2014). More details can be seen in the Appendix 2.

Relief Ratio

The relief ratio is an indicator of the intensity of the erosion process and solute transport, suspended sediment, and bedload. Relief ratio values are low in SW5, SW9, SW11, SW14, and SW18. A lower Re value indicates the presence of bedrock that is resistant to weathering, forming small hills and low slopes. While the high relief ratio values are found in the subwatershed in SW4 and SW10, these results indicate that in these areas there are strong erosion processes, the bedrock is relatively easily weathered, while the other subwatershed are categorized as moderate values. The relief ratio is also important in assessing floods, especially in hydrological and physiographic control.

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The Topographical wettability index (TWI) is the steady-state wettability index. It is commonly used to measure the topographical control of hydrological processes. The index is a function of the slope and upstream area that contributes per unit width orthogonal to the flow direction. The index is designed for hillside catenas. The amount of accumulation in flat areas will be very large, so TWI will not be a relevant variable. The index is highly correlated with several soil attributes such as horizon depth, silt percentage, organic matter content, and phosphorus. The method of calculating this index differs mainly in how to calculate the contribution area of the upslope. Soils formed on alluvial plains from exogenous energy processes include temperature, rainfall, topography, and rock types.

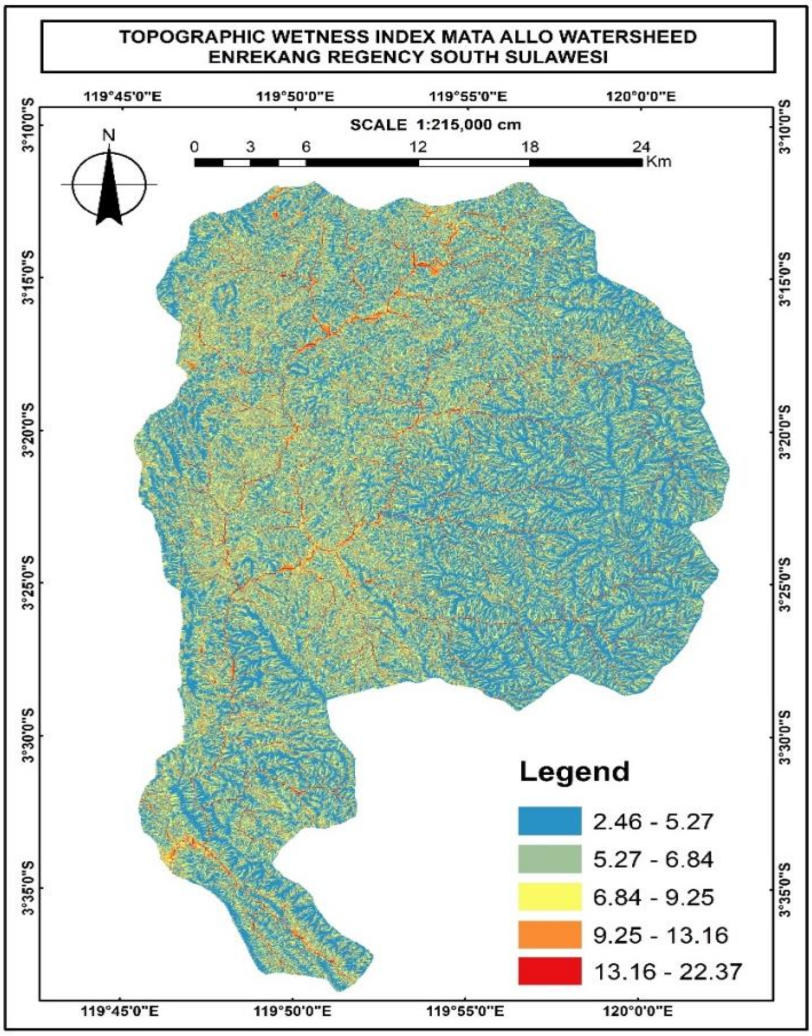

Fig. 6: TWI Map of Mata Allo Watershed

The alluvial plain in the Mata Allo watershed occupies the area between the mountain and the river valley plain, whose material comes from the upstream or upper part of the slope. The groundwater potential in the Mata Allo watershed on alluvial plains is higher so that the moisture index is higher than the soil on the steep slopes. The polar nature of water results in the attraction of water molecules for each other (cohesion) and the attraction of water for other surfaces, such as clay (adhesion). Adhesion and cohesion are important because, among other things, they provide the soil with the ability to store water. The capillarity that water will move up into the tube, can increase the wetness of soil on the surface (McLaren & Cameron, 2004). The movement of water on the slopes of the Mata Allo watershed is strongly influenced by the total potential energy of the water. The potential energy of gravity is high on steep slopes (low TWI values), indicating that the movement of water will always go to the flat lower slope (high). The TWI index is reliable information to the public about the flood risk to identify future flood-prone areas (Cook & Merwade, 2009). TWI is one of the factors that show the potential for accumulation of surface run-off, intermediate flow, and baseflow.

Table 8 Area of TWI Mata Allo Watershed

No.	TWI	Inundation Susceptibility Level	Area (Km^2)
1	2.46 - 5.27	Very Low Inundation Susceptibility	366.79
2	5.27 - 6.84	Low Inundation Susceptibility	363.68
3	6.84 - 9.25	Moderate Inundation Susceptibility	144.78
4	9.25 - 13.16	High Inundation Susceptibility	57.30
5	13.16 - 22.37	Very High Inundation Hazard	13.63

The higher the TWI value, the higher the occurrence of runoff, so it can be used as a quick method for identifying flood-prone areas. The amount of accumulated water flow in flat areas is higher than on steep slopes. TWI is highly correlated with several soil attributes such as the depth of the soil horizon, the percentage of dust, and the content of organic matter (Sørensen et al., 2006; Schoonover & Crim, 2015). Soil that has a high organic matter content, can bind water well. high because it has a high outer charge, as well as soils containing clay and dust, have high water-binding abilities, and are difficult to release water because the bond between water and soil is very strong because it is dominated by micropores and the surface charge on clay and dust is high.

TWI in the Mata Allo watershed, in response to earth's gravity (Pourali et al., 2014). This is related to the high TWI value of the Mata Allo River which is spread around the alluvial plains around the riverbanks and the alluvial plains between the mountains. This is also related to the condition of alluvial plains where the material has a relatively coarse texture, has many macropores, so the effect of gravitational potential is higher, compared to the effect of the matrix potential. The highest TWI value is 13.16 - 22.37 with a percentage of 1.44% (13.63) km^2. In 2021, agricultural land use in the Mata Allo Watershed which has reached 59.18% will increase the amount of runoff. Research in the Richland Creek Basin (Illinois, USA) shows that land-use change increases the average annual runoff by 7% (Choi, 2007; Hu & Shrestha, 2020). By knowing the distribution of TWI values in the study area, in this case the watershed. So the priority areas for efforts to avoid and prevent losses due to flood disasters can be done earlier. The resulting data can then be utilized by the local government, especially by the Regional Disaster Management Planning Agency. TWI which shows areas that are most likely to experience inundation due to surface runoff. spatially, regional development planning can be carried out in tackling and anticipating disaster events such as floods.

Conclusion

The Mata Allo watershed is elongated. The morphometric characteristics that have a response to rain are peak discharge and lag time which take a long time to achieve. The slope of the slope is 25→45%, the area is 65%, this triggers the velocity of surface flow, intermediate flow, and base flow to the bottom of the slope due to the influence of gravitational potential energy. Likewise, the change in forest land use to agriculture has reached 59.18%, which will increase surface runoff, erosion on the upper slopes and upstream of the river, while on the plains in the area between the mountains and the riverbanks there will be sedimentation in the Mata Allo watershed. Increased erosion and deposition processes will thicken the sedimentary material which will become the parent material for soil formation. Sedimentary material that's mixed between coarse and clay materials will increase the ability to bind and store groundwater. The ability to bind and store groundwater (aquifer) will increase the value of soil moisture. Soil that has high humidity will reduce the infiltration capacity so that if the rainfall intensity is higher than the infiltration capacity, there will be inundation. Thus the area in the Mata Allo watershed that has a high TWI value has a risk of inundation when it rains (13.63 km2).

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Author Contribution

Designing research concepts, U.; data processing and article writing, N.A.H.; formulation and interpretation of research results, M.L., and S.N. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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Appendix

Appendix 1. The value of relief parameters

Parameters	H	Rr	Lo	Rn
SW 1	0.36	0.18	0.76	2.29
SW 2	0.00	0.12	0.91	2.08
SW 3	0.31	0.14	0.73	2.64
SW 4	0.37	0.31	0.70	2.19
SW 5	0.46	0.07	0.79	1.04
SW 6	0.20	0.23	0.73	3.41
SW 7	0.27	0.24	0.70	3.52
SW 8	0.16	0.20	0.80	3.81
SW 9	0.21	0.05	0.85	2.59
SW 10	0.33	0.28	0.74	3.39
SW 11	0.25	0.08	0.80	1.83
SW 12	0.24	0.14	0.80	2.38
SW 13	0.20	0.19	0.75	3.86
SW 14	0.16	0.07	0.83	3.64
SW 15	0.09	0.12	0.82	2.39
SW 16	0.07	0.14	0.72	1.77
SW 17	0.06	0.10	0.70	0.75
SW 18	0.26	0.09	0.61	0.59
SW 19	0.04	0.14	0.71	1.69

Appendix 2. The value of areal parameters

Parameters	Rf	Sb	Rc	Compactness of Coefficient	Re	Rt	Dd	Fs	Constant of Channel Maintenance (Cc)
SW 1	0.20	5.01	0.37	1.65	0.50	0.77	1.52	2.34	0.66
SW 2	0.60	1.68	0.57	1.33	0.87	2.06	1.81	2.67	0.55
SW 3	0.18	5.50	0.35	1.68	0.48	1.41	1.45	3.05	0.69
SW 4	0.33	3.03	0.52	1.39	0.65	0.71	1.40	2.34	0.72
SW 5	0.29	3.42	0.48	1.44	0.61	1.67	1.57	3.16	0.64
SW 6	0.25	3.96	0.45	1.50	0.57	1.26	1.46	2.56	0.68
SW 7	0.48	2.08	0.72	1.18	0.78	2.30	1.40	2.61	0.71
SW 8	0.38	2.61	0.58	1.31	0.70	2.23	1.59	2.74	0.63
SW 9	0.19	5.38	0.15	2.59	0.49	1.99	1.70	2.67	0.59
SW 10	0.51	1.95	0.68	1.21	0.81	2.04	1.47	2.98	0.68
SW 11	0.20	4.98	0.35	1.69	0.51	1.53	1.60	2.66	0.62
SW 12	0.42	2.37	0.35	1.69	0.73	1.28	1.60	2.19	0.62
SW 13	0.32	3.11	0.38	1.62	0.64	1.93	1.50	2.78	0.66
SW 14	0.15	6.48	0.17	2.41	0.44	2.09	1.66	2.93	0.60
SW 15	0.38	2.62	0.56	1.34	0.70	2.26	1.64	2.84	0.61
SW 16	0.50	2.01	0.64	1.25	0.80	1.78	1.44	2.50	0.69
SW 17	0.29	3.40	0.49	1.43	0.61	0.86	1.40	2.99	0.71
SW 18	0.24	4.26	0.46	1.47	0.55	0.64	1.21	2.36	0.83
SW 19	0.18	5.72	0.19	2.33	0.47	1.05	1.42	2.30	0.70