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Spatial Analysis of Water Infiltration Potential in the Miu Watershed of Sigi Regency

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Abstract. The Miu Watershed is essential in supplying clean water for the community's needs and as a source of irrigation water for agricultural land in the Sigi Regency. Despite having an important role, the Miu Watershed is frequently hit by floods and landslides, resulting in economic, social and environmental losses. Low water absorption capacity will affect surface water runoff resulting in flooding. This study aims to identify the potential for water absorption in the Miu watershed based on four spatial parameters, namely land use, rainfall, soil type, and slope, as determining factors for the condition of water catchment areas. The method used in this study is the scoring and overlay method to obtain the condition of the water catchment area based on current conditions. Spatial data analysis uses a Geographic Information System (GIS) by adding up the results by multiplying the scores and weights of each different parameter. The analysis results produce four conditions of the water catchment area: good, naturally normal, critical start, and critical conditions. The condition of the Miu watershed catchment with the most significant area is 53,727.64 ha (81.98%) of the total area of the study area with normal natural conditions.

Keywords: MIU watershed, watershed potential, geographic information system (GIS)

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1. Introduction

Watersheds in Indonesia are currently experiencing damage due to changes in land use and human activities; this impacts the environment and society, such as landslides, erosion, drought and floods [1]–[3]. Changes in land use affect the function of the watershed, one of which is the impact of reducing water absorption [4], [5].

A water catchment area is an area that has a water catchment function through the process of seeping surface water into the ground [6]. Water catchment areas have a significant role in maintaining the stability of the hydrological cycle, including water catchment areas, water storage and water distribution

[7]. Some things that affect the water absorption process are soil type, land use, slope and rainfall.

Research on water absorption has been carried out in the Unda River Basin, Bali Province, regarding the identification of water catchment areas; the results of the study show that the Unda River Basin has good, normal, rather critical and very critical conditions based on the overlay results of the four parameters used [8]. Saputra, Ridwan and Nurlina [9] analyzed the Water Infiltration Rate Using a Geographic Information System in the Tabunio Basin; the results of the analysis were divided into five criteria, namely natural, normal criteria, starting critical, moderately critical, critical and very critical.

The Miu River Basin is one of the watersheds in Central Sulawesi Province, Sigi Regency, which has an area of 65,535.20 ha (Figure 1); the Miu River Basin is located in 5 Districts namely Lindu District, Palolo District, Kulawi District, Gumbasa District and South Dolo District. The Miu Watershed has an essential role for the community as a fulfilment of household needs and a provider of water for irrigation of agricultural land [10]. However, there are frequent floods [11] due to overflowing water in the Miu watershed and landslides [12] which result in economic, social and environmental losses.

Research on the analysis of water infiltration in the Miu watershed is a significant study for managing watersheds and preventing adverse effects such as floods and landslides. Information about water catchment areas in the Miu watershed still needs to be improved, so it is necessary to analyze the potential of water catchment areas. Based on the background described, this study aims to map the condition distribution of water catchment areas in the Miu watershed by utilizing a Geographic Information System (GIS) [13].

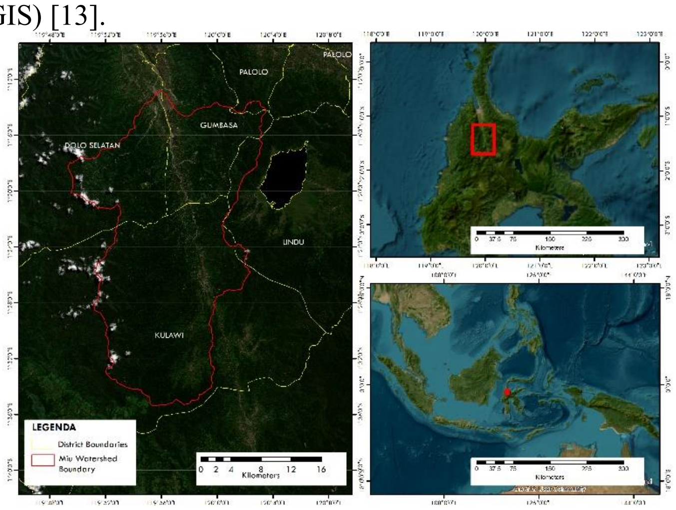

Figure 1. Map of Research Locations

2. Methods

The method used in this study is the scoring method based on the Regulation of the Minister of Environment and Forestry of the Republic of Indonesia Number 10 of 2022 concerning the Preparation of a General Plan for Forest and Land Rehabilitation of Watersheds and Annual Plans for Forest and Land Rehabilitation [14]. The materials used by the researchers are: (1) Sentinel 2A Image sourced from the Copernicus Open Access Hub web; (2) Rainfall data for the Indonesian region, sourced from the Climate Hazards Group InfraRed Precipitation with Station (CHIRPS); (3) Digital Elevation Model (DEM) data, sourced from the National Digital Elevation Model (DEMNAS); (4) Soil type data for Sigi Regency; (5) Miu watershed boundary shapefile. While the tools used are: (1) ArcMap 10.8 software is used to analyze sentinel 2A images and is used when overlaying each parameter; (2) Microsoft Office software is used to process data and write articles.

The parameters used in this study were land use, rainfall, soil type, and slope, with different scores and weights for each parameter (Table 1-4).

2.1 Water Infiltration Parameters Scoring

1. Soil type

Soil type affects the process of water absorption; sandy soil texture can absorb water faster than clay [15] due to the small particle size, which inhibits water movement. Scores and weights of soil types can be seen in Table 1.

Table 1. Score and weight of each soil type

No	Soli Type	Infiltration	Score	Weight
1	Regosol	Large	5	5
2	Aluvial dan Andosol	Rather Large	4	5
3	Latosol	Medium	3	5
4	Litosol	Rather Small,	2	5
5	Grumosol	Small	1	5

2. Slope

The slope of the slope has a significant effect on the ability of water absorption; steep slopes will drain water quickly without going through the infiltration process [16]. Conversely, a gentle slope will hinder the movement of runoff water. Scores and slope weights can be seen in Table 2.

Table 2. Score and weight of each slope

No	Slope (%)	Infiltration	Score	Weight
1	0-8	Large	5	2
2	8-15	Rather Large	4	2
3	15-25	Medium	3	2
4	25-40	Rather Small,	2	2
5	>40	Small	1	2

3. Rainfall

Rainfall affects the amount of water that falls to the ground surface; the high rain intensity will result in runoff of surface water that is higher than the water absorption capacity [17]. Scores and weights of rainfall can be seen in Table 3.

Table 3. Score and weight of each rainfall

No	Rainfall (mm/tahun)	Infiltration	Score	Weight
1	>5000	Large	5	4
2	4,500-5,000	Rather Large	4	4
3	3,500-4,500	Medium	3	4
4	2,500-3,500	Rather Small,	2	4
5	<2,500	Small	1	4

4. Land use

Land use is a parameter closely related to water absorption; land cover vegetation will increase water absorption to prevent surface water flow from increasing [18]. Land use scores and weights can be seen in Table 4.

Table 4. Scores and weights for each land use

No	Land Use	Infiltration	Score	Weight
1	Primary Dryland Forest, Secondary Dryland Forest	Large	5	4
2	Plantation	Rather Large	4	4
3	Bush	Medium	3	4
4	Dryland Agriculture, Mixed Dryland Agriculture, Fields, Drylands	Rather Small,	2	4
5	Water bodies, settlements, rice fields	Small	1	4

Data for each parameter is converted using ArcMap 10.8 software to produce vectorized data (.shp) which is then used as a map.

2.2 Classification of Water Catchment Area Conditions

Parameter vector data for each parameter is scored with an assessment of the score with the weight of each parameter; the assessment results are added to a new field in the attribute table. To determine the condition of the water catchment area, spatial vectorization results are overlayed using union analysis by combining the vector layers for each parameter into one vector layer. The overlay results are classified based on the criteria for the condition of the water catchment area.

$$Potensi\ Daerah\ Resapan = Kb.Kp + Pb.Pp + Sb.Sp + Lb.Lp \quad (1)$$

K = Soil type
P = Average rainfall
S = Land use
L = Slope
B = Weight value
p = Parameter class score

The water catchment interval value uses the Sturgess formula by dividing the most considerable and smallest data values.

$$Kelas\ Interval = \frac{(Xt - Xr)}{k} \quad (2)$$

Xt = Largest data
Xr = Smallest data
k = Number of classes

3. Results and Discussion

3.1. Spatial Parameters Determining Water Infiltration Potential

a. Type of soil

Various types of soil have different water absorption capacities. There are two types of soil in the Miu watershed, namely, alluvial and red-yellow podzolic. The Miu watershed is dominated by red-yellow podzolic soils covering an area of 60,327.17 ha with a rather large infiltration capability. Research by Amar, Muyassir and Hifnalisa [19] states that red-yellow podzolic soil types have a sandy texture to absorb water well. The alluvial soil type in the Miu watershed has a fine texture consisting of sand and clay, so this type of soil has a hollow soil structure that can absorb water quite well [20]. The following is the classification of soil types and infiltration rates in the Miu watershed (Table 5).

Table 5. Soil Type Classification and Miu Watershed Infiltration

No	Type of soil	Infiltration	Area (ha)	Percentage (%)
1	Red-Yellow Podzolik	Rather Large	60,327.17	92.05%
2	Alluvial	Medium	5,208.03	7.95%
	Total		65,535.20	100 %

b. Slope

The results of the analysis of the slope of the Miu watershed are pretty varied; as many as five classes of slope are known. Slope class, area, infiltration rate and percentage can be seen in table 6.

Table 6. Miu watershed slope

No	Slope	Information	Infiltration	Area (ha)	Percentage (%)
1	0-8	Flat	Large	2,169.09	3%
2	8-15	Sloping	Rather Large	2,869.99	4%
3	15-25	Wavy	Medium	5,182.21	8%

4	25-40	Steep	Rather Small,	11,288.01	17%
5	>40	Very Steep	Small	44,025.89	67%
		Total		65.535,20	100 %

able 6 shows that the topographical conditions of the Miu watershed are generally in steep and very steep conditions; this condition causes a lack of water seeping into the ground; this is in accordance with the research of Tamod, Aryanto and Purwiyono [21], which states that the steeper the slope will accelerate the flow of water surface area decreases as water is absorbed into the ground. Flat, sloping and undulating areas can absorb water well. The research results by Qur'ani, Harisuseno and Fidari [22] state that the lower the slope, the higher the infiltration rate.

c. Rainfall

Miu Watershed infiltration rainfall from 2014 - 2023 belongs to the small category, <2,500 mm. Based on Table 7, the average infiltration rain is 1,886.40 mm/year. According to Yunagardasari, Paloloang and Monde [23], low rainfall will minimize runoff so that the soil can absorb water. The following is Table 7 of Miu watershed rainfall data.

Table 7. Annual Rainfall from 2014-2023

No	Year	Rainfall	Average Rainfall (mm/year)	Infiltration
1	2014	1,726.32	1,886.40	small
2	2015	1,290.23		
3	2016	2,200.27		
4	2017	2,359.27		
5	2018	1,682.68		
6	2019	1,506.09		
7	2020	2,216.91		
8	2021	2,468.27		
9	2022	2,196.09		
10	2023	1,217.86		

d. Land Use

Land use is determined by several factors, including humans who use and cultivate land; excessive land use without regard to environmental and ecosystem aspects will cause problems such as floods and landslides. There are eight types of land use in the Miu watershed: primary dryland forest, secondary dryland forest, dryland agriculture, mixed dryland agriculture, settlements, paddy fields, shrubs and bodies of water. The land use of the Miu Watershed is dominated by primary dryland forest covering an area of 46,806.60 ha, which has dense vegetation in the form of trees; Anggun D stated [24] that land conditions with dense vegetation can absorb water well. The following is a data table for land use classification in the Miu watershed (table 8).

Table 8. Classification of Land Use Data

No	Land use	Infiltration	Area (ha)	Percentage (%)
1	Primary Dryland Forest, Secondary Dryland Forest	Large	51,930.51	79%
2	Bush	Medium	4,953.14	8%
3	Dryland Agriculture, Mixed Dryland Agriculture, Fields, Drylands	Rather Small,	6,604.16	10
4	Water bodies, settlements, rice fields	Small	2,047.39	3
	Total		65,535.20	100 %

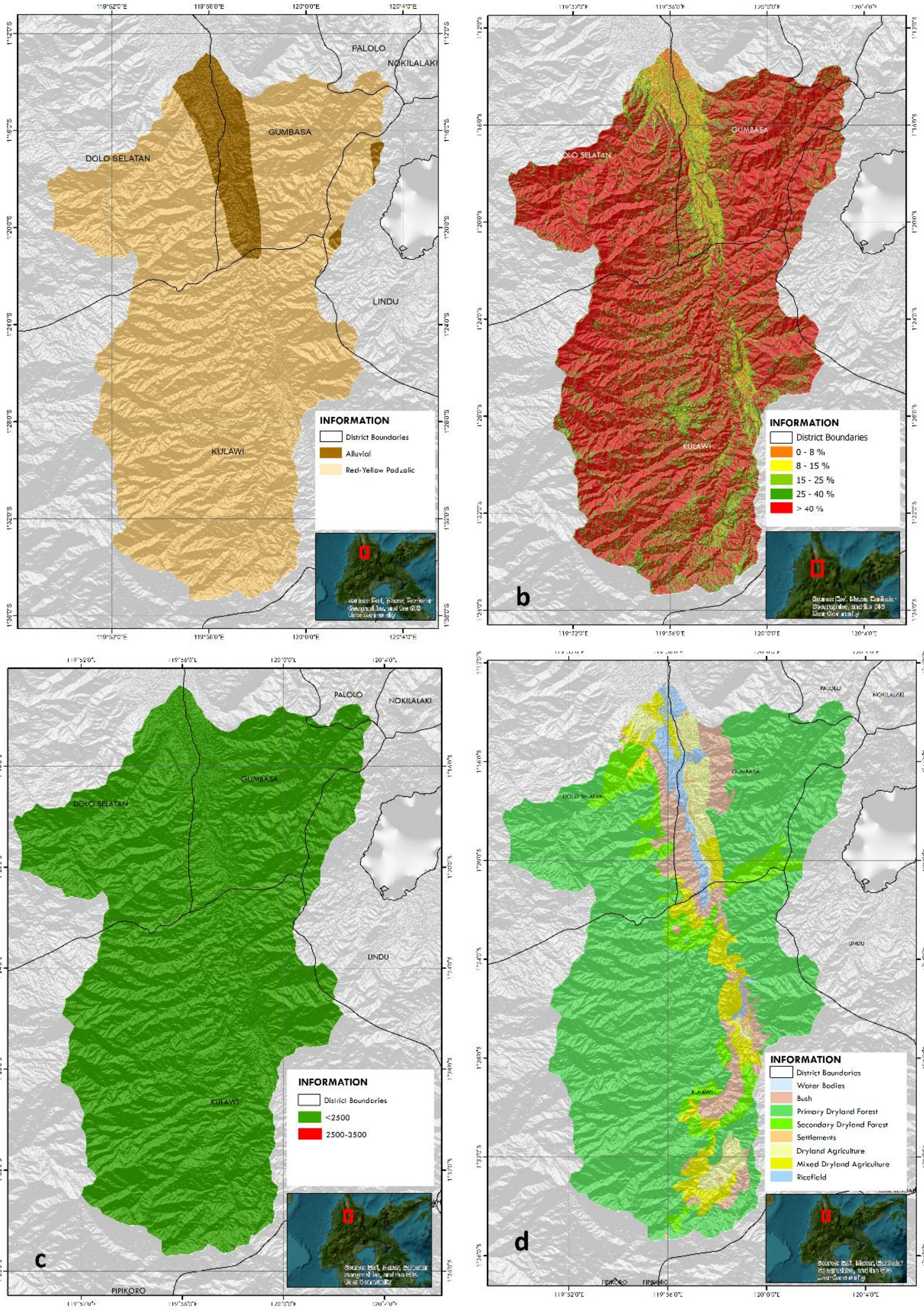

Figure 2. Map of special parameters for soil type (a), slope (b), rainfall (c), and land use (d)

3.2. Conditions of Water Infiltration

The overlay results of the four parameters used, namely soil type, rainfall, slope, and land use, produce a map of the conditions of the Miu water catchment area, which can be seen in Figure 3.

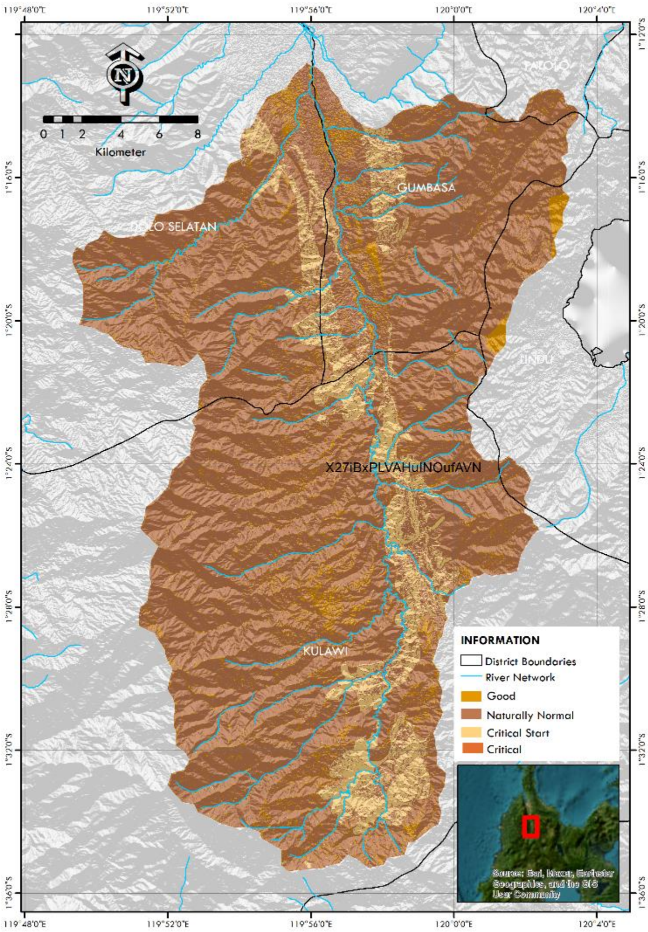

Figure 3. Spatial Distribution of Miu Watershed Conditions

Figure 3 shows that naturally normal conditions dominate the water catchment area of the Miu watershed. The calculation of the area and percentage of water absorption in the Miu watershed can be seen in Table 9.

Table 9. Area of Water Absorption Conditions in the Miu Watershed Basin

No	Conditions of Water Infiltration	Area (ha)	Percentage (%)
1	Good	5,706.33	8.71%
2	Naturally normal	53,727.64	81.98%
3	Critical start	6,101.03	9.31%
4	Critical	0.20	0.00%
	Total	65,535.20	100 %

Based on the results of the spatial analysis, it is known that the condition of the naturally normal catchment area dominates the Miu watershed with an area of 53,727.64 ha. This data informs that the Miu Watershed has natural characteristics as a water catchment area.

The condition of the Miu watershed catchment area is influenced by soil type, rainfall, slope and land use. The following describes the condition of the Miu water catchment area based on these four factors.

1. The condition of the catchment area is good

The condition of the catchment area is good; the Miu Watershed has an area of 5,706.33 ha (8.71%); this area is dominated by forests with high density, sloping slope class, and a relatively fast level of permeability. The intensity of rainfall in this area is very low. Meanwhile, land use is in the form of primary dryland forest, secondary dryland forest, dryland agriculture, mixed dryland agriculture and bush.

2. Naturally normal Infiltration Area Conditions

The condition of the Naturally normal catchment area of the Miu Watershed is 53,727.64 (81.98%); this area is dominated by primary dryland forest with a moderate permeability level. This catchment area occupies the undulating slope class with very low rainfall intensity.

3. The condition of the catchment area is Critical start

The critical condition of the area is 6,101.03 ha (9.31%); this area has steep slopes, and land use is dominated by dryland farming and mixed dryland farming. Medium permeability level and very low rainfall intensity.

4. Conditions of Critical Infiltration Areas

The condition of the critical area is 0.20 ha (0.00%); this area has a steep topography with a red-yellow podzolic soil type. Land use includes water bodies, rice fields and settlements, and deficient rainfall.

3.3. Miu Watershed Management Recommendations

Based on the category of water catchment areas of the Miu watershed, several recommendations for the management of the Miu watershed are (1) good catchment areas are focused on maintaining and maintaining the current conditions; (2) in Naturally normal catchment areas, conservation of natural vegetation is carried out and involving the community in preserving the watershed; (3) in areas with critical conditions, it is necessary to carry out soil rehabilitation and conduct training involving the community to improve watershed conditions; (4) in critical condition areas, it is necessary to rehabilitate the watershed by increasing vegetation in open land and making infiltration wells in residential areas.

4. Conclusion

In general, the water catchment conditions of the Miu watershed are divided into four conditions, good, naturally normal, critical start, and critical conditions. The condition of the water catchment area, with the largest area in the Miu watershed, which is 53,727.64 ha (81.98%) of the total area of the study, is in the normal natural category. The reasonable infiltration rate of each parameter will affect the excellent water absorption potential. In general, forest-vegetated areas will have sound absorption.

In areas with critical conditions, it is necessary to improve land management, such as planting vegetation and using organic matter, and involve the community, stakeholders and the government in managing the Miu watershed.

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