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Research Paper

Evaluation of Wanggu Watershed Carrying Capacity on Water System Indicators in Southeast Sulawesi, Indonesia

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Abstract

The water system or hydrological indicators determine the good and bad of a watershed's carrying capacity. The hydrological indicators include discharge fluctuations, annual flow coefficient, sediment load, flood frequency, and water use index. The purpose of this study was to evaluate the carrying capacity of the Wanggu watershed based on hydrological indicators. The method used is the score and weight method for all hydrological indicator data in accordance with the watershed evaluation guidelines for hydrological indicators. The research data is sourced from primary data and secondary data. Primary data comes from direct observation, while secondary data comes from agencies related to this research. Data analysis using Microsoft Excel in monthly and annual data analysis by producing tables and figures. The results of this study indicate that fluctuations in discharge or the regime coefficient of the Wanggu River Basin are 96.45 which are classified as high, as well as erosion and surface runoff, namely sediment load conditions of 19.73 which are also included in the high category. While the value of the annual flow coefficient is 0.32, the average frequency of flooding every year occurs once in two years and the water use index is 0.69. The three parameters are categorized as being in the middle class. From the accumulated weights and scores of all water system indicator parameters, a value of 111.25 is included in the bad class category. So the Wanggu watershed has a poor carrying capacity value from the water management indicator.

Keywords

Evaluation Value, Carrying Capacity, Indicators, Water Management, Watershed

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1. INTRODUCTION

The hydrological dynamics of watersheds are determined by land use/land cover changes due to both natural and anthropogenic changes (Kumar et al., 2018). The hydrological response is closely related to planning and managing land use (Garg et al., 2019; Getu Engida et al., 2021). Watersheds can maintain ecological balance, as life support, in which naturally occurring hydrological processes occur (Cao et al., 2022). While on the other hand, there are socioeconomic and cultural activities of the community to improve their welfare which are a form of human intervention in the natural watershed system which can affect the function of the watershed (Zhang et al., 2022a). The hydrological system will also be disrupted if the watershed function is disrupted (Pacheco and Sanches Fernandes, 2020).

A watershed is a hydrological system where the input collects rainwater and is processed in the watershed to produce river flow discharge (Prasad et al., 2020; Winkler et al., 2010). If the processing of the watershed is disrupted, such as reduced water absorption, it will cause an increase in surface runoff resulting in flooding during the rainy season and a decrease in river discharge and even drought in the dry season (Li et al., 2022; Wang et al., 2019). Differences or fluctuations in discharge during the rainy season and discharge during the dry season is an indicator that determines the carrying capacity of a watershed (Saedi et al., 2022; Wei et al., 2020; Xue et al., 2021).

The decrease in the carrying capacity of the watershed in terms of water management or hydrology is indicated by an increase in fluctuations in river discharge, annual flow coefficient, sediment load, water use index, and flood frequency (Juniati et al., 2021; Naharuddin et al., 2021; Saputro et al., 2021). Changes in these hydrological indicators are caused by an increase in the number of residents with settlement support facilities which can cause land compaction so that surface runoff increases (Juniati et al., 2021; Pramadita et al., 2021; Sriyana, 2018). An increase in the number of people in a watershed is inversely proportional to the condition of land cover which can affect the quality of the environment and have an impact on reducing the quantity and quality of water resources (Deng et al., 2021; Hikmat and Marselina, 2021).

The Wanggu Watershed is one of the watersheds in Southeast Sulawesi which has been widely utilized and has experienced changes in land use by the community (Alwi et al., 2021b; Marwah and Alwi, 2014). The problems found in the Wanggu Watershed are the growing development of residential areas that do not pay attention to the environment and land capabilities, conversion of agricultural land to non-vegetation land and illegal logging, causing land degradation, disruption of the hydrological function of the Wanggu Watershed, and high sedimentation (Alwi et al., 2021a). Significant impacts due to land degradation are reductions in soil porosity, soil organic matter, vegetation land cover, and soil infiltration. This is closely related to the disruption of hydrological functions, namely the increased frequency of floods and high sediment loads in the Wanggu Watershed (Alwi et al., 2021b; Fadlin et al., 2022). The floods that occurred in the Wanggu watershed have damaged public facilities and infrastructure, rice fields, gardens, and residential land, especially in the downstream areas of the watershed (Kandari et al., 2019; Saleh and Setiadi, 2020).

Based on the problems mentioned above in the Wanggu watershed, it is necessary to monitor and evaluate the water system (hydrology) of the Wanggu watershed in the form of river regime coefficients, annual flow coefficients, sediment loads, flood frequency, and water use index (Zhang et al., 2022a; Zhang et al., 2022b). It is necessary to carry out a more in-depth and specific study according to the potential problems that exist to improve the performance of the Wanggu Watershed, especially the performance of hydrological or water system indicators. So the purpose of this study was to evaluate the performance of the carrying capacity of the Wanggu watershed based on hydrological indicators.

2. EXPERIMENTAL SECTION

2.1 Research Area

This research was carried out in the Wanggu Watershed, Southeast Sulawesi, Indonesia (Figure 1). The watershed has an area of 33,950.83 hectares, geographically located at 3° 56' 54"- 4° 10' 24" South Latitude and 122° 22' 30" – 122° 35' 12" East Longitude and is at an altitude of 0-800 m asl and administratively located in South Konawe Regency and Kendari City (Saleh et al., 2022). According to Smith Fergusson's classification, the climatic conditions of the Wanggu watershed are climate type C (rather wet). The average annual rainfall is 2102 mm/year and temperatures range from 27,10°C - 30,60°C. The rainy season occurs from November to March and the dry season occurs from May to August (Kandari et al., 2019). The Wanggu Watershed has experienced changes in land cover characteristics that can affect changes in hydrological characteristics which are characterized by high erosion, flooding, and sedimentation (Fadlin et al., 2022; Saleh and Setiadi, 2020).

This research was conducted concerning the Regulation of the Minister of Forestry of the Republic of Indonesia Number 61 of 2014 concerning the Monitoring and Evaluation of DAS based on Water/Hydrology criteria. The scope of the evaluation is based on the quantity, quality, and continuity of water flow which includes, the river regime coefficient, annual flow coefficient, sediment load, flood frequency, and water use index using weighting and scoring methods. The data needed is secondary data in the form of rainfall data, water discharge data, flood incident data, population data, rice field area data, land use data, soil type data, and topographical data in the Wanggu Watershed. Data sources come from BP DAS Sampara, Southeast Sulawesi Provincial Forestry Service, Regional IV Sulawesi Regional River Center, Southeast Sulawesi BPBD, and Southeast Sulawesi Central Statistics Agency.

Data processing is done using Microsoft Excel with existing formulas. Data analysis is carried out by giving a score to the parameters that have been processed so that they have a value. The scoring method used is by multiplying the weights and scores as the equation:

$$\text{Score} = \text{Weight} \times \text{Score} \quad (1)$$

2.2 Flow Regime Coefficient Analysis

The Wanggu River flow regime coefficient is the ratio between the maximum flow rate and minimum flow rate of the Wanggu River. Analysis of the weights and scores of the river regime coefficients is presented in Table 1.

The annual flow coefficient of the Wanggu River is the percentage of the amount of rainfall that falls into the surface runoff in the Wanggu Watershed. Annual flow coefficient is the ratio between the amount of annual flow (Q_{annual}) and the amount of annual rainfall (P_{annual}). The weighted analysis and annual flow coefficient assessment scores are presented in Table 2.

2.3 Sediment Load Analysis

Sediment load is the amount of soil material that is not carried directly with the river flow but settles in the depressions of the land and the river bed causing siltation of the river. The sediment load depends on the amount of erosion present and the sediment delivery ratio, so the sediment load is calculated by the formula: $MS = A \times SDR$ (sediment delivery ratio), where MS is the sediment load (tons/ha/year), A is the amount of erosion (tons/ha/year), and SDR depends on the area of the watershed. Analysis of the weight and score of the sediment load assessment is presented in Table 3.

2.4 Flood Event Analysis

Floods in general are the overflow of water from rivers caused by the large volume of river discharge when it rains so that

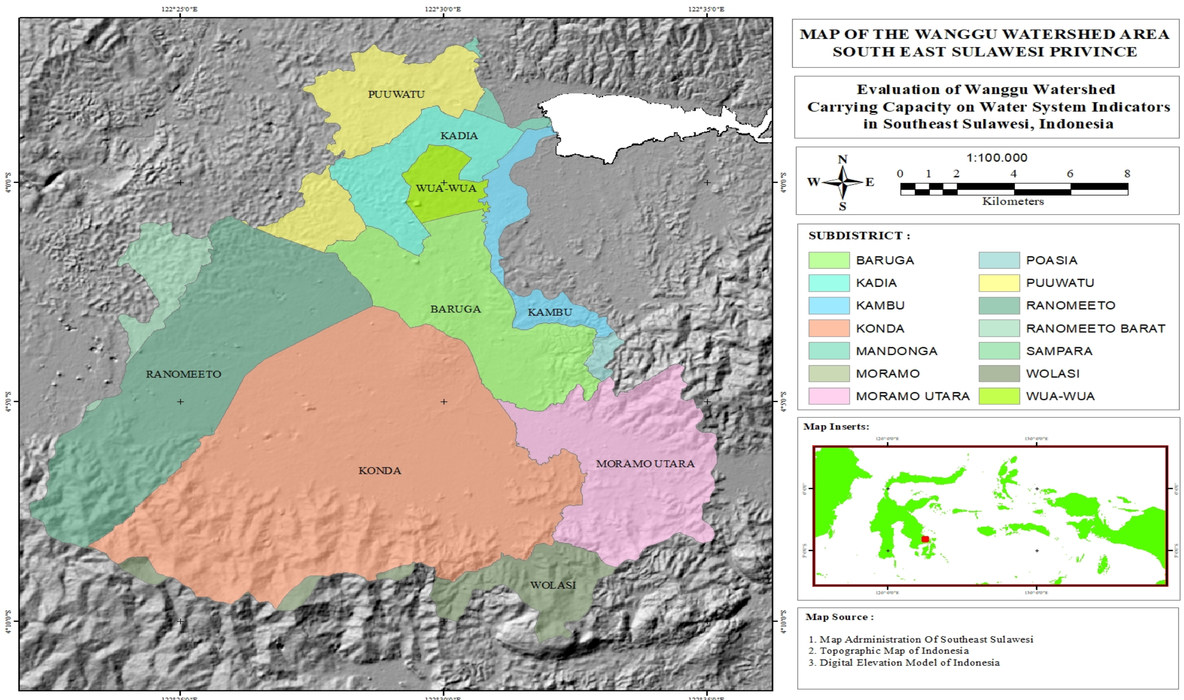

Figure 1. Wanggu Watershed (Research Sites)

Table 1. Weight and Score Analysis in the Flow Regime Coefficient Assessment

Sub Criteria	Weight	Parameter	Value	Class	Score
Flow Regim Coefficient	25	$FRC = \frac{Q_{max}}{Q_{min}}$	FRC≤20	Very low	0.50
			20≤FRC≤50	Low	0.75
			50≤FRC≤80	Medium	1.00
			80≤FRC≤110	High	1.25
			FRC≥110	Very high	1.50

the water is not accommodated or puddles occur in the area around the river. Information on the frequency of flood events in the form of inundation was obtained from the Kendari City Regional Disaster Management Agency. The weighted analysis and score of the flood event assessment are presented in Table 4.

2.5 Analysis of Water Use Index

The water use index is a value obtained by comparing the demand and supply of water in the Wanggu Watershed. The water use index parameter in evaluating carrying capacity conditions is carried out to evaluate water needs compared to water supply in the Wanggu Watershed. The weight analysis and water use index assessment scores are presented in Table 5.

The final result of the performance evaluation value of the Wanggu Watershed based on Water Management indicators is done by adding up the product of the weights and scores on all parameters. The product of the values and weights of the water system criteria is presented in Table 6.

The classification of the carrying capacity of the Wanggu Watershed based on water management criteria is determined based on Permenhut No. 61 of 2014, presented in Table 7.

3. RESULTS AND DISCUSSION

3.1 Flow Regime Coefficient

The flow regime coefficient is the ratio between the maximum discharge (Q_{max}) and minimum discharge (Q_{min}) of a river in the watershed (Asdak, 2014). The flow regime coefficient is one of the most decisive parameters in monitoring and knowing the flow capacity of a river from time to time (Xu et al., 2019), especially the highest discharge during the rainy season and the lowest discharge during the dry season (Berhanu et al., 2015; Handayani et al., 2019). The results of the analysis of river regime coefficients in the Wanggu watershed are presented in Figures 2 and 3.

The data above shows that the river flow regime coefficient in the Wanggu watershed is 96.45 which is included in

Table 2. Weight and Score Analysis in the Annual Flow Coefficient Assessment

Sub Criteria	Weight	Parameter	Value	Class	Score
Annual Flow Coefficient	25	$\mathrm{AFC} = \frac{Q_{\mathrm{annual}}}{P_{\mathrm{annual}}}$	AFC≤0.2	Very low	0.50
			0.2≤AFC≤0.3	Low	0.75
			0.3≤AFC≤0.4	Medium	1.00
			0.4≤AFC≤0.5	High	1.25
			AFC≥0.5	Very high	1.50

Table 3. Weight and Score Analysis in the Annual Flow Coefficient Assessment

Sub Criteria	Weight	Parameter	Value	Class	Score
Sediment Load	20	SL = A × SDR	SL≤5	Very low	0.50
			5<SL≤10	Low	0.75
			10<SL≤15	Medium	1.00
			15<SL≤209	High	1.25
			SL>20	Very high	1.50

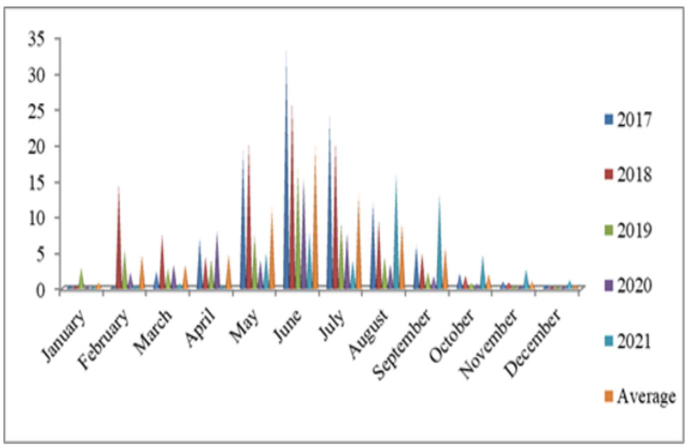

Figure 2. Monthly River Discharge in the Wanggu Watershed from 2017-2021

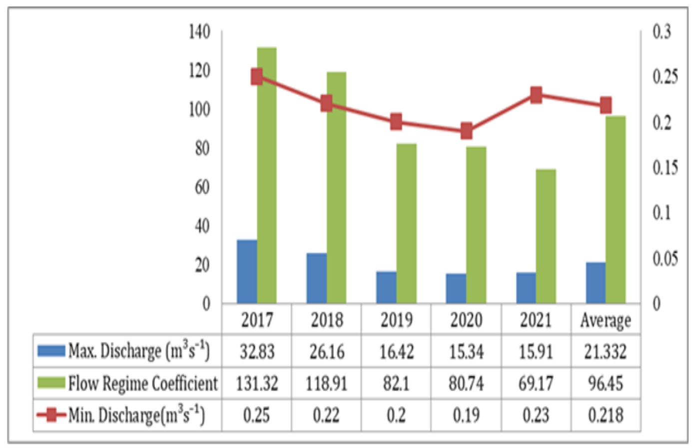

Figure 3. Maximum and Minimum Discharge and River Regime Coefficients in the Wanggu Watershed from 2017-2021

the high class. The river flow regime coefficients describe the good and impaired quality of the watershed (Bandrang et al., 2021; Sapan et al., 2022). If the ratio between the maximum discharge and minimum discharge is small it indicates that the river flow in the watershed is still flowing throughout the year (Asdak, 2014). Still, on the contrary, if the coefficient of the river flow regime is large, then the river water flow fluctuates sometimes large, small and even experiences drought or no flowing water, as an indicator of good or bad hydrological conditions (Onwuka et al., 2021; Pourfallah Koushali et al., 2021). Recently there has been a tendency to decrease the flow regime coefficient in the Wanggu watershed due to changes in climatic conditions and local geographic factors (Salinas-Rodríguez et al., 2021; Susanto, 2019). This is caused by water conservation measures with the construction of water structures in the form of check dams and ponds, which can reduce the flow rate of the river (Chalise et al., 2021; Yuan et al., 2022). In addition, it is also affected by an increase in the area of vegetated land cover, especially on mixed agricultural land planted with annual crops in the agroforestry model (Bower et al., 2022; Suryono et al., 2018).

3.2 Annual Flow Coefficient

The annual flow coefficient is the value of the ratio between the annual discharge and the amount of annual rainfall in a watershed. The annual flow coefficient shows the percentage of the amount of rain that becomes surface runoff (Rolia et al., 2021). The surface runoff coefficient is used as a benchmark in viewing and evaluating flow characteristics in a watershed. The analysis results of the annual discharge,

Table 4. Weight and Score Analysis in Flood Event Assessment

Sub Criteria	Weight	Parameter	Value	Class	Score
Flood	10	Frequency of Flood Events	Never	Very low	0.50
			1 time in 5 years	Low	0.75
			1 time in 2 years	Medium	1.00
			1 time every year	High	1.25
			More than 1 time in 1 year	Very high	1.50

Table 5. Weight and Score Analysis in the Assessment of Water use Index

Sub Criteria	Weight	Parameter	Value	Class	Score
Water Use Index	20	$WUI = \frac{Needs}{Supplies}$	WUI≤0.25	Very low	0.50
			0.25<WUI≤0.5	Low	0.75
			0.5<WUI≤0.75	Medium	1.00
			0.75<WUI≤1	High	1.25
			WUI>1	Very high	1.50

Table 6. Weight and Value of the Water System Criteria

Parameter	Total Weight (%)	Weight	Value	
			Lowest	Highest
Flow Regim Coefficient	100	25	12.5	37.5
Annual Flow Coefficient		25	12.5	37.5
Sediment Load		20	10	30
Flood		10	5	15
Water Use Index		20	10	30

annual rainfall and annual flow coefficient in the Wanggu Watershed are presented in Figure 4.

Figure 4 shows that the average annual flow coefficient value from 2017–2021 in the Wanggu Watershed is 0.32. Based on the classification of the annual flow coefficient value, it is in class in the medium category. An annual flow coefficient of 0.32 means that 32% of the rainwater that falls in the Wanggu Watershed becomes surface runoff (Naharuddin et al., 2021; Volpi et al., 2018). The moderate annual flow coefficient value has the consequence that the river flow in the Wanggu watershed is still normal or flows throughout the year, and there has not been a drought. The annual flow coefficient is happening in 2017 and 2018, while 2019, 2020, and 2021 have low annual flow coefficient values. The greater the value of the surface runoff coefficient will have consequences the higher the portion of rainfall that becomes surface runoff and vice versa (Bandrang et al., 2021).

The runoff coefficient value gives an idea of how the

Table 7. Classification of the Carrying Capacity of the Wanggu Watershed Based on Water Management Criteria

Value of Watershed Carrying Capacity (WCC)	Category
WCC≤70	Very good
70<WCC≤90	Good
90 <WCC≤ 110	Moderate
110 <WCC≤130	Bad
WCC >130	Very bad

biophysical condition of the watershed responds to rainwater that falls in the watershed (Mahmud et al., 2023; Suprayogi et al., 2022). The runoff coefficient has a very important role, namely as an indicator of surface runoff in a watershed, and can be used as a benchmark for evaluating flow in relation to watershed management. Surface runoff is usually used in determining the peak discharge of a flood, while as a benchmark in evaluating watershed management, the runoff coefficient is used as an indicator of the effect of watershed management on decreasing the amount of surface runoff (Lallam et al., 2018; Machado et al., 2022; Xiong et al., 2022).

3.3 Sediment Load

Sediments are two different things, namely the sediment load and the results of sediment transported through the cross section of the river are calculated for a year, including dissolved chemicals (dissolved or solution load), small suspended particles (suspended load), and larger particles transported along the river, river bed (bed load) (Bečvář et al., 2006; Rafsanjani, 2017). Sediments originating from erosion in watershed areas are carried through rivers and

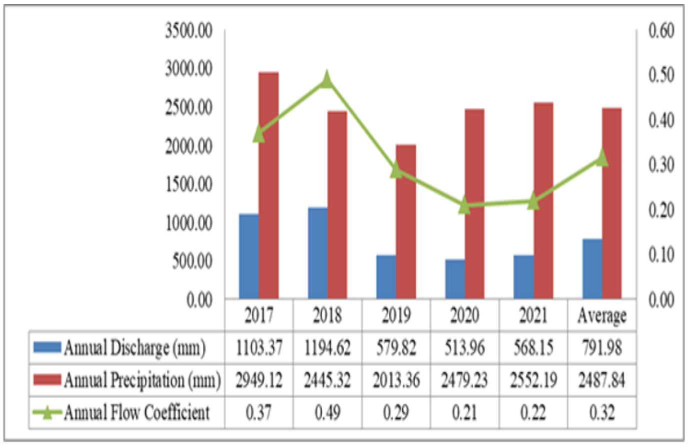

Figure 4. The Annual Discharge, Annual Rainfall and Annual Flow Coefficient

Table 8. Flood Occurrence in Wanggu Watershed

Year	Flood occurrence	Description
2017	Once	High
2018	Never	Very Low
2019	Once	High
2020	Never	Very Low
2021	Once	High
Average	Once in two years	Moderate
Value of Flood Occurrence	Once in two years	Moderate
Class		Moderate
Score		1
Weight		10
Score x Weight		10

river branches (Gunawan et al., 2019; Gwapedza et al., 2021). The total amount of erosion from the watershed is the result of sediment which is shown in terms of volume and weight per unit area. Sediment resulting from erosion will undergo a deposition process in a place where the flow rate slows down, which is known as the sedimentation process (Arsyad, 2009; Gusarov et al., 2021).

The characteristics of the sediment load in the Wanggu watershed have a very serious impact on the sustainability of the waters because it empties into the waters of Kendari Bay where the sedimentation process occurs from the amount of erosion that continues with a large supply of sediment loads from the mainland (Liu et al., 2022; Rogers and Ramos-Scharrón, 2022; Winckler et al., 2023). The results of erosion and sediment load calculations in the Wanggu watershed are presented in Figure 5.

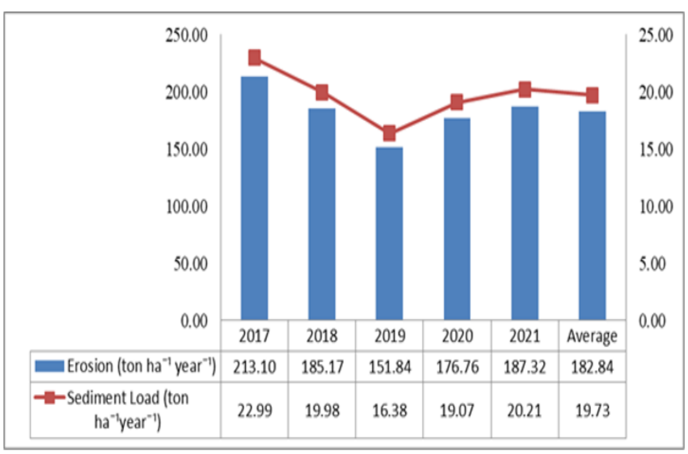

Figure 5. The Results of Erosion and Sediment Load Calculations in the Wanggu Watershed

Based on Table 8, the results show that the annual average erosion rate in the Wanggu watershed is 182.84 tons $ha^{-1}year^{-1}$, and the sediment delivery ratio is 0.1079, so that the annual average sediment load is 19.73 tons $ha^{-1}year^{-1}$ indicating the category tall. So that the classification of Sediment Load in the Wanggu Watershed is at a value of $15<SL\leq20$ (tons $ha^{-1}year^{-1}$) included in the High class.

Sedimentation in a watershed is influenced by several factors including the amount and intensity of rainfall, erosion that occurs, soil type, topography, rock formations, sediment types, and river channel characteristics (Gunawan et al., 2019). The effect of climate change, especially rainfall, causes erosion and sedimentation in a watershed, which is a very important assessment in relation to sediment loads and sediment yields (Bannatyne et al., 2022; Theron et al., 2021). High amounts of erosion also contribute to high sediment loads (Gwapedza et al., 2021), and also have negative effects on land and livelihoods, aquatic ecosystems, water availability, and power generation infrastructure (Bannatyne et al., 2022; Vercruysse et al., 2017). The contributions of climate change and human activities have a very significant effect on increasing erosion, surface runoff, and sediment in a watershed from year to year (Chen et al., 2022; Golosov and Tsyplenkov, 2021).

3.4 Flood

Flooding is the occurrence of an area or plains inundated by water in large quantities beyond normal natural limits due to an increase in the volume of water in water bodies such as rivers and lakes (Dadson et al., 2017). In the Wanggu Watershed, recent flood events have increased in frequency due to the high flow coefficient due to increased human settlement activity (Fadlin et al., 2022). Flood events in the Wanggu watershed as one of the parameters in the water system indicator are very important in determining the carrying capacity of the watershed (Table 8).

Flood occurrence in the Wanggu Watershed, especially in the downstream part of the watershed from 2013 to 2016, often inundate every year. However, recently from 2017 to 2021 the intensity of floods has begun to decrease once in two or three years and even now inundation floods can be controlled due to water conservation measures in the form of check dams and water retention ponds in the Wanggu Watershed (Abror Mustafa et al., 2021; Muzdalifah et al., 2021; Shao et al., 2021). Before the water retention pond was built, the water was stagnant in residential areas (Figure 6), while the condition of the Wanggu river water after the water retention pond was built (Figure 7).

Figure 6. Waterlogging in the Wanggu Watershed

Figure 7. Flood Management in Wanggu Watershed with a Retention Pond

There are several factors that can cause flooding including climate change factors, rainfall patterns and distribution as well as an increase in the frequency and magnitude of extreme rainfall events in an area (Ariyani et al., 2022; Bian et al., 2020). Other factors that affect flooding are physiographic and geometric hydrological conditions (Kusumandari et al., 2018; Rana and Suryanarayana, 2021), topographical conditions regarding the slope of the area are related to the mapping of flood areas, especially lowland areas and basins (Samarasinghe et al., 2022), soil types related to the physical and chemical properties of the soil, especially in the soil's ability to bind water to the soil (soil permeability) (Basri et al., 2022; Karmakar et al., 2010), changes in land cover related to the needs of the human population for land resources so that it can reduce water retention capacity due to soil compaction so that it can increase surface runoff and inundation floods (Basri et al., 2022; Bian et al., 2020; Rana and Suryanarayana, 2021), as well as the factors of garbage and sediment that accumulate and block the flow of water in river channels can reduce the capacity and capacity of rivers so that water overflows out of the river inundating residential areas (Ariyani et al., 2022).

3.5 Water Use Index

The index value of water use in a watershed is carried out to determine the ratio between the amount of water needed and the availability of water (Touch et al., 2020). If the water use index value is said to be good, then the amount of water used is still less than the available water potential so that the watershed still produces a lot of water flowing downstream, otherwise it is said to be bad if the amount of water used is greater than its potential so that the volume of water flowing into downstream already a little Zhang et al., 2019. The water use index indicator in watershed management is very important in terms of annual drought mitigation in the watershed (Hasan et al., 2021; Thomaz et al., 2023).

A water demand analysis was carried out to determine the water demand in the Wanggu Watershed. There are three sectors of water demand analyzed, namely domestic demand, paddy field agriculture, and animal husbandry (Zhang et al., 2019). Meanwhile, water availability is based on potential water data in the Wanggu River through the minimum discharge and mainstay discharge (Ganiyu et al., 2019). The calculation results of the three sectors are then calculated as the total water demand for the Wanggu Watershed and the Water Use Index for the Wanggu Watershed based on a comparison between water demand and water availability in the Wanggu Watershed, as presented in Table 9.

Based on Table 9 it shows that the value of the Water Use Index in the Wanggu Watershed is at a value of 0.69 which is in the middle-class range. This indicates that the use of water in the Wanggu watershed is still sufficient for the needs of community activities. The use of water in the Wanggu Watershed is very important because water is a community economic resource that needs to be controlled for its available capacity so that it is more efficient in its sustainable use (Tena et al., 2021; Tidwell et al., 2018).

The availability of water in a watershed is said to be good if it exceeds the allocation for water use and is the most important indicator in assessing the carrying capacity of a watershed (Tena et al., 2021). Some of the needs in water use that affect water availability are population

Table 9. Water Use Index in the Wanggu Watershed

Sector	Water Demand (m^3s^{-1})	(m^3d^{-1})
Domestic	0.2076	17.939.60
Agriculture	3.1485	272.026.94
Livestock	0.0014	117.33
Sum	3.3575	290.083.87
Water Needs	3.3575	290.083.87
Q_{min} (Minimum Discharge)	1.5300	132.192.00
Q_a (Mainstay Discharge)	4.8578	419.709.60
Water Use Index	0.69	0.69
Water Use Index Value	0.5<IPA≤0.75	0.69
Class		Medium
Score		1.00
Weight		20
Score×Weight		20

growth, industrial needs, agriculture, and livestock (Marston et al., 2020; Zhang et al., 2019). Meanwhile, water availability is influenced by the hydrological characteristics of the watershed which are determined by rainfall, interception, infiltration, surface runoff, groundwater infiltration, sediment yields, river flow, and water reserves in the upstream watershed (Che et al., 2022; Zengin et al., 2017). High river flows can reduce the availability of water for humans, so there is a need to control and manage river flows to meet the requirements required for the environment (Balist et al., 2022; Touch et al., 2020).

3.6 Wanggu Watershed Carrying Capacity on Water System Criteria

The carrying capacity of the watershed in terms of water management criteria is very important to monitor and measure because it is a very dynamic aspect at any time and place. The carrying capacity of the water system is the accumulation of the parameter values of the flow regime, annual flow, sediment load, flood frequency, and water use index. The value of the carrying capacity of the water system in the Wanggu Watershed from the total value of the five parameters of the water system obtained a value of 111.25 with the criteria being in a bad category.

4. CONCLUSIONS

Based on the assessment and weighting of several water system criteria parameters in the Wanggu watershed, the carrying capacity value of the Wanggu water system is included in the bad category. The poor condition of the water system is caused by the high difference between the discharge of the river in the rainy season and the discharge in the dry season. Also, the sediment load parameter makes a high contribution to the decrease in the carrying capacity of the Wanggu watershed.

5. ACKNOWLEDGEMENT

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