Performance Assessment of Bondoyudo Watershed Management

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ABSTRACT

Continues decrease of vegetation will result in a high erosion and sedimentation rate in the Bondoyudo watershed. This will result in reduced water retention capacity and accelerate land degradation. This study aims to monitor and evaluate the performance conditions of the Bondoyudo watershed according to the assessment parameters of the weighting criteria, which include land criteria, water management criteria, socio-economic criteria, water construction investment criteria, and space utilization criteria. Information about the upper part, middle part, and lower part of Bondoyudo River collect from primary data, secondary data, and analysis results. The watershed evaluation score's carrying capacity obtain from the analysis results from each weighting and scoring value of each criterion and sub-criteria. Watershed performance classifications obtain by adding up the scores of each criterion. The watershed classification's total score is 103.25, which classification as a medium recovery level category. It is necessary to manage and restore the carrying capacity of the Bondoyudo watershed in supporting the development of water resources so that there is no decline in the performance of the Bondoyudowathersed. Recommended activity plans are water resources conservation, and utilization integrated control and involving stakeholders in watershed management.

1. Introduction

The uncontrolled impact of land use in the Bondoyudo watershed without paying attention to soil and water conservation principles has resulted in high erosion and sedimentation rates. Decreasing vegetation cover in the upstream Bondoyudo watershed accelerates land degradation. These changes lead to an increase in critical land area, decrease in quantity, quality, and continuity of flow, even prone to flood and drought risks so that socio-economically causes people to lose their ability to run their land as a efforts to improve the general welfare. There have been many studies on watershed assessment in other areas [1]–[4].

The increase in population in the Bondoyudo watershed and the development of agribusiness, agriculture, and industry have pushed policies that have not synergized with the new regulations.. The conversion of land and planting functions along the river and upstream of the Bondoyudo watershed has contributed to the disruption of the current decade's natural balance.

This study focused on monitoring and evaluating the Bondoyudo watershed's management to find out information on the performance of the Bondoyudo watershed. It is necessary to formulate the following matters the current condition of the Bondoyudo watershed, the availability of water in the watershed area of the Bondoyudo River, starting in the upstream, middle to the river mouth. The performance management of the Bondoyudo watershed in developing sustainable water resources in the future is also discussed in this study.

Performance conditions of the Bondoyudo watershed according to the assessment parameters from weighted criteria were evaluated. Various conditions, including land conditions, river, and hydrological conditions, socio-economic and institutional conditions, were considered [5]. Conditions of area designation, asset conditions, and water construction investment were monitored so that the watershed carrying capacity takes place effectively, efficiently, and sustainable. The aspects of quantity, quality, and continuity are the basis for developing sustainable water resources in the future.

2. Literature Review

2.1 Land Analysis Criteria

2.1.1 Sub Critical Land Criteria

Critical land is a land inside and outside the forest area that has decreased its function as an element of production and a medium for regulating watershed water management [6]. Critical land monitoring is conducted to determine the percentage of critical land area in the watershed. The calculation of the percentage of critical land area uses the classification as given by Minister of Forestry Regulation 2014 [7], as follows

$$Percentage\ Critical\ Land\ (PCL) = \frac{critical\ land\ area}{watershed\ area}$$

2.1.2 Vegetation Cover Criteria

Monitoring and evaluation of vegetation cover are carried out to determine the

The percentage of land area with permanent vegetation cover in the watershed, which is the ratio of the area of permanent vegetation to the watershed area. The calculation of the percentage area of vegetation, as follows

$$\text{Percentage Cover Vegetation } (PCV) = \frac{\text{cover vegetation area}}{\text{watershed}} \, x100\%$$

2.1.3 Erosivity Index Sub Criteria

Land monitoring related to erosion is approximate by the erosion index value in the watershed, which is the ratio of actual erosion to permissible erosion [8]. The actual erosion data is obtained from erosion calculations using the Universal Soil Loss Equation (USLE) method.

A = R. K. LS. C. P

Discription :

R = Rain Erosivity Factor[9]

K = Soil Erodibility Factor [10]

LS = Length and Slope Factor

C = Land Cover Factor

P = Land Management Factor

2.2 Water System Criteria

2.2.1 Flow Regime Coefficient Sub Criteria

The factors influencing river discharge are rainfall, topographical, geology, vegetation, and human conditions [11]. The calculation of the flow regime coefficient, as follows

$$\text{Flow Regime Coefficient } (FRC) = \frac{\text{Qmax}}{\text{Qmin}}$$

Description: Qmax is a maximum discharge; Qmin is a minimum discharge;

2.2.2 Annual Flow Coefficient Sub Criteria

The analysis of annual flow coefficient calculations obtained from the calculation of rainfall data and river discharge. The calculation of the annual flow coefficient, as follows

$$\text{Annual Flow Coefficient } (AFC) = \frac{\text{Q}}{\text{P}}$$

Description: Q is an annual discharge; P is an annual rainfall;

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2.2.3 Water Use Index Sub Criteria

In this analysis, the water use index calculation uses a comparison between water demand and water availability in the watershed. The calculation of the annual flow coefficient, as follows

$$\text{Water Use index } (WUI) = \frac{\text{Water Demand}}{\text{Water Availability}}$$

2.3   Socio – Economic Criteria

2.3.1 Population Pressure Analysis

The land availability index's population pressure analysis compares agricultural land and the number of farmer families in the watershed. The population pressure index for the land calculates using the formula.

$$\text{Population Pressure Analysis } (PPA) = \frac{A}{P}$$

Description: A is an area of agricultural land; P is a number of farmer families

2.3.2 Population Welfare Analysis

The criteria for the level of population welfare are approached by a percentage of low-income families or the average per-capita income level per year [12]. The Population Welfare Index (PWA) for the land calculated using the formula.

$$\text{Population Welfare Analysis } (PWA) = \frac{\text{Poor households}}{\text{Total households}} x100\%$$

2.4   Space Utilization Criteria

Protected areas are defined with the primary function of protecting the environment's preservation, including natural and human-made resources[13]. The characteristics of land with steep slopes and erosion-sensitive soil are areas that need protection [14]. The Protected Area Analysis (PAA) calculated using the formula.

$$PAA = \frac{\text{vegetation coverage}}{\text{area of vegetation coverage in protected areas}} x100\%$$

3. Research Method

The topographical condition of the Bondoyudo watershed in the upstream area has an extreme high difference so that the flow is quite heavy, in the middle, it varies with

Lowlands, undulating plains, and highlands (hilly), covered with rice fields and hilly vegetation, tend to be transitional, while downstream areas tend to have shallow currents.
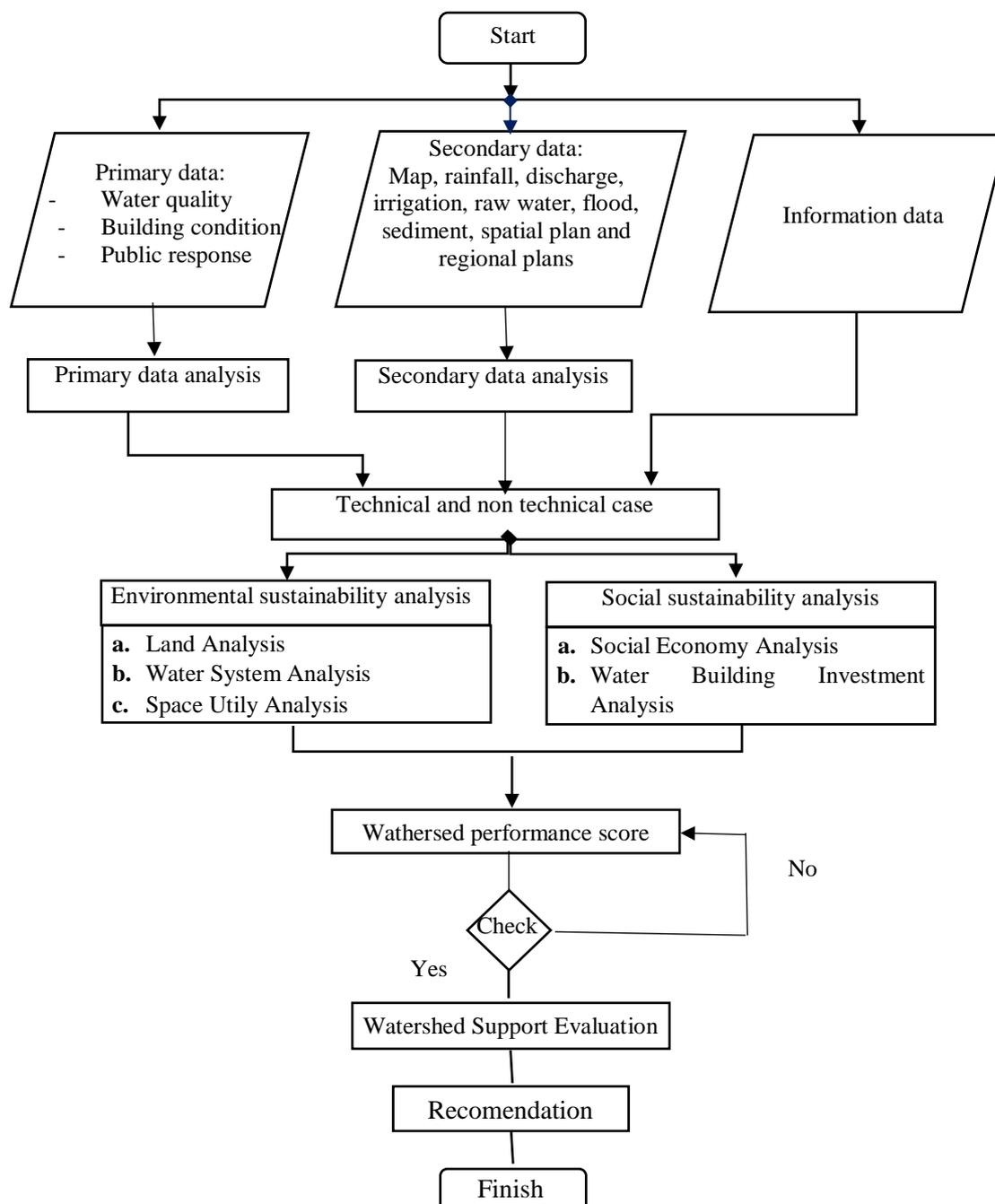
Figure 1.   Research steps of Performance Assessment of Bondoyudo Watershed Management

The research steps are presented in Figure 1. The data collection process consists of primary data, secondary data, and other information. Primary data are water quality data, building condition data, and public response. In contrast, secondary data includes maps, rainfall, discharge data, irrigation data, raw water data, flood occurrence data, and sediment data. After data collection,

conducted environmental and social sustainability analyses to obtain a watershed performance score. Watershed support evaluation and recommendation are discussed as the final step.

4. Results and Discussions

4.1 Land Analysis Criteria

4.1.1 Critical Land Analysis

The potential for critical land in the Bondoyudo-Bedadung watershed is classified into 5 types [15]. Determination of the classification of critical land was obtained by comparing the area of critical land to the total area of the Bondoyudo watershed. $PCl = \frac{44,62}{1345,2} X \ 100\%$. The obtained PCL value was 3.32, belonging to the very low land recovery qualification class criteria.

4.1.2 Vegetation Cover Analysis

Based on the land use map of Lumajang, Jember, and Probolinggo districts, it is know that most of the Bondoyudo watershed is a production forest area and community forest area of 55,198 ha (41%). Data on the area of land use in the Bondoyudo watershed is presented in Table 1

Table 1. Types of Land Cover in the Bondoyudo Watershed

No.	Land Cover	Area	
		Ha	Percentage
1	Protected Forest Area	6.855,73	5,10
2	National Parks	11.681,20	8,86
3	Production Forest Area	11.960	8,89
4	Community Forest Area	43.238,35	32,14
5	Settlement	11.963,26	8,89
6	Agricultural land	44.041,00	32,74
7	Plantation land	4,560	3,39
8	Fishery land	95,53	0,07
9	Rivers and streams	125,00	0,09
Total		134.52	100

Source : Author's analysis, 2020

From Table 1, it is obtained that the area of permanent vegetation is calculated of protected forest area, national parks, production forest area, and the community forest area is 78,295.29 ha with a value of land cover presentation or PCV obtained at 58%. The PCV value of 58% belongs to the medium recovery class vegetation cover.

4.1.3 Erosivity Index Analysis

A.   Erosivity Index (R)

The calculation of the rain erosivity factor was obtained from the monthly average rainfall data using the Thiessen polygon method based on 10 years of rainfall data from the PUSDA Office of East Java Province obtained from 6 rainfall stations in the Bondoyudo watershed [16]. Based on the calculations of rainfall erosivity for 10 years, the average total monthly rainfall in 10 years is calculated. The average of total monthly precipitation in 10 years is 1.577,121 cm/year.

B.   Slope length and slope factor (LS)

Based on the data from the topographical map of the Bondoyudo watershed, the distance between the elevations is obtained. The values are used to calculate the LS value (Table 2).

Table 2. Calculation of LS values

No.	Elevation	Interval (m)	L (m)	S	Ls (m)
1	2000 – 2500	500	3,156.77 15	.84%	0.2732679
2	1500 – 2000	500	6,800.58	7.35%	0.1478925
3	1000 – 1500	500	8,997.20	5.56%	0.1182217
4	500 – 1000	500	10,374.75 4.	82%	0.1054875
5	200 – 500	300	14,579.74 2.	06%	0.0393002
6	100 – 200	100	12,533.18 0.	80%	0.0095274
7	50 – 100	50	7,139.35	0.70%	0.0056631
8	0 – 50	50	47,353.38 0.	11%	0.0012465

Source : Author's analysis 2020

Based on Table 2, the longest Ls value (0.273 m) was obtained at elevation 2000-2500 m, while the shortest Ls value (0.0012 m) was obtained at elevation 0-50 m. The higher the elevation, the higher the Ls value is obtained.

C.   Erodibility Index (K)

Soil erodibility factor, in other words, soil erosion sensitivity factor, is defined as whether or not the soil is easily eroded[17]. In addition to the value of the slope length and slope factor (LS), other factors such as soil erodibility (K), land cover, and land management (CP) factors are also calculated per elevation interval. The soil erodibility factor depends on the type of soil in the location related to the amount of K value for each type of soil[18]. A recapitulation of the average K value of the watershed can be seen in Table 3.

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Table 3. Calculation of the average value of soil erodibility

No	Elevation	Type of soil	Area	K	Area x K	Average of K
1	2000 – 2500	Andosol and regosol	3.80	0.4	1.5216	0.400
2	1500 – 2000	Andosol and regosol	26.51	0.4	0.0568	0.400
3	1000 – 1500	Andosol and regosol	47.39	0.4	0.0804	0.400
4	500 – 1000	Andosol and regosol	100.66	0.4	0.1264	0.400
5	200 – 500	Brown regosol soil	30.77		12.307	0.400
		Andosol and regosol	91.01		36.403	
		regosol gray brown	10.75	0.4	4.2990	
		Brown regosol soil	13.79		5.5164	
		regosol gray brown	10.04		4.0172	
		Alluvial Hydromof	2.30	0.47	0.0164	
6	100 – 200	Brown regosol soil	137.71		0.1526	0.410
		regosol gray brown	46.96	0.4	0.0800	
		regosol gray brown	14.27		0.0391	
		Reddish brown lithosol	69.21	0.43	0.1117	
		Mediterranean brown and Hydromoph	4.56	0.46	0.0240	
		Alluvial lithosol	2.48	0.47	0.0171	
7	50 – 100	regosol gray brown	40,1	0,4	0.0729	0.414
		Brown regosol soil	73.27		0.1045	
		Reddish brown lithosol	70.89	0.43	0.1134	
		Mediterranean brown and lithosol	11.32	0.46	0.0414	
8	0 – 50	Brown regosol soil	96.11		0.1230	0.417
		Gray regosol soil	111.87	0.4	0.13470	
		regosol gray brown	170.52		0.17355	
		Gray brown alluvial	24.06	0.47	0.06716	
		Alluvial Hydromof	23.27	0.47	0.06582	
		Mediterranean brown and lithosol	84.80	0.46	0.13877	
		Mediterranean brown and lithosol	84.80	0.46	0.13877	
		Reddish brown lithosol	26.68	0.43	0.06309	
		Brown regosol soil	73.27		0.10453	
		Reddish brown lithosol	70.89	0.43	0.11340	
		Mediterranean brown and lithosol	11.32	0.46	0.04145	

Source : Author's analysis 2020

Based on Table 3 the highest average K value at elevation 0-50.

D.   Land cover factor (C) and tillage factor (P)

The value of the land cover factor (C) is influenced by plant density and maintenance. The level of erosion that occurs due to the effects of soil management and conservation (P) activities varies, mainly depending on the slope area.

Table 4. Calculation of the average CP value

Elevation	Land Use Type	Area	CP value	Area x CP	Average of CP
2000 – 2500	Forest	3.81	0.03	0.1144	0.03
1500 – 2000	Forest	26.56	0.03	0.0015	0.03
1000 – 1500	Forest	47.48	0.03	0.0021	0.03
500 – 1000	Forest	100.86	0.03	0.0034	0.03
200 – 500	Forest	143.07	0.03	4.2921	
	Settlement	4.77	0.6	0.1431	0.05
	Rice fields	11.13	0.05	0.3338	
100 – 200	Forest	234.36	0.03	0.0056	
	Settlement	13.79	0.6	0.0010	0.0575
	Rice fields	27.57	0.02	0.0015	
50 – 100	Forest	114.98	0.03	0.0036	
	Rice fields	57.49	0.02	0.0024	0.0356
	Settlement	19.16	0.03	0.0012	
	Plantation	4.50	0.4	0.0196	
0 – 50	Forest	195.43	0.03	0.0050	
	Rice fields	235.71	0.02	0.0056	0.0256
	Settlement	104.53	0.03	0.0034	

Source : Author's analysis 2020

Based on Table 4, the highest average of CP value was obtained at elevation 100-200 m, while the lowest average of CP value was obtained at elevation 0-50 m with the same land use (forest, settlement, and rice fields).

E.   Calculation of the rate of erosion (A)

The erosion value is calculated with the USLE formula. The calculation of the amount of land erosion is presented in Table 5, calculated for each elevation interval.

Table 5. Calculation of Bondoyudo Watershed Erosion Rate (A)

Elevation	R	LS	K	CP	A
2000 – 2500	1577.121	0.27	0.400	0.0300	5.172
1500 – 2000	1577.121	0.15	0.400	0.0300	2.799
1000 – 1500	1577.121	0.12	0.400	0.0300	2.237
500 – 1000	1577.121	0.11	0.400	0.0300	1.996
200 – 500	1577.121	0.04	0.400	0.0485	1.202
100 – 200	1577.121	0.01	0.409	0.0575	0.353
50 – 100	1577.121	0.01	0.414	0.0356	0.132
0 – 50	1577.121	0.00	0.417	0.0256	0.021
	Total erosion				13.910

Source : Author's analysis 2020

The total land erosion in the Bondoyudo watershed is 13.91 mm / ton/ha/year.

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F.   Erosion Index Calculation (IE)

The average soil thickness of the Bondoyudo watershed is 100 - 150 cm. A tolerable erosion value is obtained of 8 tonnes/ha/year. The amount of the calculation of the erosion index value is $IE = \frac{13,91}{8} = 1,739$. The value is included in the erosivity index class category of the high recovery class.

4.2   Water System Analysis

4.2.1 Flow Regime Coefficient Analysis

In this analysis, the 10 years discharge data from the East Java Provincial PUSDA Office at Umbul DAM is used. Flow regime coefficient calculations are presented in Table 6. Based on the calculations, the average Flow Regime Coefficient is 25.04, with is included in the low recovery rate category.

Table 6. Calculation of Flow Regime Coefficients

No.	Year	River Discharge		KRS	Score	Class
		QMaks	QMin			
1	2008	114,510	6,384	17.94	0.5	very low
2	2009	98,216	444	221.21	1.5	very high
3	2010	153,210	445	344.29	1.5	very high
4	2011	124,140	9,822	12.64	0.5	very low
5	2012	108,541	6,651	16.32	0.5	very low
6	2013	44,954	7,854	5.72	0.5	very low
7	2014	139,160	1,261	110.36	1.5	very high
8	2015	108,943	20	5,322.60	1.5	very high
9	2016	53,943	556	97.02	1.25	high
10	2017	86,475	7,774	11.12	0.5	Very low
Average		103,209	4,121	25.04	0.75	Low

Source :   Author's analysis 2020

4.2.2 Annual Flow Coefficient and Sediment Load Analysis

The analysis of annual flow coefficient calculations is obtained from the calculation of rainfall data and river discharge at Umbul Dam. Based on the results of the analysis, the average annual flow coefficient value is 0.27, with this value included in the low recovery rate category.

The amount of sediment load is obtained as follows:

MS = A x SDR = 13.91 ton / ha / year x 15.15% = 2.108

Based on the above calculations, the average sediment load value is 2.108. It is included in the very low recovery rate category.

4.2.3 Flood Criteria Analysis

Flood event data in the Bondoyudo watershed is presented in Table 7. The average value of flood events is more than once in 1 year. These conditions are included in the very high recovery rate category.

Table 7. Data on the Number of Flood Events in the Bondoyudo Watershed

No.	Watershed	Year	Flood incident
1	Bondoyudo	2016	2
2	Bondoyudo	2017	3
3	Bondoyudo	2018	2
4	Bondoyudo	2019	1
Average	2		

Source : Department of Public Works and Water Resources of East Java Province

4.2.4 Water Use Index Analysis

Data on water needs and availability are obtained from the PUSDA Office of East Java Province it presented in Table 8.

Table 8. Water Balance of Bondoyudowathershed

Watershed	Catchment Area (km2)	Water availability (m3/years)	Water Availability			irrigation (m3/years)	total (m3/years)	Water Balance (m3/years)
			Domestic (m3/years)	Industry (m3/years)	pond (m3/years)			
Bondoyudo	1345.2	743,206,755	48,958,304	18,813,536	1,904,110	685,737,225	755,413,176	12,206,420
Total	1345.2	743,206,755	48,958,304	18,813,536	1,904,110	685,737,225	755,413,176	

Source : Department of Public Works and Water Resources of East Java Province

The Water Use Index value is, Water Use index = water demand / water availability =755,413,176.66 / 743,206,304.10 = 1.02 Based on the above calculations, the water use index value is 1.02. It is included in the very high recovery rate category.

4.3 Socio-Economic Analysis

4.3.1 Population Pressure and Population Welfare Analysis

The area of agricultural land in the Bondoyudo watershed is 44.041 ha (Lumajang Regency 31.044 ha [19], Jember Regency 10.697 [20], Probolinggo Regency 2.300 [21]) with the number of farmer families in the Bondoyudo watershed area of 103,334 households. The population pressure index for land is calculated as follow:

PPA = A / P= 44,041 / 103,334= 0.43

Based on the above calculations, the population pressure index value for land is 0.43. The value is included in the very low recovery rate category. The total number of poor

Families were 43,403, and the number of families in the Bondoyudo watershed was 214,386. The calculation of the level of population welfare is approached as follows: PWA = 43,403 / 214,386 x 100% = 20.25%

Based on the above calculations, the value of the welfare level of the population is 20.25%. The value is included in the category of poor recovery rate.

4.4   Building Investment Analysis

Most of the Bondoyudo watershed areas are in Lumajang Regency. Based on the number of residents (82,187 people in 2019), this location is included in small cities with a population. The city in the Bondoyudo watershed is in the low recovery level category. Bondoyudo Watershed has 8 provincial and central management authority weirs located in Lumajang and Jember Regencies with an irrigation area of 23,357 ha and 3 reservoirs. It is estimated that the investment value of the building is more than 60 billion rupiahs. Thus, the classification analysis of water construction investment in the Bondoyudo watershed is a very high recovery rate.

4.5   Space Utilization Analysis

4.5.1 Protected Area Analysis

Based on satellite imagery maps and land use maps, the protected area in the Bondoyudo watershed consists of 11,681.2 ha of national parks and 6,855.55 ha of protected forest. The area of vegetation coverage in protected areas is obtained based on satellite image data with an area of 12,605.12 ha. Based on calculations, the value of the protected area level is.

$$PAA = \frac{12.605,12}{18.536,94} X \ 100\% = 68\%.$$

The value is included in the very high recovery rate category.

4.5.2 Cultivation Area Analysis

The amount of elevation of the slope is obtained from the slope map data of the BondoyudoWatershed at the Public Works and SDA Office of East Java Province. The land area with a slope of 0-25% in the Bondoyudo watershed is 123,939.51 Ha or 92.13%, with this value included in the category of very bad recovery rate.

4.6   Evaluation of Watershed Carrying Capacity

The weighted value of the DAS classification was obtained with a total score of 103.25. Following the classification Table 9 for the watershed's carrying capacity, Bondoyudo watershed has a value of 90 <DDD <110, which is included in the medium category.

Table 9. Evaluation of Watershed Carrying Capacity

No	Criteria/Sub Criteria		Weight	Calculation Criteria			Value (Weight x Score)		
				Calc.	Class	Score	Existing	Lowest	Highest
I	**Land**	**(40)**							
a	Perccentage of Critical Land		20	3.32%	Very low	0.5	10	10	30
b	Percentage of Vegetation Cover		10	58%	Medium	1	10	5	15
c	Erosion Index		10	1.74	High	1.25	12.5	5	15
II	**Water System Analysis**	**(20)**							
a	Flow Regime Coefficient		5	25	Low	0.75	3.75	2.5	7.5
b	Annual Flow Coefficient		5	0.27	Low	0.75	3.75	2.5	7.5
c	Sediment Load		4	2.11	Very low	0.5	2	2	6
d	Flood		2		Very high	1.5	3	1	3
e	Water Use Index		4	1.02	Very high	1.5	6	2	6
III	**Social Economy Analysis**	**(20)**							
a	Populaton Pressure		10	0.43	Very high	1.5	15	5	15
b	Population Welfare		7	0.20	Bad	1.25	8.75	3.5	10.5
c	Existence of law and law enforcement		3		Good	0.75	2.25	1.5	4.5
IV	**Water Building Investment Analysis**	**(10)**							
a	City Classification		5		Low	0.75	3.75	2.5	7.5
b	Water Building Value Classification		5		Very high	1.5	7.5	2.5	7.5
V	**Space Utilization Analysis**	**(10)**							
	Protected Area Analysis		5	68	Very bad	1.5	7.5	2.5	7.5
	Cultivation Area		5	92.13	Very bad	1.5	7.5	2.5	7.5
	Total		**100**				**103.25**	**50**	**150**

Source :   Author's analysis 2020

4.7   Recommendation in Supporting Water Resources Development

It is necessary to restore the criteria for the carrying capacity of the watershed that are lacking and maintain the criteria for the carrying capacity that are already good. To restore the watershed's carrying capacity, it must be integrated from upstream to downstream and involve interested parties or stakeholders. The priority of natural resources conservation activities is to maintain the sustainability of water resources' carrying capacity and function by conducting activities to protect and conserve water resources, water preservation, water quality management, and water pollution control [22]. The utilization of water resources is carried out following the spatial use directions in the river area by taking into account the water resources processing pattern. It aims to sustainably utilize

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Water resources by prioritizing the fulfillment of the community's basic needs fairly. It is possible to be done by stewardship of water resources, water resource provision, and wise use of water resources. Control of the destructive force of water is carried out comprehensively, including efforts to prevent, overcome, and restore the condition. Prevention effort is managed by planning to control the destructive force of water compiled in an integrated and comprehensive manner.

5. Conclusion and Recommendation

5.1 Conclusion

Based on the performance management of Bondoyudo Watershed in developing sustainable water resources, the result of the environmental sustainability score is 66 (medium category). This score is calculated based on land criteria, water management criteria, and space utility criteria. At the same time, the result of the social sustainability score is 37,5 (low category). This score is calculated based on social economy criteria and water building investment criteria. The total score of 103,25 indicates the medium category of Bondoyudo Watershed performance management. A higher than 100 means that watershed carrying capacity needs to be improved. Otherwise, the watershed will be degraded. Land criteria highly affect the performance of watershed carrying capacity. Thus, land criteria have to be prioritized for improvement. Water resources conservation, water resource utilization, and water damage control have to be wisely planned to restore watershed carrying capacity.

5.2 Recommendation

As an effort to conserve the Bondoyudo watershed in supporting the development of sustainable water resources, it is necessary to plan for integrated watershed restoration, starting upstream with reforestation and construction of check dams in tributaries, carrying out river restoration and organizing cultivation areas, and downstream with engineering rivers to prevent flooding.

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