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Evaluation on biophysical carrying capacity to support land rehabilitation planning in the upstream watershed

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Abstract. A comprehensive Soil and Water Conservation (SWC) plan is needed, supported by information on the condition of the Biophysical Carrying Capacity (BCC) of the watershed so that land rehabilitation activities will be right on target. The research aims to evaluate the BCC to support the SWC planning for the upstream watershed. The research area was in the Naruan Micro Watershed (NMW), the upstream of Keduang Sub Watershed, the Bengawan Solo Watershed. The analysis of the BCC used evaluation criteria based on the Ministry of Forestry Regulation (PerMenhut) No. P.61/Menhut-II/2014 concerning monitoring and evaluation of watershed management. The evaluation showed that the BCC in the research area was in the "Bad" category with a value of 128.0. It means that the watershed needs to be restored, particularly in terms of biophysical features. Several parameters indicated a poor category, i.g. the land aspect such as Percentage of Degraded Land (PDL) and Erosion Index (EI) parameters, while in the water system aspect such as the Flow Regime Coefficient (FRC), Annual Flow Coefficient (AFC), and Sediment Load (SL) parameters. These five parameters must become a concern and an important starting point for land rehabilitation planning in the form of SWC measures.

1. Introduction

The upstream watershed area has a strategic role in maintaining the hydro-orological function of the downstream. The upstream watershed is characterized by the abundance of land with steep slopes, higher rainfall, and relatively fertile soils [1]. Therefore, land use is often carried out intensively and often has negative impacts on the environment, such as high erosion, sedimentation, and degraded land [2–5].

Land degradation in the upstream watershed occurs due to changes in land cover from forest to non-forest, which triggers high erosion, and various hydrometeorological disasters. This land degradation has a broader impact on decreasing land productivity and further decreases the carrying capacity of the watershed environment [3,6].

Due to the vulnerability of environmental conditions in the upstream watershed, efforts are needed to control and prevent degradation, mainly through soil and water conservation (SWC) [7,8]. However, to apply SWC appropriately requires proper planning, including determining the type and type of SWC, according to the problem and location. Watershed Carrying Capacity (CC) information is needed as important basic data to support the SWC planning. CC information describes the status and types of natural resource problems that must be addressed.

The CC concept has been widely used in various sectors as management tools in sustainable development processes worldwide [9]. In Indonesia, the concept of CC was initially intended for

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environmental CC in general, namely the ability of the environment (biotic) to support human life, other living things, and the balance between the two [10]. During its development, the CC concept is widely used in natural resource management to identify and determine the condition and health status in various aspects, including water resources [9-13], land resource [14], settlements [15], as well as the watershed as a whole [6,16].

Watershed Carrying Capacity (WCC) is defined as the ability of the watershed to realize the sustainability and harmony of the ecosystem and increase the benefits of natural resources for humans and other living things sustainably [17]. The WCC component consists of 5 criteria, but specifically for the biophysical aspect, it only consists of 2 criteria, namely the condition of the land and water system. In practice, the WCC assessment can be carried out partially for each criterion or as a whole, depending on analysis purposes.

This study analyzed the Biophysical Carrying Capacity (BCC), especially in the upstream areas that have a strategic role in watershed management. The upstream part of the Solo Watershed, especially in the Keduang Sub-watershed, plays an important role, especially as a recharge area for the Multipurpose Reservoir of Gajah Mungkur (MRGM). As one of the upstream areas, the Naruan Micro Watershed (NMW) also plays an important role in maintaining the protection function of its downstream areas, especially from the potential for erosion and sedimentation that enters the MRGM. Therefore, it is necessary to have proper management through proper planning. The research aims to evaluate the BCC to support the SWC planning for the upstream watershed. In addition, the results of this study can support land rehabilitation planning through soil and water conservation activities.

2. Materials and Methods

2.1. Research location

The research is in the Naruan Micro Watershed (NMW), the upstream area of the Keduang Sub-Watershed, the upper Bengawan Solo Watershed. The geographic location of the NMW is between 7°74'30" – 7°70'40" S dan 111°10'50 - 111°10'60" E, while administratively located in Girimarto District, Wonogiri Regency and Jatiyoso District, Karanganyar Regency, Central Java (Figure 1). NMW has a total area of 957.1 ha.

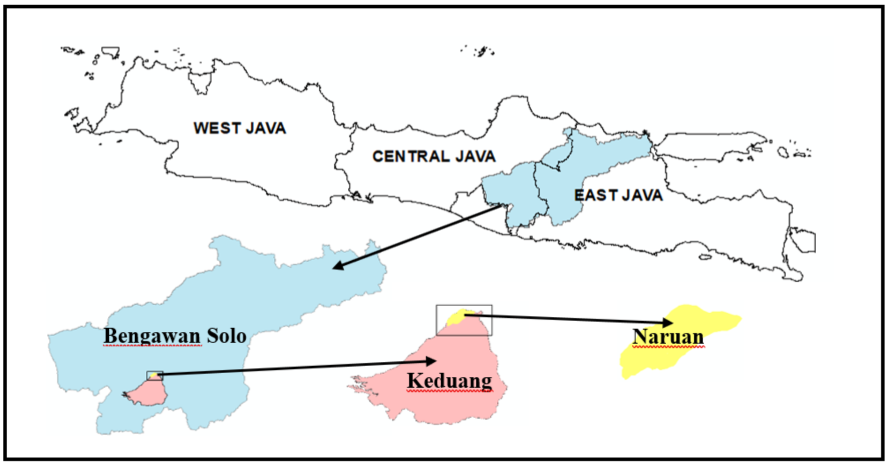

Figure 1. Research area, Naruan Micro Watershed, Keduang Sub Watershed, the upper part of Bengawan Solo Watershed.

2.2. Data collection

BCC calculation was done using criteria based on the Indonesian Ministry of Forestry Regulation No. P.61/Menhut-II/2014 regarding guidelines for monitoring and evaluation of watersheds. These regulations include criteria for determining watershed health from a biophysical aspect, including land conditions and water management. Each criterion includes several supporting parameters for the biophysical carrying capacity of the watershed. For example, the land criteria include three parameters, while the water system criteria include five parameters presented in Table 1.

Table 1. Biophysical Carrying Capacity constituent criteria and parameters.

Criteria/Parameter	Unit	Source of Data	Formula	Remarks
Percentage of Degraded Land (PDL)	%	Primary	(Degraded Land Area / Watershed Area) X 100%	Degraded land analysis using Director-General of Watershed and Protected Forest Management Regulation No. P.3/2018
Percentage of Vegetation Cover (PVC)	%	Primary	(Vegetation Cover Area / Watershed Area) X 100%	Land cover analysis with google earth imagery taken in 2015
Erosion Index (EI)	-	Primary	Actual Erosion / Tolerable Erosion	Prediction of Erosion with the USLE equation [18]
Flow Regime Coefficient (FRC)	-	Primary	Maximum Discharge / Minimum Discharge	Direct measurement 2016-2020
Annual Flow Coefficient (AFC)	-	Primary	Annual Direct Flow / Annual Rainfall	Direct measurement 2016-2020
Water Use Index (WUI)	$m^3.year^{-1}.people^{-1}$	Primary /Secondary	Total Runoff / Total Population	Direct measurement 2016-2020
Sediment Load (SL)	$tonnes.ha^{-1}.year^{-1}$	Primary	SL = k x SC x Q	Direct measurement 2016-2020
Flood (F)	times	Secondary	Frequency of flood events	Ancillary data from related agencies

Source: Modification of Regulation No. P.61/2014.
Remarks: k (coefficient); SC (sediment concentration); Q (discharge).

2.3. Data analysis

The collected parameters/criteria were then assessed, categorized, scored, and weighted. The weighting of the parameters was modified due to the five criteria in P.61/2014, and only two criteria were analyzed, including biophysical aspects, namely land and water management. BCC is obtained from the sum of the scores multiplication with the weights for each of the parameters/criteria.

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Table 2. Value range, category, and score for each Biophysical Carrying Capacity parameter.

Parameter	Weight	Value	Category	Score
Land				
		≤ 5%	Very Low	0.50
		>5 – 10%	Low	0.75
PDL	25	>10 – 15%	Moderate	1.00
		>15 – 20%	High	1.25
		≥ 20%	Very High	1.50
		>80%	Very Good	0.50
		61 – 80%	Good	0.75
PVC	20	41 – 60%	Moderate	1.00
		21 – 40%	Bad	1.25
		< 20%	Very Bad	1.50
		≤ 0.5	Very Low	0.50
		>5 – 1.0	Low	0.75
EI	20	>1.0 – 1.5	Moderate	1.00
		>1.5 – 2.0	High	1.25
		≥ 2.0	Very High	1.50
Water System				
		≤ 20	Very Low	0.50
		>20 – 50	Low	0.75
FRC	8	>50 – 80	Moderate	1.00
		>80 – 110	High	1.25
		≥ 110	Very High	1.50
		≤ 0.2	Very Low	0.50
		>0.2 – 0.3	Low	0.75
AFC	8	>0.3 – 0.4	Moderate	1.00
		>0.4 – 0.5	High	1.25
		≥ 0.5	Very High	1.50
		WUI > 6,800	Very Good	0.50
		5,100 < WUI ≤ 6,800	Good	0.75
WUI	7	3,400 < WUI ≤ 5,100	Moderate	1.00
		1,700 < WUI ≤ 3,400	Bad	1.25
		WUI ≤ 1,700	Very Bad	1.50
		≤ 5	Very Low	0.50
		>5 – 10	Low	0.75
SL	7	>10 – 15	Moderate	1.00
		>15 – 20	High	1.25
		≥ 20	Very High	1.50
		Never	Very Low	0.50
		Once in 5 years	Low	0.75
F	5	Once in 2 years	Moderate	1.00
		Once a year	High	1.25
		More than once a year	Very High	1.50

Source: Modification of Rule No. P.61/2014.
Remarks:

PDL :	Percentage of Degraded Land	FRC :	Flow Regime Coefficient	SL :	Sediment Load
PVC :	Percentage of vegetation covers	AFC :	Annual Flow Coefficient	F :	Flood
EI :	Erosion Index	WUI :	Water Use Index		

Then the BCC value is categorized into (1) excellent, if the BCC is less or equal to 70, then it is, (2) good if the BCC is between 70 and 90, (3) moderate if the BCC is between 90 and 110, (4) bad if the BCC is between 110 and 130, and (5) very bad if the BCC is greater than 130 (Modification of Regulation No. P.61/2014).

3. Results and Discussion

3.1. Land condition

The criteria for land conditions include three parameters that weigh 65% of all biophysical aspects (land and water management) while the water criterion weights 35%. Land conditions have a large weight because they are considered a source of problems in the watershed, such as the lack of permanent vegetation cover, erosion, and land degradation. On the other hand, the criteria for water management are more of symptoms or impacts as a result of carried out on the land management as a relationship between upstream and downstream and causes and effects [19,20].

The Percentage of Degraded Land (PDL) parameter shows a value of 38.33, which is included in the "very high" category. This category shows that many areas are very susceptible to degradation in the NMW. For example, of the 957.1 ha total area, 63.1 ha were degraded, and 303.8 ha were severely degraded, as illustrated in Figure 2.

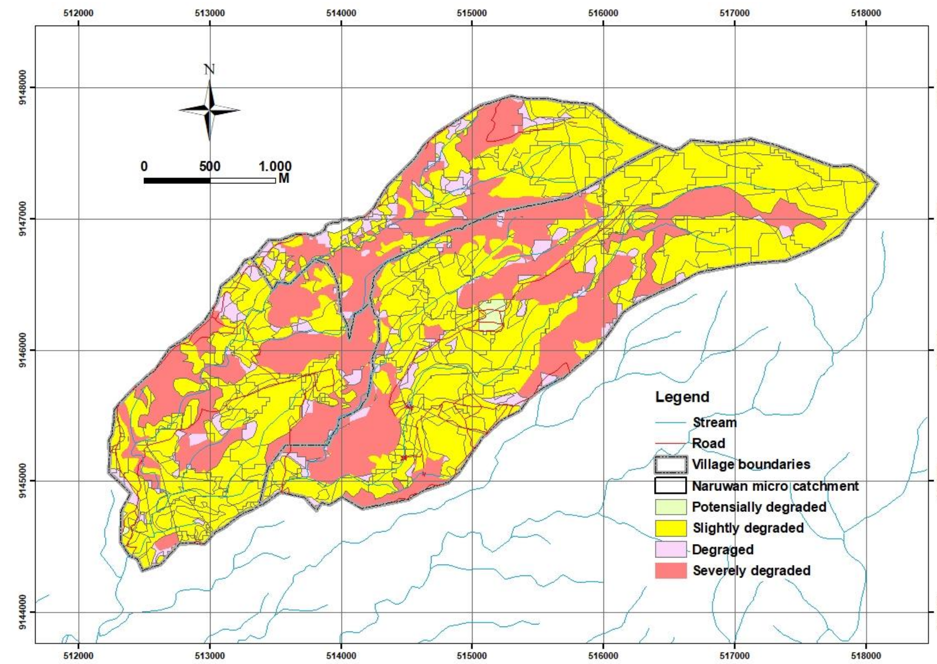

Figure 2. Map of degraded land in Naruan Micro Watershed.

Information on the presence of degraded land is very important to understand the process of erosion damage that occurs in a watershed. The cause of land degradation in the watershed is primarily due to the change/conversion of land cover to relatively more open land cover types [21], besides that also by agricultural practices on sloping land [22]. Furthermore, information on erosion and land degradation in the watershed is needed in policymaking and conservation planning [7,21].

The second parameter in the criteria for land conditions is the Percentage of Vegetation Cover (PVC), which shows a value of 43.72 which is included in the "moderate" category. This value is due to the sufficiently large area of permanent vegetation cover covering an area of 418.4 ha consisting of forest, scrub, and mixed gardens (based on P.61/2014), as shown in the land cover map in Figure 3.

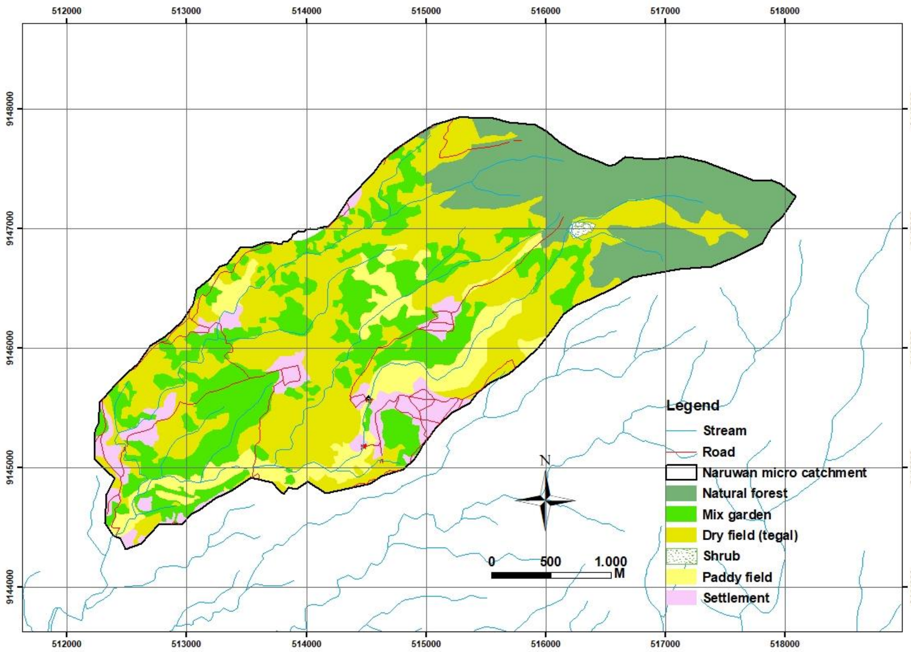

Figure 3. Map of land cover in Naruan Micro Watershed.

The third parameter of the land condition criteria is the Erosion Index (EI). EI describes the ratio between the actual possible erosion and the tolerable erosion value. The EI value in the NMW area is 37.92, which is included in the "very high" category. The high EI value is caused by the high average erosion at the NMC (341.28 tonnes ha^{-1} year^{-1}). More than 50% of the NMW area experiences a "very severe" erosion (Figure 4).

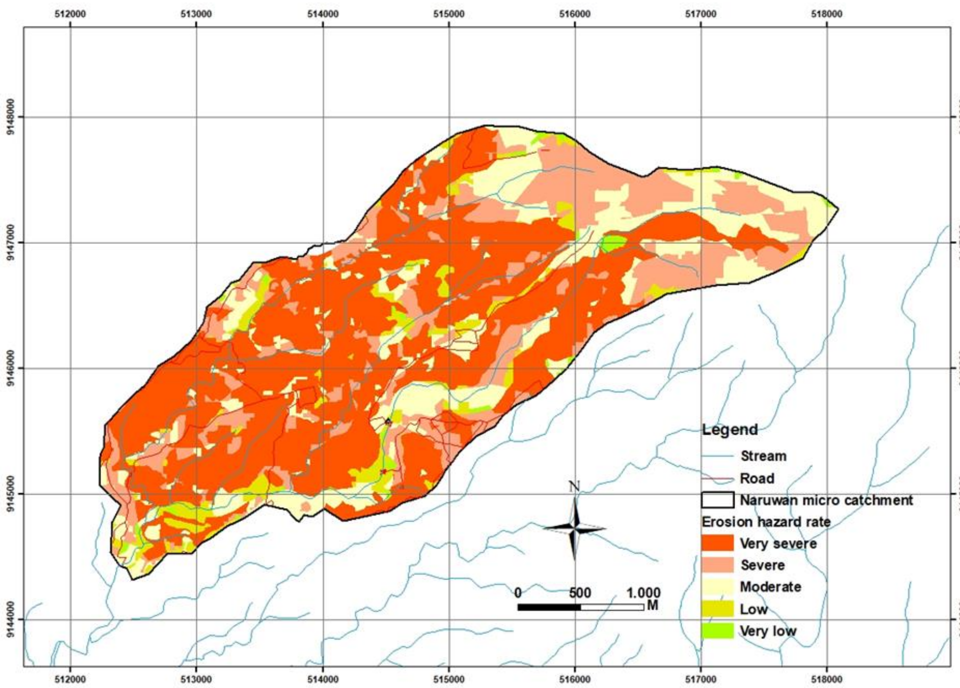

Figure 4. Map of erosion hazard in Naruan Micro Watershed.

High levels of erosion are closely related to land cover and slope as the main factors causing soil erosion. Figure 2 shows that in addition to the area of forest cover, which is less than 30%, the coverage area of the dry field, which is almost 40% of the watershed area, indicates high erosion resulting from seasonal agricultural practices. The study of [23] reinforces this phenomenon that in NMC, 56.24% of land cover does not match the land capability class. Meanwhile, 33.14% have experienced very heavy erosion. Also, more than 50% of the erosion that occurred in the watershed comes from agricultural land, compared to erosion from forest land, which is only 16% [24].

3.2. Water system

Based on the five parameters compiling the water system carrying capacity criteria, three parameters indicate bad scores, namely FRC, AFC, and SL, in the "very high" category. Two other parameters indicate a safe condition, namely WUI in the "very good" category and F in the "very low" category, respectively. The complete results of the water system criteria assessment are presented in Table 4.

Table 3. Water system category.

Parameter	Value	Category
FRC	579.490	Very high
AFC	0.546	Very high
WUI	8076.800	Very good
SL	68.010	Very high
F	Never	Very low

Source: Data analysis
Remarks:
FRC : Flow Regime Coefficient SL : Sediment Load
AFC : Annual Flow Coefficient F : Flood
WUI : Water Use Index

The high category of FRC and AFC parameters shows that the watershed conditions less perform as water regulation. Poor FRC shows a very high maximum discharge in the rainy season, whereas the minimum discharge in the dry season is very small. Poor AFC is indicated by the large proportion of rainwater that becomes direct runoff. The poor condition of FRC and AFC indicates that the watershed's water storage function (sponge function) is not running well. This is possible because of permanent vegetation cover, especially forest less than 30% of the total area (Figure 3). One of the main factors affecting the runoff coefficient value is the land cover [25, 26]. These conditions also impact the high potential for drought in the dry season and the potential for flooding in the rainy season.

The high value of the SL parameter is in line with the high rate of erosion that occurs both on surface area and on-road/riverbank, which contributes to high transported sediment content (TDS) in river and water bodies. The high sediment level in river bodies is often caused by watershed degradation due to various human activities such as forest conversion and land clearing, which potentially increase soil erosion [27,28].

The high SL will also have a further impact on downstream sedimentation problems. A study from [29] shows that the average sediment entering MRGM is very high, reaching 3.18 million $m^3 year^{-1}$. The largest source (33%) came from the Keduang Sub-Watershed, including from NMW. With an average erosion value of 341.28 tonnes ha^{-1} $year^{-1}$ (Figure 2), the potential for sediment in water bodies will be very high as well.

The other two parameters, WUI and F, are in a good category. The WUI parameter shows the criteria of "very good," indicating that the quantity of water resources is still abundant enough to meet the needs of human life in the watershed. The F parameter indicates the "very low" category because the location of the NMW in the upstream area with undulating topography allows for minimal flooding. The fluctuation of water yield and monthly sediment yield is illustrated in Figure 5.

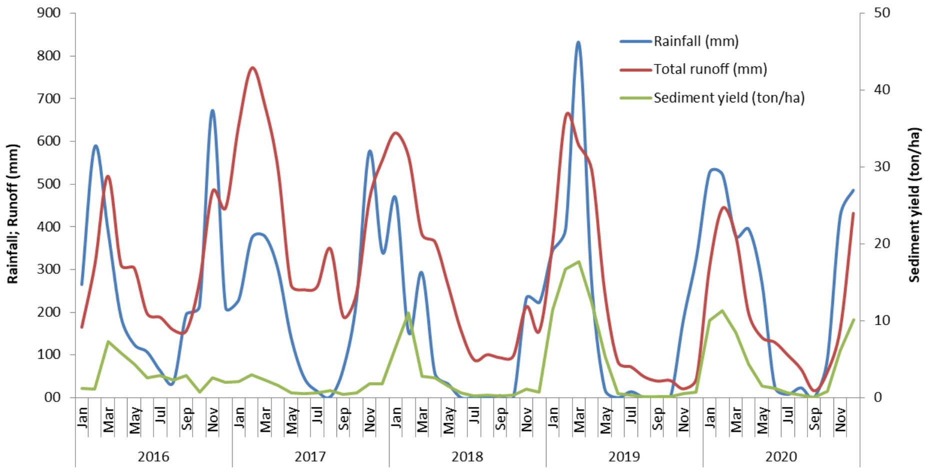

Figure 5. Distribution of monthly rainfall, runoff, and sediment yields in NMW.

3.3. Classification criteria of BCC

The weighting of each parameter from the land and water system criteria is 65% and 35%, respectively. The final analysis results showed that the BCC condition in NMW was in the "bad" category, with a value of 128.0 (Table 5). This value makes NMW a watershed whose carrying capacity needs to be restored based on watershed health criteria, particularly in terms of biophysical aspects.

The results of the final score of the carrying capacity of the watershed are classified into 2, namely watersheds that need to maintain their carrying capacity (final score ≤ 90) and watersheds that need to restore their carrying capacity (final score > 90). The final score at NMW deserves attention because it is in the "bad" category (110 <BCC ≤ 130) and even almost reaches the "very bad" criteria (BCC> 130).

Table 4. Scoring and classification criteria of BCC.

Criteria/Parameter	Weight (%)	Score	Score*Weight	Category
Land	**65**			
PDL	25	1.5	37.5	Very high
PVC	20	1.0	20.0	Moderate
EI	20	1.5	30.0	Very high
Water System	**35**			
FRC	8	1.5	12.0	Very high
AFC	8	1.5	12.0	Very high
WUI	7	0.5	3.5	Very good
SL	7	1.5	10.5	Very high
F	5	0.5	2.5	Very low
Category of BCC			**128.0**	BAD

Source: Data analysis

Remarks:

PDL :	Percentage of Degraded Land	FRC :	Flow Regime Coefficient	SL :	Sediment Load
PVC :	Percentage of vegetation covers	AFC :	Annual Flow Coefficient	F :	Flood
EI :	Erosion Index	WUI :	Water Use Index		

3.4. Prioritized parameter determination in planning management

The results of the BCC assessment are used to evaluate the condition of the constituent parameters. The final score results show that the watershed being evaluated is one of the watersheds whose carrying capacity is maintained or restored. Meanwhile, a detailed evaluation needs to be carried out on the value of each BCC parameter to see the health level of these parameters, both in land and water system aspects.

As described in the previous sub-chapter, which parameters indicate the "bad" criteria with the "very high" score category is known. In the land criteria, there are two parameters (PDL and EI), while in the water system criteria, there are three parameters (FRC, AFC, and SL). The parameters in the "bad" category are the basis for determining SWC actions in planning land rehabilitation activities. On the other hand, poor parameters are the objective of implementing SWC activities. Therefore, SWC activities are directed to improve these problematic parameters to be right on target (Table 6).

Table 5. SWC recommendations in land rehabilitation planning.

Problem	Purpose of SWC	SWC types
High PDL	To increase the percentage of forest land cover	Vegetative rehabilitation and conservation; community forest, agroforestry, social forestry
High EI	To reduce the rate of erosion	Technical and vegetative SWC; terrace development and repairment, drainage system development, grass barrier, sloping-grassing, alley cropping, mulching, contouring.
High FRC	To increase infiltration and water storage in the watershed	Soil conservation (community forest / agroforestry); Water conservation (water pond/retention, infiltration wells, bio-pore)
High AFC	To increase infiltration and water storage in the watershed	Soil conservation (community forest / agroforestry); Water conservation (water pond/retention, infiltration wells, bio-pore)
High SL	To control sedimentation	Sediment control structures; Check Dam, Retaining Dam, Gully Plug

Source: Data analyses
Remarks:
PDL : Percentage of Degraded Land FRC : Flow Regime Coefficient SL : Sediment Load
EI : Erosion Index AFC : Annual Flow Coefficient

The indicative direction for SWC activities is indispensable in the preparation of the implementation plan at T-1. However, priority locations and problem-solving require direct identification in the field through ground checks. Furthermore, community involvement is important because the local community knows more about the problems in the location. Therefore, a participatory approach in the form of participatory planning must be carried out [3, 7].

4. Conclusion

Identification of BCC conditions in the upstream watershed area is very important as a basis for SWC and land rehabilitation planning. The results of the BCC evaluation in the NMW, upstream part of the Bengawan Solo watershed, show a "bad" category that explains that the watershed's biophysical carrying capacity must be restored. Planning for land rehabilitation activities is focused on specific problems indicated by parameters that have a "bad" category, namely from the land criteria (PDL and EI) and the water system criteria (FRC, AFC, and SL). The selection of SWC types is aimed at correcting these bad parameters.

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Authors' contribution

All authors made equal contributions to conceptualization, methodology, analysis, writing, review, and editing of the manuscript. All authors have read and agreed to the published version of the manuscript