Jurnal Presipitasi
Media Komunikasi dan Pengembangan Teknik Lingkungan
e-ISSN: 2550-0023

Vol 20, No 2, 2023, 305-315
Article available at [homepage presipitasi]

Regional Case Study

Evaluation of the Success of the Watershed Rehabilitation Project in Bombana Regency Based on Cook Method's Runoff Coefficient

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Abstract

Watersheds have an important role in managing rainwater. A good watershed can provide sufficient water for the community in the dry season and does not cause flooding in the rainy season. Therefore, watershed preservation is necessary as an effort to maintain or improve its function. Rehabilitation is an effort to restore, maintain, and improve the watershed function. In this study, rehabilitation was carried out in an area of 285 ha which cuts two watersheds, Langkapa and Poleang watershed. The success of this rehabilitation can be reviewed through the runoff coefficient before and after rehabilitation. The runoff coefficient is a value that expresses the percentage of rainwater that turns into surface runoff water. That value can be an indicator of the watershed quality. The determination of the runoff coefficient in this study used the Cook Method which considers four physical parameters, land cover, slope, soil infiltration, and surface deposit/flow density. The results showed the runoff coefficient decreased after the rehabilitation from 68.54% to 65.85% which means the rehabilitation has improved the watershed quality. But those change is not significant because the rehabilitation location actually is not the priority land (critical land) that needs rehabilitation.

Keywords: Watershed; rehabilitation; runoff coefficient; cook method; physical parameters

1. Introduction

The amount of water on earth is sustainable at a certain value because water has a continuous cycle or also known as the Hydrological Cycle. The hydrological cycle links interactions between the atmosphere, lithosphere, biosphere, and anthroposphere, and it is also affected by human activities and socioeconomic development (Yang, D., Yang, Y., & Xia, J., 2021). Selin Ocak (2023), explained that the hydrological cycle begins when solar energy evaporates water from the earth's surface. The vapor rises into the atmosphere, cools, and forms clouds. These clouds then move around earth through the influence of winds and eventually release their water as rain or snow. The precipitation falls onto the earth's surface and can either infiltrate the soil or become part of groundwater or flow over the surface into rivers, lakes, and oceans. Surface water can also evaporate back into atmosphere, completing the cycle.

A watershed is a land area that is an integral part of rivers and tributaries, which functions to hold, store, and drain rainfall to lakes or the sea naturally, whose boundaries on land are separators of waters that are still affected by land activities (Regulation of Ministry of Environment and Forestry Number P.59, 2019). A watershed is a topographically delineated area that is drained by a stream system—

it is the total area above some point on a stream or river that drains past that point. A watershed is also a hydrological response unit, a biophysical unit, and a holistic ecosystem in terms of the materials, energy, and information that flow through it. Therefore, as well as being a useful unit for physical analyses, it can also be a suitable socioeconomic-political unit for management planning and implementation. Watersheds can vary in size from thousands of square kilometers to a small area drained by a freshet (Wang, G., Mang, S., Cai, H., et al., 2016). Within the watershed, there are interactions between biotic, abiotic, and social components. Every component will affect each other so if there is damage to one of the components, it can disrupt other components (Astuti, Yuniastuti, Nurwihastuti, & Triastuti, 2017). Watershed management can be defined as "the study of the relevant characteristics of a watershed aimed at the sustainable distribution of its resources and the process of creating and implementing plans, programs, and projects to sustain and enhance watershed function that affects the plant, animal, and human communities within a watershed boundary" (California Department of Conservation 2015).
One of the underlying principles of watershed management is the recognition of the interrelationships among land use, soil, and water, and the linkages between upland and downstream areas. Physical changes in a watershed can result in a variety of responses ranging from short-term events, such as flooding, landslides, and point-source pollution, to long-term processes, such as soil degradation, water depletion, and non-point-source pollution (Wang, G., Mang, S., Cai, H. et al., 2016).

Poyang Lake in Jiangxi Province, China was degraded in the early 1980s because of land conversion of forest to grain production, land reclamation from the lake, sand-dredging, pollution, ship traffic, and over-fishing to fulfill the needs of increasing population (Gong et al. 2006). The result is the surface area of Poyang Lake has been drastically reduced over the last few decades (Liu et al. 2011), its ecological functions have become compromised, and floods have occurred regularly (Liu et al. 2015). Mountain-River-Lake (MRL) is a project from Jiangxi Government that aims to sustainably manage water resources, preserve ecosystem function, and support economic development through a holistic approach. The MRL management strategy emphasizes the inter-dependency among the surrounding mountains, lakes, tributaries, and human populations in maintaining productivity and quality of the watershed. Numerous collaborations between local universities and international organizations have been carried out to improve research and monitoring of conditions within the basin (MRL 2006). This management also focuses on ecosystem restoration. The returning land from farming to forest program increased the forest area by 623,333 ha between 2001 and 2008 through replanting of agricultural land and afforestation of bare land (State Forestry Administration 2008). This initiative increased forest landscape connectivity and decreased ecological risk in the project areas, which was previously high due to landscape fragmentation and exploitation associated with conversion to agricultural land (Xie et al. 2013). Reforestation has also significantly delayed the average timing of flow and reduced the duration and magnitude of flow during high flow periods, countering the effects of deforestation in the previous decades that had increased magnitude, return period, and timing of flow (Liu et al. 2015).

The research area located at the watershed rehabilitation project site includes two watersheds, Poleang Watershed and Langkapa Watershed. Both have an important role for the community as a water source for domestic, plantation, and agricultural needs. Based on the interview with local residents, the majority of communities around the Poleang Watershed and Langkapa Watershed use surface water, river water, as their water source, so the water discharge obtained in the rainy and dry seasons will have a significant difference. In the rainy season, the community's water needs are fully met for daily activities and the irrigation of plantations. In the dry season, water can only meet people's needs for daily activities.

Watersheds that cover forest areas are often used by surrounding communities. Uncontrolled changes in the utilization of natural resources will affect the functioning and balance of the environment including hydrological processes within the watershed area. To minimize, uncontrolled utilization of natural resources, PT. Indmira created a hydroponic farming program as an alternative gardening method that does not require forest encroachment. This is also in line with the mission of the Tina Orima Forest Management Unit (KPH) which wants the communities to obtain non-timber forest products and stop forest encroachment. In addition, watershed conservation is needed to keep the interaction of each component harmonious. Watershed conservation can be carried out by conducting Forest and Land Rehabilitation as regulated in Government Regulation Number 26 of 2020 concerning Forest Rehabilitation and Reclamation. Forest and Land Rehabilitation is an effort to restore, maintain, and improve the function of the watershed so the carrying capacity, productivity, and role as support systems are maintained.

The research site is a watershed rehabilitation project area covering an area of 285 ha (**Figure 1**) carried out by PT. Indmira as a form of fulfilling the obligations of PT. Antam has a Forest Area Loan and Use Permit. This is regulated in the Minister of Environment and Forestry Regulation Number 59 of 2019. The area is in Tina Orima Forest Management Unit (KPH), Bombana Regency, and Southeast Sulawesi. The watershed rehabilitation area includes three villages, Lakomea Village covering an area of 116.84 ha, Taubonto Village covering an area of 126.25 ha, and Rarowatu Village covering an area of 42.29 ha.

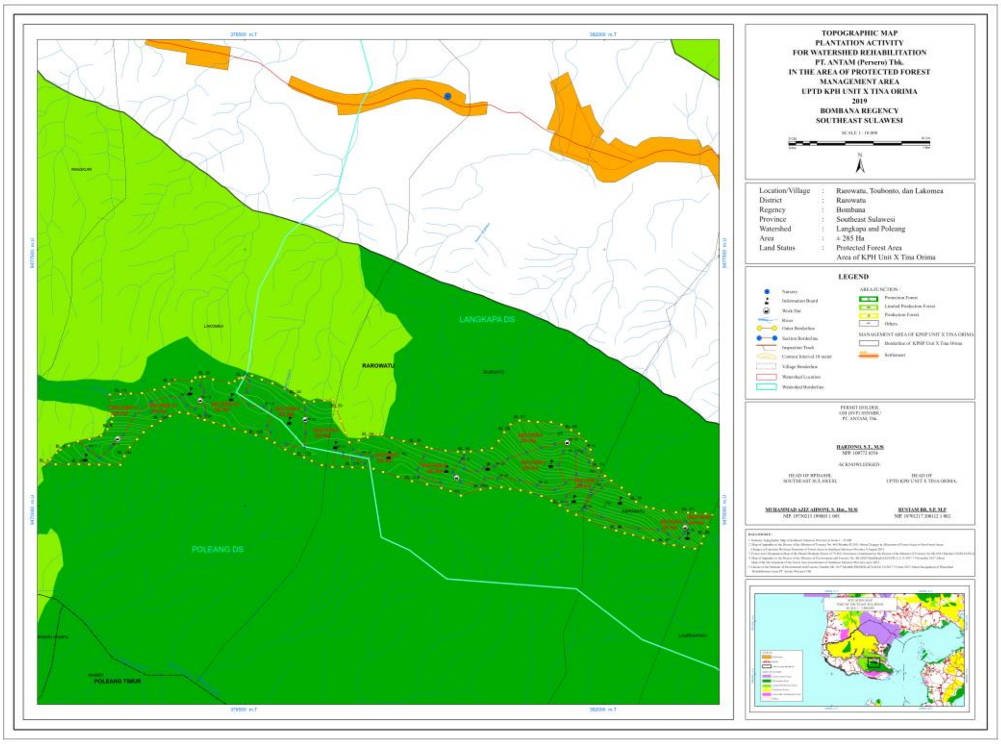

Figure 1. Research area map
(Source: PT. Indmira, 2019)

2. Methods

Runoff coefficient (C) is a parameter to find out how much rainwater that infiltrates the ground and runoff to the surface by comparing the runoff volume and precipitation volume (Lia, 2021). The value of C can be used as an indicator of physical disturbances in a watershed (Zope, Eldho, et al, 2016). If the value is close to 1 or 100%, then the amount of runoff water formed will be close to the amount of rainwater and it can be said that the watershed is impaired in function. The runoff coefficient is the watershed's response to rainfall that indicates how much rainwater is surface runoff water. Its value can be an indicator of the disturbance of a watershed (Sukariyan and Hardwinarto, 2010). The surface runoff value is influenced by meteorological elements and elements of the jetting area. Factors of meteorological elements in the form of type of precipitation, rainfall intensity, and duration of rain (Sriwati, 2014). Elements of the flow area are in the form of regional physical conditions such as land use conditions, flow density, topographic conditions, and soil types (Febryanto, 2016).

Many methods can be used to predict the value of runoff coefficients, such as the U.S. Forest Service Method (1980), Hassing Method (1995), and Cook Method (1988). Each method uses almost similar physical parameters, such as topographic conditions, land cover, soil infiltration, and surface deposits or flow density. In this study, the Cook Method was chosen as a method to predict the runoff coefficient in the Bombana Watershed Rehabilitation project area. The runoff coefficient of an area is the average of the area times score based on the criteria of every parameter. The detailed criteria for the parameters are shown in Tables 1, 2, 3, and 4.

The Cook method was chosen because the physical parameters used were quite thorough compared to other methods. The physical parameters used include land cover, slope, soil infiltration, and surface deposits or flow density (Samaawa and Hadi, 2016). This research uses primary data for soil infiltration and secondary data for land cover, slope, and flow density. Soil infiltration data was collected by taking samples from the rehabilitation site meanwhile land cover, slope, and flow density were collected from the executor of the project, PT. Indmira.

The runoff coefficient of an area is obtained using the following formula:

$$C\ DAS = \frac{C1 * A1 + C2 * A2 + \cdots + CnAn}{A1 + A2 + \cdots + An}$$

Note:

C : runoff coefficient

C1, 2, n : physical parameters of runoff coefficient

A1, 2, n : area of physical parameters

2.1 Land Cover

Land cover is the appearance of the physical material of the earth's surface. Land cover can describe the relationship between natural processes and social processes. Land cover can provide very important information for modeling purposes as well as for understanding natural phenomena that occur on the earth's surface (Liang, 2013). Land cover data is obtained by processing secondary data from the satellite imagery for conditions before the rehabilitation, while after the rehabilitation, land cover data is taken from the percentage of the successful plantation in Technical Guidance Documents and Planting Monitoring for Watershed Rehabilitation PT. Antam was created by Management Center for Watershed and Protected Forest (BPDASHL) in 2021. The classification of land cover is shown in **Table 1.**

The research site is part of a protected forest in Bombana Regency. There are only two types of areas, dense forest which shown with dark green color and fields which shown with light green color in satellite imagery **Figure 2**. Land cover condition after rehabilitation was shown in the monitoring document which shows the percentage of successful plantations on the site.

Figure 2 Area of dense forest and field in the watershed rehabilitation site
(Source: AlpineQuest, 2021)

Table 1. Land cover classification for runoff coefficient

Land Cover Characteristics	Criteria	Score
Ineffective, bare, or rare	Open land, built-up land	20
Not dense enough	Shrubs/thickets, fields, rice fields	15
Quite dense, up to 50% is mixture of grasses and trees	Plantations and less dense forests	10
Very good, 90% of the area is covered with tree vegetation or equivalent	Dense forest	5

Source: Meijerink (1970) in Febryanto & Farda (2016)

2.2 Slope

The slope is a comparative value between elevation and distance. The slope affects the flow that occurs in a region. The greater the slope of the slope, the greater the flow will be. This is due to the large slope will provide the opportunity for rainwater to seep into the soil with a relatively small amount (Astuti, Yuniastuti, Nurwihastuti, & Triastuti, 2017). The slope of the Bombana Watershed Rehabilitation project site was obtained from a topographic map of the site. The elevation data is divided by length to obtain the land slope value used as a runoff coefficient parameter with the classification and score as shown in **Table 2**.

Table 2. Slope classification for runoff coefficient

Slope Class	Score
Relatively flat with an average slope of <5%	10
Undulating with an average of 5-10%	20
Hilly, with an average slope of 10-30%	30
Steep mountainous, with an average slope of >30%	40

Source: Gunawan (1991) in Febryanto & Farda (2016)

2.3 Soil Infiltration

Infiltration is defined as the event of water ingress into the soil. If enough water, then the infiltration water will move steadily downwards i.e., into the soil profile. The downward movement of water within the soil profile is called percolation (Arsyad, 2006). The high infiltration rate not only increases the amount of water stored in the soil for plant growth but also reduces flooding and erosion caused by runoff (Hakim, 1986). Infiltration rate measurements generally use the Horton Model. Horton states that infiltration capacity will decrease as time increases until it approaches a constant value (Arfan and Pratama, 2012).

Soil infiltration at the Bombana Watershed Rehabilitation project site was obtained by taking primary data in the field using an infiltrometer. Sampling was carried out at 23 points with details of 12 in the field-vegetated land and 11 in the forest-vegetated land as shown in **Figure 3**. The sampling was purposive sampling based on the total area and the vegetation of the research site. The sample was taken in two points in every section from the different vegetation, dense forest and field. So, the number of samples is 11 samples from dense forests and 12 samples from fields. The classification of soil infiltration is shown in **Table 3**.

Table 3. Soil infiltration classification for runoff coefficient

Soil Infiltration Characteristics	Infiltration (mm/h)	Score
Very low	<2.5	20
Low	2.5 – 15	15
Normal	15 – 28	10
High	28 – 53	5

Source: Meijerink (1970) in Febryanto & Farda (2016)

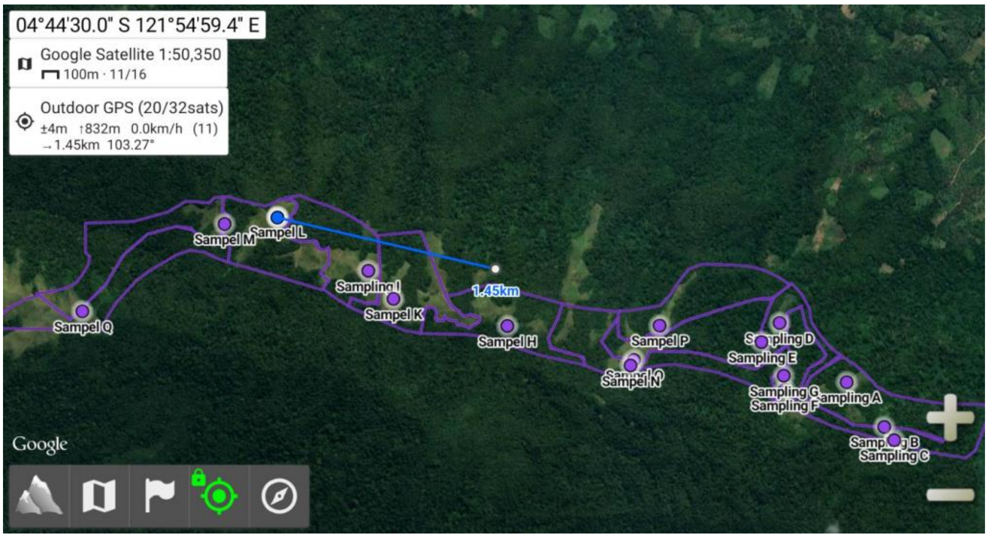

Figure 3. Soil infiltration sampling point
(Source: AlpineQuest, 2021)

2.4 Flow Density

Surface deposits are considered by determining the flow density. The greater the density of the flow, the smaller the surface storage will be. River flow density expresses the length of the river channel in each unit of watershed area or sub-watershed (Astuti, Yuniastuti, Nurwihastuti, & Triastuti, 2017). The flow density parameter is obtained by processing secondary data in the form of a map of the Bombana Watershed Rehabilitation location. The flow density is obtained by determining the order of each flow segment by the Strahler Method. Order 1 is a tributary located at the very end and is considered the first source of water. The meeting between 2 segments of the same level will form the next, while the meeting of segments that are not level will form a higher order of segments. After that, the total length of the rivers of the 1st, 2nd, and 3rd order is divided by the area of the Catchment Area to obtain the value of the flow density. Based on the Strahler Method, all rivers in the study area are tributaries or rivers of order 1, 2, and 3 that affect the value of flow density. The classification of flow density is shown in **Table 4**.

Table 4. Flow density classification for runoff coefficient

Linsley Classification	Flow Density (km/km²)	Score
Extreme run out, no puddles, steep slopes	>5	20
Good system and flow pattern, water flows smoothly	2 - 5	15
Normal, river flow exists, there is inundation but =<2% of the total area	1 - 2	10
Poor drainage, always flooded	<1	5

Source: Linsley (1959) and Meijerink (1970) in Febryanto & Farda (2016)

3. Result and Discussion

3.1 Land Cover

Before the rehabilitation, land cover in the rehabilitation project site was divided into two types, forest area 73% and field area 27% as shown in **Table 5**. After the rehabilitation, the field area began to be overgrown by planted trees. Based on the Technical Guidance Documents and Planting Monitoring for Watershed Rehabilitation PT. Antam was created by Management Center for Watershed and Protected Forest (BPDASHL), the percentage of planted trees due to the rehabilitation reaches 93.19%, so the field area has turned into a forest area. After the rehabilitation, it can be said that the entire project area is 100% forested mathematically as shown in **Table 6** so the runoff coefficient before and after the rehabilitation will be different, from 7.69% to 5%. The insignificant change in runoff coefficient from the land cover parameter is caused by the rehabilitation site which already has good vegetation. There is only 27% of the total area can be improved from field area to forest area. Meanwhile, the rest of the site is dense forests which already have the lowest coefficient from the land cover parameter.

The rehabilitation location was chosen by the Ministry of Environment and Forestry through the Decree of the Minister of Environment and Forestry Number: SK.3673/Menlhk-PDASHL/KTA/DAS.1/6/2017 concerning the Determination of Planting for Watershed Rehabilitation of PT. Antam. Tbk-UBPN Southeast Sulawesi for Forest Lease Permit Number: SK. 601/Menhut-II/2013 covering an area of 285 Ha in the Protected Forest at Tina Orima Management Forest Unit, Bombana Regency, Southeast Sulawesi Province. Determination of the rehabilitation location is based on the National Critical Land Map and/or Indicative Map of Watershed Rehabilitation Locations. Referring to the Regulation of the Ministry of Environment and Forestry Number P.59, 2019, critical land is land inside or outside a forest area that has decreased its functions as a production element and as watershed management.

Table 5. Classification of land cover before watershed rehabilitation

Land Cover Characteristics	**Criterion**	**Score**	**Area (ha)**	**Area (%)**	**C (%)**
Ineffective, bare, or rare	Open land, built-up land	20	0	0%	0
Not dense enough	Shrubs/thickets, fields, rice fields	15	76,5705	27%	4,03003
Quite dense, up to 50% is mixture of grasses and trees	Plantations and less dense forests	10	0	0%	0
Very good, 90% of the area is covered with tree vegetation or equivalent	Dense forest	5	208,43	73%	3,65666
				C Total	**7,69**

Table 6. Classification of land cover after watershed rehabilitation

Land Cover Characteristics	**Criterion**	**Score**	**Area (ha)**	**Area (%)**	**C (%)**
Ineffective, bare, or rare	Open land, built-up land	20	0	0%	0
Not dense enough	Shrubs/thickets, fields, rice fields	15	0	0%	0
Quite dense, up to 50% is mixture of grasses and trees	Plantations and forests are less dense	10	0	0%	0
Very good, 90% of the area is covered with tree vegetation or equivalent	Dense forest	5	285	100%	5
				C Total	**5**

3.2. Slope

The slope affects the runoff coefficient due to the nature of water which always flows into the lower plains by gravitational forces. Rainwater that falls on the earth's surface will enter the soil due to infiltration capacity and flow to the surface due to the land slope. The rehabilitation site has a slope classification as hills and mountains. 56% of the site has a slope 10%-30% and 44% of the site has a slope higher than 30% as shown in **Table 7**. In critical land classification, slope is able to represent infiltration potential. Surfaces with higher slopes will have lower infiltration rates which means the land is more critical. The hilly surface makes the rainwater easier to become surface runoff. The rehabilitation project was focused on planting local endemic trees inside and outside the forest area without topographic change processes. Topographic change processes (TCPs) are the mechanisms by which a landscape is interpreted to be experiencing landform deformation and are defined by the specific actions occurring within a contiguous, localized region that cause sediment to be either deposited or eroded (Wyrick & Pasternack, 2016). So, the runoff coefficient from the slope parameter does not change after the rehabilitation, it is still 34.44%.

Table 7. Slope classification before and after watershed rehabilitation

Slope Class	Score	Area (ha)	Area (%)	C (%)
Relatively flat with an average slope of <5%	10	0	0%	0
Undulating with an average of 5-10%	20	0	0%	0
Hilly, with an average slope of 10-30%	30	158.453	56%	16.6792
Steep mountainous, with an average slope of >30%	40	126.547	44%	17.761
			C Total	**34.44**

3.3. Soil Infiltration

Infiltration happens because of soil porosity. Each type of soil has its porosity due to the size of the soil. Soil with greater particles has greater porosity and vice versa. Theoretically, the soil infiltration will have the same value if there are no changes in soil type. Although, the soil infiltration can change due to soil saturation and soil density.

Saturated soil has a low ability to infiltrate rainwater into the ground because a lot of space is already filled. The sample taken in the rainy season causes many samples to have low infiltration rates due to soil that has been saturated with water. Dense soil also has low infiltrate ability because it has smaller porosity. Samples near the inspection track have lower infiltration rates than samples that are quite far from the track because the soil near the inspection track is frequently compacted due to its functions for walking.

The rehabilitation was done without changing any soil type in the location, but the process compacted some parts of the soil on the site. The compacted soil part is very small compared to the total site area. So, this research assumed that there is no change in soil porosity which means the soil infiltration will have the same value after the rehabilitation. The runoff coefficient from the soil infiltration parameter still has the same value after the rehabilitation, 11.06% as shown in **Table 8**.

Table 8. Classification of soil infiltration before and after watershed rehabilitation

Infiltration Characteristics	Infiltration (mm/h)	Score	Area (ha)	Area (%)	C (%)
Very low	<2.5	20	0	0%	0
Low	2.5 - 15	15	145.062	51%	7.63484
Normal	15 - 28	10	55.1761	19%	1.936
High	28 - 53	5	84.762	30%	1.48705
				C Total	**11.06**

3.4. Flow Density

Surface deposits or flow density are the ratios between the length of rivers of order 1, 2, and 3 and the Catchment Area. The river will catch and store the rainwater as much as it can. Its capability is based on the capacity of the rivers or it can be represented by its length. The longer rivers can catch and store more rainwater. The rehabilitation site has many rivers but no large natural reservoirs. Even though the location has many rivers, the flow density is relatively low because of the large catchment area. the runoff coefficient from the flow density parameter is 15.35% as shown in **Table 9**. That value does not change after the rehabilitation because there is no change in the river's length.

Table 9. Classification of flow density for runoff coefficient

Linsley Classification	Flow Density (km/km^2)	Score	Area (ha)	Area (%)	C (%)
Extreme run out, no puddles, steep slopes	>5	20	166,444	0,58402	11,6803
Good system and flow pattern, water flows smoothly	2 - 5	15	69,7351	0,24468	3,67027
Normal, river flow exists, there is inundation but =<2% of the total area	1 - 2	10	0	0	0
Poor drainage, always flooded	<1	5	0	0	0
				C Total	**15,35**

3.4. Runoff Coefficient

Table 10 shows that the runoff coefficients before and after rehabilitation are 68.54% and 65.85%. The decreased value of the runoff coefficient is an indication of watershed improvement quality. Despite the decline, the runoff coefficient is still high. The research site in the hills is the main reason for the high runoff coefficient.

The slope parameters of the land that had a high-value contribution to this study did not change after rehabilitation because there were no efforts to change the earth's surface in this project. Soil infiltration parameters are taken only post-rehabilitation making it quite difficult to analyze. Besides, the planted trees are still young and have no significant impact on the environment. Land cover parameters have greater changes than other parameters, but are still not significant enough to decrease the runoff coefficient because the area converted from a field to a forest is a little part of the total area. The parameters of the surface storage have no changes before and after rehabilitation because in this project no changes were made to the flow of the river.

Table 10. Comparison of watershed runoff coefficient

Physical Parameters	C (%)	
	Before Rehabilitation	**After Rehabilitation**
Land Cover	7.69	5
Slope	34,44	34,44
Soil Infiltrate	11.06	11.06
Flow Density	15.35	15.35
Total	**68.54**	**65.85**

The runoff coefficient changes from 68.54% to 65.85% is not significant because the location is not in a condition that needs rehabilitation. This rehabilitation project is carried out as a fulfillment of the obligations for the Forest Area Loan and Use Permit. In this case, the permit holder is PT. Antam and the rehabilitation executor is PT. Indmira, but the decision maker for the rehabilitation location is the Ministry of Environment and Forestry through Management Center for Watershed and Protected Forest. From the first time, Poleang and Langkapa Watershed, visually, has good quality as a forest. Even if those locations are part of the critical land based on the National Critical Land Map, if it is re-identified by the method in Regulation of the Ministry of Environment and Forestry of the Republic of Indonesia Number 10, 2022, Poleang and Langkapa Watershed is not critical land.

Critical land identification is based on infiltration potential (topographic condition, infiltration rate, and rainfall) and land cover. Areas with high natural infiltration potential should have dense vegetation like forests so the rainwater will effectively infiltrate the ground. Meanwhile, areas with bad vegetation are priority areas for rehabilitation. Poleang and Langkapa Watershed already has dense forest so it is not a priority location for rehabilitation.

4. Conclusion

The watershed rehabilitation was carried out by PT. Indmira has decreased the runoff coefficient of the watershed from 68.54% to 65.85%. The rehabilitation is succeeded but the change is not significant because the rehabilitation location, Poleang and Langkap Watershed, is not a critical land that needs rehabilitation. The rehabilitation should be done on critical land as the rehabilitation priority area. So, the rehabilitation impact will give a significant change to the rehabilitation location.

Government, in this case, the Ministry of Environment and Forestry and Management Center for Watershed and Protected Forest, should not decide on the rehabilitation location only from the National Critical Land Map. Survey of the location is needed to ensure the real condition of the land and update the National Critical Land Map.

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