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LAND CONSERVATION FOR REHABILITATION OF CRITICAL WATERSHEDS: CASE IN WAY CENGKAAN, WAY BESAI SUB-WATERSHEDS, LAMPUNG, INDONESIA

Didik KUSWADI[1], Fitriani FITRIANI[1,*], Sutarni SUTARNI[1],
Robet ASNAWI[2], Slameto SLAMETO[2], Ratna Wylis ARIEF[2]

[1]Politeknik Negeri Lampung, Jl. Soekarno-Hatta, Rajabasa, Bandar Lampung, Lampung, Indonesia, 35145
[2] Indonesian National Research and Innovation Agency, CWS BRIN Jl. ZA Pagar Alam, Rajabasa, Bandar Lampung, Lampung, Indonesia, 35145

Abstract

Land and water conservation are the keys to success in controlling the rate of sedimentation. The sediment runoff rate represents the catchment area that increases erosion. This study was conducted to analyze the sedimentation rate in the upstream part of the Way Cengkaan, Way Campang tributary rivers located in Pekon Karang Agung, Way Tenong District, West Lampung Regency. It was carried out from January to December 2020. The research equipment included: a current meter, a stopwatch, a rollmeter, a rainfall recorder, an automatic water level recorder (AWLR), a peiscal, sediment bottles, scales, ovens, and cups. While the materials used are sediment samples, discharge measurement results, and water level. The calculation of flow was carried out at two observation points, upstream and downstream of the Cengkaan River before entering the Way Campang River. Calculation of flow rate using the velocity-area methods using the current meter and the float method. During the observation period from January to July 2020, the sediment velocity increased in line with the trend of the sediment velocity map. The sediment velocity curve for upstream stations is steeper than for downstream stations. The sediment volume decreased relatively in December 2020, and the slope of the sediment velocity graph at the downstream observation point is larger than that at the upstream observation point. This finding reflected that in the one-year observation period from January to December 2020, the evaluation resulted from a decreasing trend of sedimentation in the Way Cengkaan River. Based on these conditions, the implementation of a land conservation program carried out in collaboration between farmer groups and beneficiary stakeholders has a positive impact and effectively contributes to improving the quality of the watershed by reducing the sedimentation rate.

***Keywords**: Sedimentation; Erosion; Conservation; Soil bioengineering; Watersheds*

Introduction

A watershed is an area that is hydrologically connected and, in a broad sense, provides ecological, economic, and social services to the community. As a biophysical system, watersheds describe how land units are connected by water currents. They are also suitable systems for developing sustainable use and management of multiple resources under the principles of jointly managing land and water, affecting human well-being and the functioning of natural ecosystems. Increasing attention is being paid to preserving or restoring natural river systems, riparian communities, wetland ecosystems, and floodplains to maintain good hydrological conditions in

* Corresponding author: fitriani@polinela.ac.id

watersheds [1]. Water conservation is defined as the judicious use and conservation of water supplies and includes both quantity and quality of water. The benefits of having water resources of the required quality for various purposes must be offset by their use [2].

Inappropriate use of water bodies by the community causes damage and conditions that are detrimental to the downstream environment. Population growth, which is very significant, affects the needs of society. Actionable community activities include interventions in settlements, plantations, and downstream forests that generate high runoff and percolation. Surface runoff also causes erosion and sedimentation. Erosion can affect the productivity of the dominant land stream and cause negative impacts in the form of downstream deposition, also resulting in seasonal droughts and rainy season floods. Over time, soil fertility in the upstream watershed reaches decreases, and sediment loads accumulate in the middle and lower reaches, causing siltation of the river bed. Land use not in accordance with soil and water conservation in the upper watershed causes large-scale erosion [3]. Continuous exploitation of agricultural land without protective measures results in a temporary or permanent decrease in soil productivity, which in turn contributes to ecosystem changes that lead to environmental degradation. In general, the decline in soil quality and the decline in the hydrological function of the watershed are caused by changes in land use that are not in accordance with the designation of conservation protection areas, the absence of principles and techniques for soil protection and water conservation, and tillage in water catchment areas that do not meet the requirements.

Biogeophysically, the upstream watershed is a conservation area; the drainage density is higher, the slope is greater (above 15%), and the vegetation types are generally forest stands. In 2018, the Ministry of Environment and Forestry noted that as many as 2,145 watersheds (12.6%) needed to restore their carrying capacity, while the number of watersheds whose carrying capacity was maintained reached 14,931 watersheds (87.4%). This level of criticality is indicated by the decline in permanent land vegetation and the expansion of critical land, which results in a decrease in the ability of the watershed to store water. It is important to study the characteristics of forest landscapes in critical and non-critical watersheds to determine sustainable forest landscape planning and management systems. Currently, the classification of critical and non-critical watersheds is still based only on ecological characteristics. Critical watersheds are characterized by a decrease in their ability to store water, which in turn has an impact on reduced water discharge, flooding, and landslides during the rainy season and drought during the dry season [4].

Negative externalities of agricultural practices pose a threat to environmental sustainability. Changes in land cover due to land conversion cause deforestation, land degradation, erosion, loss of carbon stocks, loss of biodiversity, floods, and droughts, among the extreme impacts of global climate change. Uncontrolled grazing, overexploitation for local use, habitat degradation, deforestation, landslides, and uncontrolled visitor movement also treat and become the main risks to the population of these endemics in their natural habitats [5].

The main watersheds in Lampung are the Sekampung Watershed and the Way Seputih Tulang Bawang Watershed. Way Besai sub-watersheds are the main upstream of Way Seputih watersheds. According to [6], over a span of 30 years (1970–2000), the Way Besai sub-watershed was reported to have experienced a decrease in forest land cover by 48% as a result of the high activity of monoculture coffee farming and seasonal crops. The results of the study showed that the level of soil erosion was light at 42.98%, moderate at 14.57%, severe at 15.38%, and very heavy at 3.45%. 45% of the area covered by coffee plantations experienced mild to very heavy erosion on all slopes and soil types. According to *B. Verbist et al.* [6] and *B. Verbist & G. Pasya,* [7] noted that in the last 15 years, more and more coffee cultivation, which was originally in the form of a monoculture system, has gradually changed to mixed coffee cultivation with shade trees. Then *M.T. Bim Salam et al.* [8], reports that a decrease in forest cover area can increase discharge and run-off, while an increase in forest cover area will increase soil infiltration and evapotranspiration. According to [9], the condition of the Way Besai hydropower plant is currently experiencing a decrease in energy supply of 40MW. This is due to the soil conditions in this river, which are "metastable," which results in rapid silting of the river cross section, so that an increase in the cross section of the river is required up to initial conditions, where the energy supply in the PLTA reaches 90MW.

Land use change in the two main watersheds occurred partly due to the expansion of agricultural production areas for commercial crops, including coffee, cocoa, pepper, oil palm, and rubber. Although several previous studies have shown that the development of commercial crop production in the upstream watershed area can continue to be carried out by applying conservation principles, Land use change causes damage or degradation of the upstream watershed (on site) as a result of changes in the function of forests to cultivation or agricultural land and farming without considering the potential for agrotechnology as well as soil and water conservation [10]. Woody roots serve to hold soil together and resist large-scale displacement during landslides. The critical load at which individual roots break is related to root lignin content (woodiness). The shear strength of the soil volume above each level increases in proportion to the number and strength of individual roots [11].

The choice of appropriate conservation techniques is strongly influenced by specific country biophysical factors (soil, topography, cultivation, rainfall, and climate). Soil and water conservation techniques that can be selected and applied range from mild to strict, including mulching, contour planting, contour cultivation, plant protection (no cultivation, minimal cultivation), spacing, strip planting, and rotational planting. One of the first steps to overcome the increasingly severe damage to the watershed is to form a community movement to jointly protect and preserve the watershed ecosystem [12-14]. Community movements in protecting and preserving watersheds are very dependent on the level of participation and the tendency of people's attitudes toward watershed management activities [15].

Land-use changes, weak enforcement of regulations, and oversight of the implementation of soil and water conservation techniques in the watershed area have resulted in the community not feeling obligated to further increase efforts to reduce land degradation. This is indicated by the lack of clear programs to prevent land degradation or the application of soil and water conservation techniques in all cultivation [16–18]. The activities in the upstream watersheds are generally driven by economic motives because their welfare is very low due to limited human resource capacity and weak access to technology, which does not support other (formal) jobs outside the agricultural sector. It caused the management of the land to not be optimal in implementing conservation. Deforestation and even desertification ultimately cause a decrease in watershed quality. The low level of welfare and poverty problems are closely related to watershed damage. Efforts to manage watersheds based on community empowerment aim to increase the ability and self-sufficiency of the community so that they are able to manage land, improve their welfare, and maintain the sustainability of the watershed [19]. The problem is that the farmers have little capital and are reluctant to invest in land due to volatile raw material prices. The average level of farmer education is relatively low, and limited farmer capital is the main challenge [20]. Community behavior in managing land will have an impact on the environment. Increased conservation activities are carried out to improve watershed conditions, thus increasing the stability of land conditions and minimizing erosion and sedimentation. Appropriate land management will certainly be able to maintain the sustainability of the watershed area [21].

Destruction of watershed areas has an impact on reducing the quality of water as a source for various purposes. Damage or degradation along the upstream side of the river can be seen in the turbidity of the flowing water. Turbid river water indicates the amount of sediment load contained in the river flow [22]. Sediment runoff is the total sediment runoff from a watershed at a defined point within a riverbed over a specified period of time. Sediment recovery is typically determined by sampling the sediment and comparing the measurements with runoff from rivers or by conducting sediment deposition surveys at reservoirs. Sediment release rates are influenced by the texture of eroded soil material, land use conditions, climate, local river environment, and general geographic location. For upstream watersheds and highland catchment areas, these data are often not available. Many studies describe the impact of different land-use activities on sediment production without specifying the sediment source. Spatial and temporal land-use diversity in watersheds can lead to large variations in sediment yields from catchments [1].

Therefore, it is necessary to apply integrated land and water conservation technologies to sustainable agricultural practices. The application of mechanical land and water conservation technologies and soil bioengineering together is necessary. At the farmer level, which still faces limited access to capital, skills, and institutions, stakeholder involvement, especially among the direct beneficiaries of the watershed, is mandatory. The Way Besai power plant has a direct interest in repairing the critical upstream watershed by directly involving the people who own the land and carry out agricultural production activities in the watershed area. In 2019, the Way Besai power plant launched a river care program IV in the upstream region of the Campang tributary, the Way Cengkaan sub-watershed in Pekon Karang Agung, Way Tenong District, West Lampung. The program covers an area of 41 ha owned by 41 farmers. The implemented land and water conservation programs include mechanical conservation (terraces and rorak) and soil bio-engineering with Odotan grass strips and shade plants (fruit trees). To what extent the effectiveness of the success of this land conservation program in controlling the rate of sedimentation in the Campang tributary, the Way Cengkaan sub-watershed, needs to be explored more deeply,

How to analyze the magnitude of the sedimentation rate in the Way Cengkaan upstream sub-watershed, a tributary of the Way Campang river, requires a more in-depth investigation. There is not yet adequate information available about the rate of sedimentation in the Way Besai watershed. In general, the sediment runoff rate increases as the catchment area increases. Erosion and sediment data should be collected or otherwise obtained before developing sediment release rates or more detailed sediment models. Therefore, research needs to be carried out by taking sediment samples and measuring flow rates, followed by an analysis of sedimentation rates. It is necessary to prepare a rating curve showing the relationship between flow rate and sedimentation rate that occurs in the Cengkaan river. This curve will form an equation-function relationship between flow rate and sedimentation rate. This equation can then be used to approach the calculation of the amount of sediment entering the river body, which results in siltation of the water reservoir, especially for the Way Besai hydropower plant and other purposes. Way Besai hydropower plant reported that sedimentation caused a decrease in the electric power capacity that almost reached 50%.

This study aims to analyze the magnitude of the sedimentation rate in the upstream part of the Way Besai watershed, namely in the Way Campang sub-watershed, or, to be precise, a tributary of the Way Cengkaan river. In the first year, sediment sampling and analysis of the sedimentation rate in the Way Cengkaan river were carried out when land conservation and conservation efforts had not been carried out as the initial stage of land conservation efforts. The priority of this research is the formulation of a model of the relationship between sediment rate and river flow discharge as a basis for evaluating the results of conservation activities in the water catchment area of the Cengkaan River, Way Besai Watershed, West Lampung.

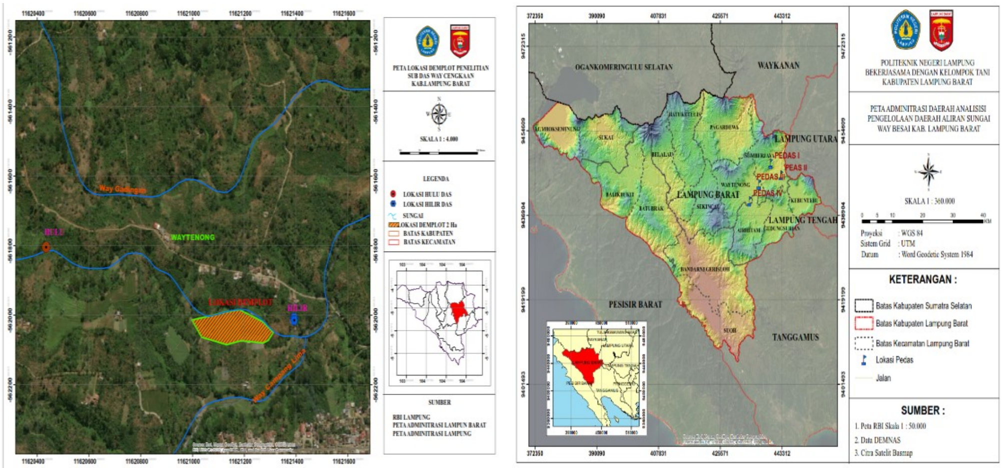
Experimental part

Materials

The research equipment included: a current meter, a stopwatch, a roll meter, a rainfall recorder, an automatic water level recorder (AWLR), a peiscal, sediment bottles, scales, ovens, and cups. While the materials used are sediment samples, discharge measurement results, and water level, The study location survey was conducted to determine the points of measurement and observation locations necessary to achieve the objectives of this study. It was also coordinating with stakeholders (a farmer group involved in river care programs), measuring river cross sections, and installing Peiscal and AWLR. Equipment installation and data collection were carried out by field observers who had been trained, coming from farmer members of the Pekon Karang Agung farmer group, Way Tenong District, West Lampung Regency. Some of the equipment must be properly installed in the river body and comply with the rules and requirements for installing hydrological and hydrometric equipment in the field.

Site Plant

This research was conducted in the Way Besai Sub-watershed, in the Cengkaan River, which is a tributary of the Campang river located in Pekon Karang Agung, Way Tenong District, West Lampung Regency (Fig. 1). It was carried out from January to December 2020.



(a) Way Cengkaan Site location (b) West Lampung Regency

Fig. 1. Way Cengkaan, Karang Agung Village, Way Tenong sub-district, Lampung Province, Indonesia

Methods

The calculation of flow was carried out at two observation points, upstream and downstream of the Cengkaan River before entering the Way Campang River. Calculation of flow rate using the velocity-area methods using the current meter and the float method While the area is measured based on the cross section of the observation point of the river body. Measurement of river flow uses the flow rate measurement method with the velocity-area method. Calculating flow velocity with the equation:

$$v = 0{,}2491n + 0{,}0171(N < 0{,}93), \quad (1)$$

$$v = 0{,}2583n + 0{,}0086(N \geq 0{,}93), \quad (2)$$

where: v - flow rate (meter/second); n - number of rounds; N - n/time.

Calculating river flow discharge (Q) in each segment with the equation:

$$Q_i = A_i x v_i, \quad (3)$$

Calculating the total debit, with the equation:

$$Q_t = \sum_{i=1}^{n} Q_i \quad (4)$$

An illustration of river flow discharge measurements using the Velocity-Area Method can be seen in figure 2.

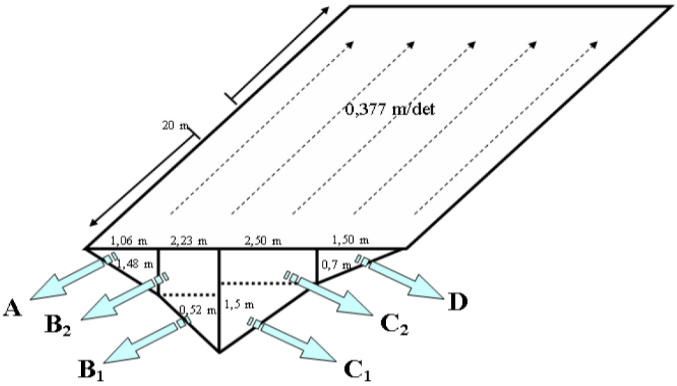


Fig. 2. Ilustration of river flow discharge measurement (Velocity-Area Method)

River sediment measurements were carried out using the gravimetric method. Sediment concentration (ms) is calculated by the equation:

$$m_s = 20x(m_{cs} - m_s)(gram/liter) \quad (5)$$

Information: cups that have been affixed with label paper (mc); dishes containing sediment (mcs); sediment concentration (ms). Analysis of discharge and sediment data is aimed at making discharge and sediment curves. The data of flow rate (Qw) and sediment rate (Qs) collected daily from January to December 2020. The Qc value is obtained by entering the Qw value. Graph of rating curve relationship between Qc and Qw. Deviation correction calculation:

$$DQ = \frac{Q_c - Q_m}{Q_c} x100\%, \quad (6)$$

where: DQ = amount of correction discharge (%); Qc = discharge from the curvature of the flow curve; Qs = discharge measurement; If DQ < 10%, then the resulting flow curve equation does not need to be corrected; If Qm < Qc, then sedimentation will occur in the river; If Qm > Qc, then river erosion occurs.

Data analysis was carried out to determine the relationship between river flow and sedimentation that occurred in the river body before and after conservation efforts were carried out in the catchment area.

Results and discussion

The combination of land conservation program to recover critical watersheds at Way Cengkaan River (Table 1 and figure 3)

Table 1. Data on Land Conservation Program Development for Way Cengkaan River Critical Watershed Recovery.

Area	Mechanical Soil conservation		Soil bio-enginering	
	Ditch (*Rorak*)	Terace	Grass strip	Shade tress multipurposes
Unit (or lines)	4,050	489	489	5,000
Area (m^2)	61,575	61,575	61,575	5,000
Total area (ha)				41

Sources: Way Besai Power Plant, 2020

Fig. 3. Combination land conservation (mechanical-soil bioengineering):
a – Ditch; b - grass strip; c - terace strip; d - Pennisetum purpureum cv. Mott Grass strip

Based on *I. Andriyani et al.* [23], robusta coffee can lower the SLR(C) value due to its high density of soil cover subfactor value and can make the soil structure stronger due to the presence of roots. The higher, the greater the plantation's ability to reduce the destructive force of precipitation in the soil. Sengon's canopy effectively reduces knockdown force with the increasing addition of Robusta coffee cover crops. Another factor is the planting pattern. This allows you to increase the density of the trunk and reduce surface runoff. Increased land use change in the Sengong land cover in the Tangul watersheds increased erosion yields, with moderate to very high erosion yields (258.15 tonnes/ha/year) in more than 75% of plantations. In this sense, soil protection should be applied to Sengong plantations. However, for sustainable soil conservation practices, soil conservation methods must have not only soil conservation benefits but also economic benefits for farmers.

Sedimentation Rate Analysis

Stream sediment analysis aims to determine the rate of sedimentation that occurs in the Way Cengkaan River. Sediment analysis is based on water samples from the Way Cengkaan River taken by field observers. The sediment analysis was carried out at the Soil and Water Engineering Laboratory of the Lampung State Polytechnic. The stages of sediment analysis start with weighing the water sample, baking, weighing the sediment content, and calculating the sediment rate.

Sediment recovery is typically determined by sampling sediment and comparing measurements with runoff from rivers or by conducting sediment deposition studies on reservoirs. Sediment release rates are influenced by eroded soil texture, land use conditions, climate, the local river environment, and general geographic location. In general, the sediment runoff velocity decreases as the catchment area increases. Erosion and sediment data should be collected or otherwise obtained before sediment release rates or more detailed sediment models are developed. For highland catchments, these data are often not available. Many studies describe the effects of different land-use activities on sediment production without specifying the sediment source. Spatial and temporal variability of land-use change in watersheds, which can lead to large variations in catchment sediment yields [1]. The determination of the relationship between flow rate and sedimentation rate is based on the least squares approach. The accuracy of the equation that arises from the correlation or relationship between flowrates is indicated by the value of the coefficient of determination (R^2). The equation with the better correlation is shown by the value of R^2 approaching 1. Figure 4 informed the sedimentation rate at upstream dan downstream of Cengkaan River's (January-July 2020).

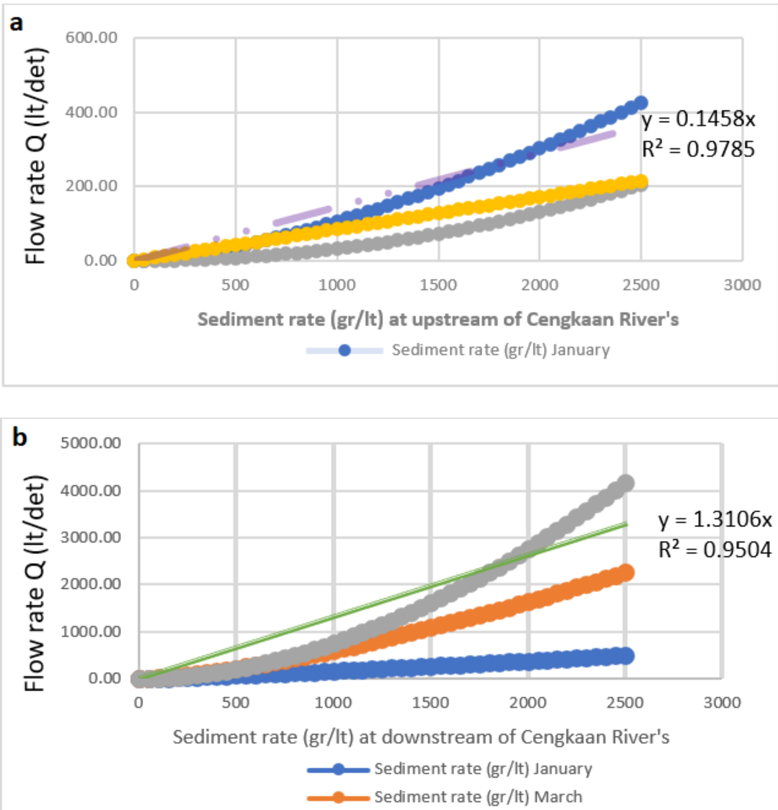


Fig. 4. Sedimentation rate at upstream (a) and downstream (b) of Cengkaan River's

During the observation period from January to July 2020, the sedimentation rate increased based on the tendency of the sediment rate graph, where the sediment rate graph at the upstream observation point was more sloping than the downstream observation point. Responses to the implementation of conservation activities at the study site can be identified by comparing the sediment rates between observation points in the upstream and downstream of the Way Cengkaan River. The results of the comparison of the sediment rate estimation model for January in the Way Cengkaan River are as follows.

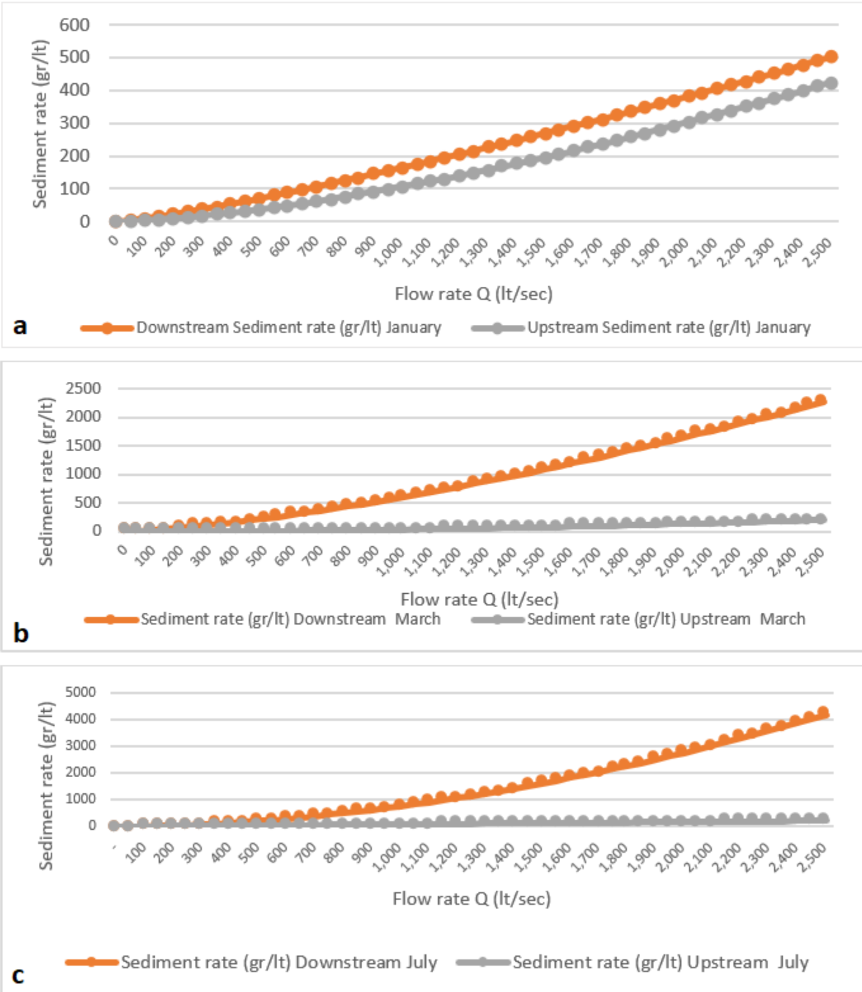


Fig. 5. Sedimentation rate at upstream dan downstream of Cengkaan River's (January-July 2020): a – in January, b – in March and c – in July

The sediment rate from January to July 2020 in the Way Cengkaan river (Fig. 5) at the downstream observation point was still higher when compared to the upstream observation point. The sediment rate in March on the Way Cengkaan river at the downstream observation point was still higher when compared to the upstream observation point. The sediment rate in July for the Way Cengkaan river at the downstream observation point was still higher when compared to the upstream observation point. This condition is probably caused by conservation activities in the study area that have not been completed or have been implemented but have not had an impact on decreasing the sediment rate in the Way Cengkan river. Land conservation involves all activities that compact or alter the soil surface, soil porosity or vegetation cover that can reduce soil infiltration capacity [1].

Meanwhile, during the observation in August – December 2020 (Fig. 4), the sedimentation rate was relatively stable, where the graph of the sediment rate at the upstream observation point coincided with the downstream observation point.

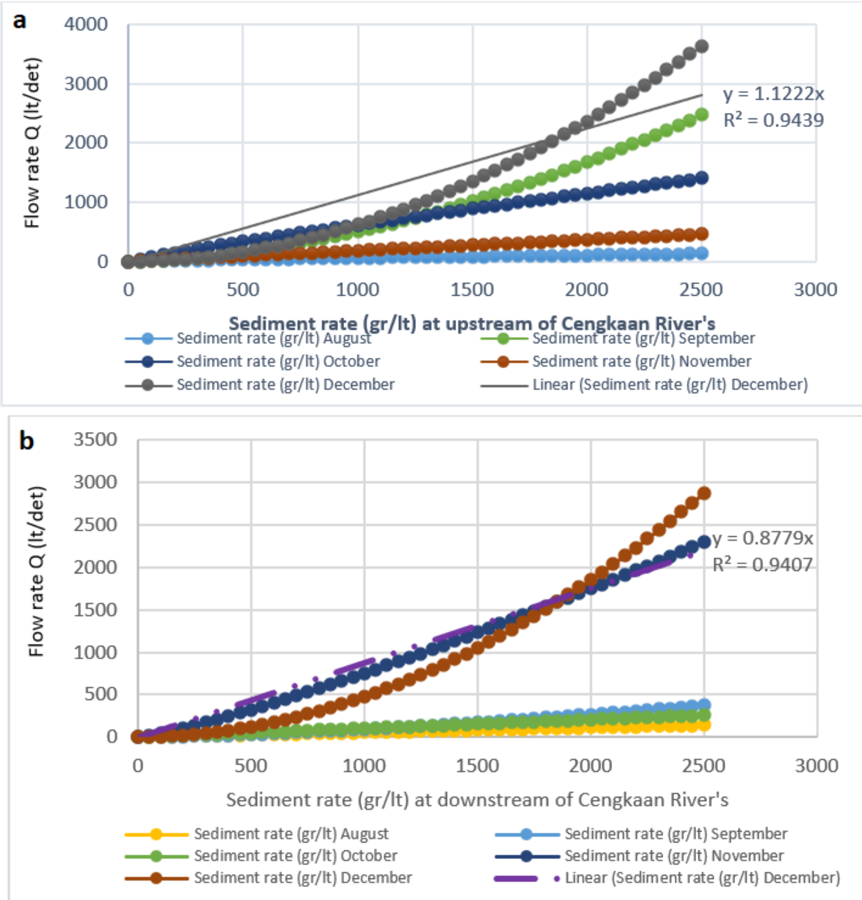


Fig. 6. Sedimentation rate at upstream (a) and downstream (b) of Cengkaan River's (August-December 2020)

Observations from September to October 2020 showed that the sedimentation rate was decreasing based on the tendency of the sediment rate graph, where the sediment rate chart at the downstream observation points was more sloping compared to the upstream observation points. Meanwhile, during the November 2020 observation, the sedimentation rate increased based on the tendency of the sediment rate graph, where the sediment rate graph at the upstream observation point was more sloping than the downstream observation point. However, in the results of observations in August - December 2020 (Fig. 7), the sediment rate relatively decreased based on the trend of the sediment rate graph, where the sediment rate graph at the downstream observation point was more sloping than the upstream observation point.

The tendency of the sediment rate in September for the Way Cengkaan river at the downstream observation point is more sloping compared to the upstream observation point. This is probably due to the fact that conservation activities in the study area have had an impact on decreasing the rate of sediment in the Way Cengkaan river. The tendency of the sediment rate in October for the Way Cengkaan river at the downstream observation point is more sloping compared to the upstream observation point. This is probably due to the fact that conservation activities in the study area have had an impact on decreasing the rate of sediment in the Way Cengkaan river.

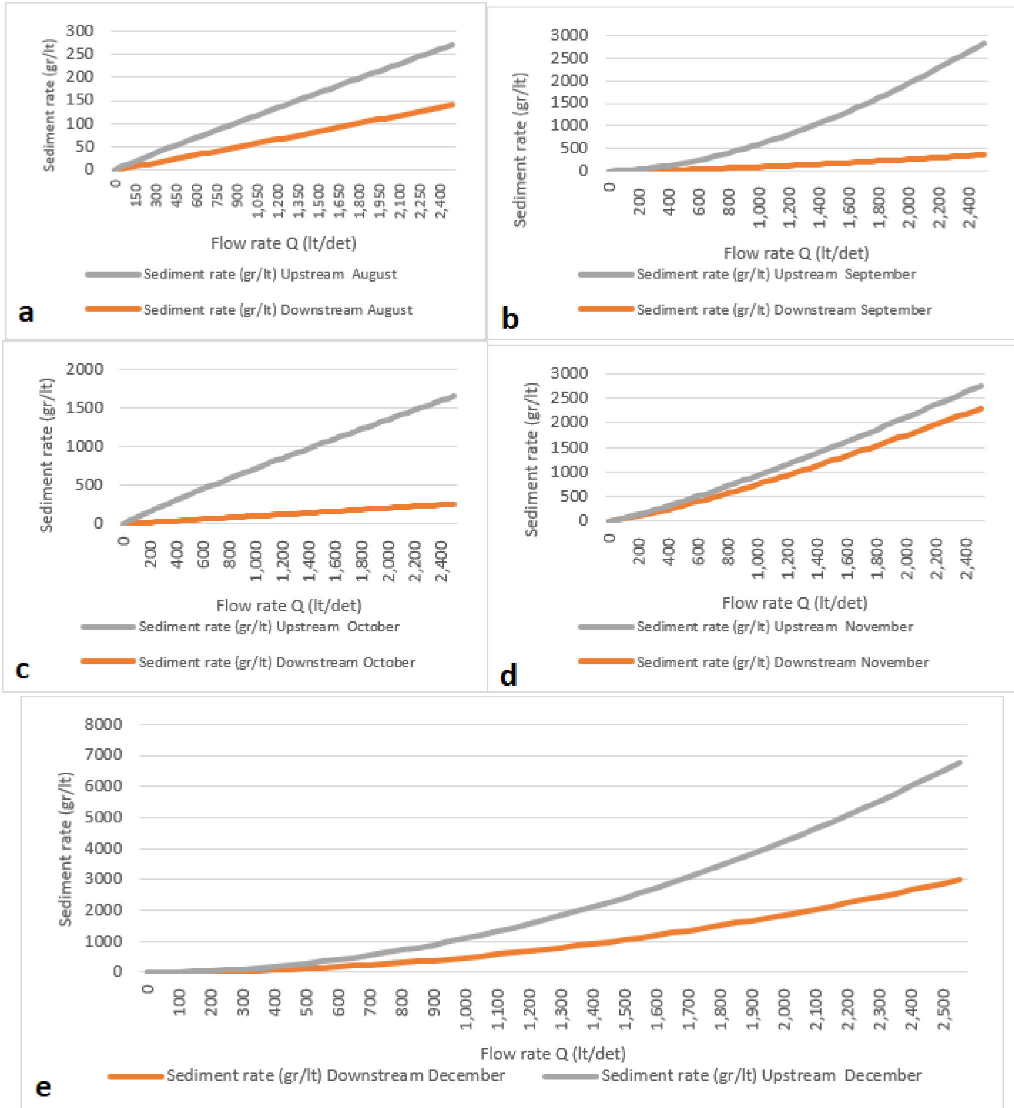


Fig. 7. Comparison of sediment rates in August-December Cengkaan River's: a – August, b – September, c – October, d – November, e – December 2022

Meanwhile, the results of the comparison of sediment rates in November for the Way Cengkaan River at the upstream observation point were more sloping compared to the downstream observation points. This indicates that sediment decrease occurred into the Way Cengkaan river body between the two observation points. This is probably caused by extreme rainfall conditions so that conservation measures are not able to withstand run-off which carries sediment.

The tendency of the sediment rate in September for the Way Cengkaan river at the downstream observation point is more sloping compared to the upstream observation point. This is probably due to the fact that conservation activities in the study area have had an impact on decreasing the rate of sediment in the Way Cengkaan river. The tendency of the sediment rate in October for the Way Cengkaan river at the downstream observation point is more sloping compared to the upstream observation point. This is probably due to the fact that conservation activities in the study area have had an impact on decreasing the rate of sediment in the Way Cengkaan river.

Meanwhile, the results of the comparison of sediment rates in November for the Way Cengkaan River at the upstream observation point were more sloping compared to the downstream observation points. This indicates that sedimentation decreased in the Way Cengkaan river body between the two observation points. This is probably caused by extreme rainfall conditions, so conservation measures are not able to withstand run-off, which carries sediment.

Direct exposure of the soil to raindrops also reduces the openness and infiltration capacity of the surface soil. Momentum gains due to surface runoff on slopes and the consequent amount of soil that can be lost from the area depend on both the slope angle and the length of the undeveloped slope. As slope length increases, soil loss per unit length initially accelerates but then approaches a constant rate. Soil loss increases with an increasing slope gradient. Disturbance from vegetation management practices generally increased suspended sediment transport over that of control watersheds.

Sediment supply and stream flow depend on the climate, topography, geology, soils, vegetation, and land-use practices of the basin. Degradation and accumulation processes are important when considering current dynamics. This is because it is the primary mechanism for sediment storage and release in rivers. The channels upstream and downstream of the aggregation front behave like two different stretches with different flows until aggregation stops and dynamic equilibrium is restored. Such relationships should only be used to provide approximations, as erosion and sediment concentrations can vary widely across watersheds [1].

Meanwhile, the tendency of the sediment rate in December of the Way Cengkaan river at the downstream observation point was more sloping compared to the upstream observation point. This indicates that sediment addition occurred to the Way Cengkaan river body between the two observation points. This is probably due to the fact that conservation activities in the study area have had an impact on decreasing the rate of sediment in the Way Cengkaan river. Build a sediment retention system at the inlet of the reservoir to minimize problems at the water treatment station [24].

Conclusion

Based on the observation period from January to July 2020, the sedimentation rate increased based on the trend of the sediment rate chart. The sediment rate graph at the upstream observation point is more sloping than at the downstream observation point. During the observation in August 2020, the sedimentation rate was relatively stable, the graph of the sediment rate at the upstream observation point coincided with the downstream observation point. During the observation period from September to October 2020, the sedimentation rate decreased, with the sediment rate at the downstream observation point being gentler than the upstream observation point. In November 2020, the sedimentation rate increased, with the graph of the sediment rate at the upstream observation point being gentler than at the downstream observation point. In December 2020, the sediment rate relatively decreased and the graph of the sediment rate at the downstream observation point was more sloping compared to the upstream observation point. Thus, during the one-year observation period from January to December 2020, the evaluation results showed that there was a tendency to decrease the rate of sediment flowing in the Way Cengkaan River. Based on these conditions, the implementation of a land conservation program carried out in collaboration between farmer groups and beneficiary stakeholders has a positive impact and effectively contributes to improving the quality of the watershed by reducing the sedimentation rate.

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