Effectiveness of soil and water conservation structures in increasing community perception and controlling erosion and sedimentation

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Abstract. The increasing frequency of floods and landslides has prompted the Ministry of Environment and Forestry to intensify the construction of soil and water conservation (SWC) structures in various watersheds in Indonesia. However, the evidence on how the high-cost measure can effectively increase community perception and participation while controlling erosion and sedimentation is still limited. For this reason, this preliminary research was conducted in 2019 to observe community perception and assess the effectiveness of the SWC structures in controlling gully erosion and sedimentation. The activities carried out in the Jeneberang and Lisu Sub Watersheds consisted of two parts: 1) social and economic data collection and 2) observing the effectiveness of the SWC structures in controlling sedimentation. Based on the socio-economic survey, respondents in the Jeneberang showed a better understanding and higher incomes than respondents in the Lisu Sub Watershed, despite their lower education levels. These phenomena relate to the length of time the community has learned from surrounding examples and the applied SWC techniques on their land. In terms of the effectiveness of SWC structures, more than half of the retaining dam and gully plug capacity had been filled with sediment in just one year after construction and is expected to be full at the end of the rainy season. The leading cause is the high erosion of the tillage area on both sides. As a suggestion, agricultural land in the catchment area needs to be managed by applying SWC techniques according to site conditions through incentives given to landowners.

1. Introduction

Floods and landslides are natural disasters with the highest frequency of occurrence and number of casualties and damage to infrastructure compared to other natural disasters in Indonesia [1]. Of the 277 disasters in early 2021, 98% were hydrometeorological disasters, especially floods and landslides [2]. Although the leading cause is the presence of extreme rain phenomena, the poor biophysical condition of the watershed has caused the impact of the disaster to be even more significant [1,3]. Excessive use of protected areas without appropriate soil and water conservation (SWC) measures also causes erosion and sedimentation, reduces infiltration rate, and increases surface runoff, which has the potential to cause flooding and landslide [4-6]. As continuous erosion occurs, soil fertility decreases, and the landscape changes, hindering land use for productive activities [1,7,8]. Besides, sediment transported in
the erosion process causes siltation in water bodies, which results in disruption of the function and threatens their carrying capacity. To overcome this problem, the Indonesian Government has made various efforts to rehabilitate the degraded environment and stop further degradation involving community participation. Trillions of rupiah have been disbursed to protect and rehabilitate a million hectares of erosion-prone areas with SWC measures as well as plant of billions of trees. However, information on how these high-cost measures can effectively increase community perception and participation while controlling erosion and sedimentation is still limited. Therefore, this paper was written based on research activities carried out in South Sulawesi in 2019. The research was conducted to obtain data and information on the effectiveness of SWC structures in controlling erosion and sedimentation and increasing community perception and participation.

2. Methods

2.1. Study Area
The study was carried out in 2019 in the upper Jeneberang watershed, which is administratively located in Gowa regency, and in Lisu watershed in the administrative area of Barru regency, South Sulawesi province.

2.2. Data Collection
In general, the activity consisted of two parts:
• RRA (Rapid Rural Appraisal) or PRA (Participatory Rural Appraisal) with interview method/Focus Group Discussion (FGD) followed by a ground check to explore community understanding about erosion, sedimentation, surface runoff, and SWC structures and their benefits. Interviews were conducted using two models: open-ended questions to determine the respondent's knowledge level and closed-ended questions to uncover respondents' perceptions of SWC structures. Open-ended questions are questions in which respondents' complete knowledge, feeling, and understanding are suggested instead of limited to a set of options [10]. Meanwhile, the close-ended question to assess respondents' perceptions consisted of five questions, with five answer choices: strongly disagree, disagree, undecided, agree, and strongly agree.
• Observing the effectiveness of SWC structures in controlling rill and gully erosion and sedimentation (gully plug and retaining dam) and sheet erosion and sedimentation (silt pit). To assess the effectiveness of gully plugs and retaining dams, the trapped sediment volume was measured by comparing the building dimensions at the time of the study with the building's initial dimensions according to the design made at the planning stage. Nevertheless, to assess the effectiveness of the silt pit, direct measurements were performed utilizing a scaled erosion stick to measure the amount of sediment trapped in the silt pit at a certain period.

2.3. Data Analysis
The respondents' socio-economic characteristics were analysed descriptively. Regarding perception, the perception data collected were analysed using a Likert scale analysis [11,12], with the following stages: 1). Summing up the scores of each respondent’s statement. The scores of respondents' answers are as follows: strongly agree = 5, agree = 4, undecided = 3, disagree = 2, and strongly disagree = 1. 2) Determining the respondent's perception area. To determine the effectiveness of gully plugs, retaining dams, and silt pits in controlling sedimentation, the data from measurements of trapped sediment were analysed by calculating the age of the building and linked to rainfall data in the period between SWC structures starting to function until the last rainfall before the study was conducted.
3. Results and discussion

3.1. Respondent Characteristics

3.1.1. Education level. In Jeneberang watershed, the education level of respondents varied from no education to bachelor’s degrees. However, the most dominant education level of respondents was elementary school graduates. Meanwhile, in Lisu watershed, all respondents had received education and varied from elementary school graduates to bachelor’s degrees, with the dominant respondents of high school education (Table 1).

Table 1. Composition of respondents by education level

| Education level   | Jeneberang watershed | Lisu watershed |
|-------------------|-----------------------|----------------|
|                   | The number of respondents | Percentage | The number of respondents | Percentage |
| Uneducated        | 4                     | 19            | 0                         | 0           |
| Elementary School| 7                     | 33            | 2                         | 17          |
| Junior High School| 5                     | 24            | 2                         | 17          |
| High School       | 3                     | 14            | 7                         | 58          |
| Bachelor’s Degree | 2                     | 10            | 1                         | 8           |
| Total             | 21                    | 100           | 12                        | 100         |

3.1.2. Age group. In terms of age, the respondents’ overall age in both research locations was adulthood, and the majority were in the age range of 40-55 years. In the study area, this age group was the group most actively working on farms. The age distribution of respondents in the research locations is presented in Table 2.

Table 2. Composition of respondents by age group

| Age group | Jeneberang watershed | Lisu watershed |
|-----------|-----------------------|----------------|
|           | The number of respondents | Percentage | The number of respondents | Percentage |
| 25-40     | 3                     | 14            | 4                         | 33.33       |
| 40-55     | 11                    | 53            | 7                         | 58.33       |
| >55       | 7                     | 33            | 1                         | 8.33        |
| Total     | 21                    | 100           | 12                        | 100         |

3.1.3. Livelihood. The main livelihoods of the respondents in the two locations, in general, were farmers, both rice fields and gardens. Rice fields were generally planted with rice and corn alternately. Meanwhile, their gardens were generally planted with cocoa, coffee, cloves, bananas, tomatoes, and chilies in between the plants for daily consumption. The composition of respondents based on livelihood is displayed in Table 3.

Table 3. Composition of respondents by livelihood

| Livelihoods    | Jeneberang watershed | Lisu watershed |
|----------------|-----------------------|----------------|
|                | Number of respondents | Percentage | Number of respondents | Percentage |
| Farmer         | 17                    | 81           | 11                        | 92          |
| Government employee | 3             | 14           | 1                         | 8           |
| Others         | 1                     | 5            | 0                         | 0           |
| Total          | 21                    | 100          | 12                        | 100         |
3.1.4. **Area of agricultural land ownership.** The majority of respondents owned land with an agricultural area of less than one hectare. The number of respondents based on the area of agricultural land ownership is shown in Table 4.

**Table 4.** Composition of respondents based on the area of farmland owned

| Agricultural land area (Ha) | Jeneberang watershed | Lisu watershed |
|-----------------------------|----------------------|----------------|
|                             | Number of respondents | Percentage | Number of respondents | Percentage |
| < 1                         | 11                    | 53          | 10                    | 84         |
| 1-2                         | 7                     | 33          | 1                     | 8          |
| >2                          | 3                     | 14          | 1                     | 8          |
| Total                       | 21                    | 100         | 12                    | 100        |

3.1.5. **Agricultural land ownership.** Most of the respondents cultivated their land. Meanwhile, a small number of respondents cultivated the rented land and other people’s land with a profit-sharing system.

**Table 5.** Composition of respondents by land ownership

| Land Status     | Jeneberang watershed | Lisu watershed |
|-----------------|----------------------|----------------|
|                 | Number of respondents | Percentage | Number of respondents | Percentage |
| Private land    | 16                    | 76          | 10                    | 84         |
| Rented          | 2                     | 10          | 1                     | 8          |
| Profit sharing  | 3                     | 14          | 1                     | 8          |
| Total           | 21                    | 100         | 12                    | 100        |

3.1.6. **Income.** In terms of household income, almost half of the respondents in the Jeneberang watershed earned more than IDR 10 million per year. Twenty-eight percent were between IDR 5 million to IDR 10 million, and the rest was under IDR 5 million. Meanwhile, in contrast to the Jeneberang watershed respondents, in terms of household income, half of the respondents in the Lisu Watershed had an income below IDR 5 million per year. The other 25 percent earned between IDR 5 million and IDR 10 million, and the remaining 25 percent earned above IDR 10 million. The composition of respondents based on income is exhibited in Table 6.

**Table 6.** Composition of respondents by farm income

| Gross Income       | Jeneberang watershed | Lisu watershed |
|--------------------|----------------------|----------------|
|                   | Number of respondents | Percentage | Number of respondents | Percentage |
| < IDR 5,000,000    | 5                    | 24          | 6                     | 50         |
| IDR 5,000,000-IDR  | 6                    | 28          | 3                     | 25         |
| 10,000,000         |                      |             |                       |            |
| > IDR 10,000,000   | 10                   | 48          | 3                     | 25         |
| Total              | 21                   | 100         | 12                    | 100        |

3.2. **Level of knowledge and perception of respondents regarding SWC**

3.2.1. **The level of knowledge about SWC.** Of the 21 respondents interviewed in the Jeneberang watershed, only two were unfamiliar with SWC techniques. However, all respondents generally understood the need for good land management to prevent further land damage due to prolonged erosion and sedimentation and knew how to prevent it. Respondents generally lived around the Jeneberang river, which since the construction of the Bili-Bili Dam has become the location of activities for the Bili-Bili Dam management and the Public Works and Forestry Agencies in constructing various types of
buildings to control landslides, erosion, and sedimentation to protect the Bili-Bili Dam from accelerated silting processes. Thus, the terms related to the SWC technique had already been widely known by the public. At the study site, BPDASHL (Watershed Management Center and Protected Forest) Jeneberang built the retaining dam and gully plugin in 2017 and 2018. The type of SWC structures, benefits, constraints, and reasons for application based on respondents' knowledge of the Jeneberang watershed are described in Table 7.

Table 7. Benefits, constraints, and application reasons of each structure based on respondents' knowledge of the Jeneberang watershed

| SWC structures | Benefits/usage                                      | Constraints                                                                 | Reason for application |
|----------------|----------------------------------------------------|------------------------------------------------------------------------------|------------------------|
| 1 Gabion       | Preventing erosion, soil damage, and collecting sediment | Requires a large amount of time, money, and energy                           | Landslide prone areas  |
| (bronjong)     |                                                    |                                                                               | Land productivity maintenance |
| 2 Bench Terrace| Reducing slope and potential for landslides and maintaining fertility | Requires a large amount of money, time, and energy as well as equipment     | Landslide prone areas  |
| (teras bangku) |                                                    | Cannot be applied in vegetable fields that require good drainage            | Land productivity maintenance |
| 3 Bunds        | Maintaining water availability and fertility      | Land condition and energy                                                   | Landslide prone areas  |
| (pematang/guludan) |                                                | Requires energy and time                                                    | Land productivity maintenance |
| 4 Check Dam    | Preventing soil erosion and water reserves in the dry season | Requires a large amount of money, time, and energy as well as equipment     | Landslide prone areas  |

Similar to the results in the Jeneberang watershed (Table 7), of the 12 respondents interviewed in the Lisu watershed, in general, all respondents understood the need for good land management to prevent land damage and knew how to do it (Table 8). However, their understanding was not as good as that of respondents in the Jeneberang watershed. It is understandable because in the Jeneberang watershed, with the existence of the Bili-Bili Dam, the Ministry of Public Works and the Ministry of Environment and Forestry have carried out various SWC efforts and built various structures in various places upstream of the Jeneberang watershed since the construction of the dam began in early 1993. The type of SWC structures, benefits, constraints, and reasons for application based on respondents' knowledge in Lisu watershed are explained in Table 8.
Table 8. Benefits, constraints, and application reasons of each structure based on respondents' knowledge in the Lisu watershed

| No | SWC structures          | Benefits/usage                        | Constraints                                                                 | Reason for application               |
|----|-------------------------|---------------------------------------|-----------------------------------------------------------------------------|--------------------------------------|
| 1  | Bench Terrace           | Creating new crop fields              | Requires a large amount of money, time, and energy as well as equipment     | Panting on sloping land              |
|    | (teras bangku)          |                                        | Cannot be applied to vegetable fields that require good drainage            |                                      |
| 2  | Bunds                   | Controlling landslides                | Land condition, Requires energy and time                                    | Landslide prone areas                |
|    | (pematang/guludan)      |                                        |                                                                             |                                      |
| 3  | CheckDam                | Water reserve                         | Requires a large amount of money, time, and energy as well as equipment     | Water reserves in the dry season     |
| 4  | Gully Plug              | Controlling landslides, erosion, and sedimentation | Costs                                                          | Landslide prone areas                |

From the two tables above, it can be seen that the understanding of respondents in the Jeneberang watershed about soil and SWC structures was more comprehensive and better than the respondents in the Lisu watershed. In fact, when viewed from the level of education, respondents in the Jeneberang watershed had lower education than respondents in the Lisu watershed. Thus, in the case of these two locations, the high level of education was not directly related to the respondents' high understanding of the SWC techniques. Other findings from in-depth discussions and field visits revealed that the respondents' high income in Jeneberang watershed was from agriculture which is also higher than the incomes of those in Lisu watershed. It was closely associated with a high understanding of SWC techniques and their application in their agricultural land. These findings align with a previous study’s finding by Bravo-Ureta, Solis, Cocchi, and Quiroga [13] that implementing SWC structures and adopting forestry systems lead topositive and statistically significant effect on the farm income. The high level of farming knowledge and income of respondents in the Jeneberang watershed could be understood because they had known and applied SWC techniques on their land for a relatively long time compared to respondents in the Lisu watershed, especially since the Bil-Bili dam construction project began in the early 1990s.

However, although the SWC implementation in sustainable land management has generally received support, the socio-economic conditions of the community often make SWC implementation difficult [14]. Farmers often refuse to apply soil and water conservation practices even though they understand their function and realize that it can protect their land and increase agricultural productivity [7]. Sustainable land management practices must be economically profitable and financially feasible for farmers [14]. To overcome this, the government and financial institutions need to help in the form of financial incentives or soft loans in the SWC implementation. It will benefit not only the farmers but also the watershed and society as a whole. In reality, the cost of preventing land damage is much lower than the cost of land restoration and rehabilitation [14]. The outreach also needs to be improved to provide continuous training and advice to farmers in implementing SWC, especially to those far from the location of the government’s pilot projects [15].
3.2.2. Respondent perception. The most critical determinants of conservation outreach efforts are perceptions of soil erosion as a threat to soil productivity and sustainable agriculture. When farmers do not perceive soil erosion as a problem, they will not expect erosion control benefits and adopt any offered soil and water conservation technologies [7]. Ervin and Ervin [16] pointed out that in addition to the issue of financial capacity to overcome cost constraints, the perception that soil erosion is a problem is a factor that plays a vital role in the decision-making process for implementing conservation actions. The distribution of perceptions of each respondent can be seen in Table 9.

Table 9. The distribution of respondent’s perception

| Perception category        | Score category | Frequency | Percentage (%) |
|----------------------------|----------------|-----------|----------------|
| Very positive perception   | 20-25          | 15        | 36.58          |
| Positive perception        | 15-20          | 25        | 60.98          |
| Negative perception        | 10-15          | 1         | 2.44           |
| Very negative perception   | 5-10           | -         | 0              |
| Total                      |                | 41        | 100            |

Based on the table above, it can be seen that each respondent's perception of SWC was spread over a very positive perception of 36.58%, a positive perception of 60.98%, and a negative perception of 2.44%.

3.3. Effectiveness of SWC structures in controlling erosion and sedimentation

3.3.1. Gully erosion control structures. Soil and water conservation structures are all mechanical or structural measures designed to control the speed of surface runoff so that it can hold water in the desired place while minimizing soil erosion [17].

Among all forms of erosion, gully erosion is the most destructive form of water erosion, which cannot be controlled without a permanent civil engineering structure [18]. Research on the impact of SWC structures on erosion and sedimentation has been focused on evaluating the effectiveness of gully plug and retaining dams in controlling gully erosion. To assess the effectiveness of gully plugs and retaining dams in controlling sedimentation and channel erosion, observations were made by measuring the sediment in the building and predicting the sediment accumulation process that occurred by connecting the sediment volume at a certain period (started functioning until the last rain before the measurement) and rainfall that occurred in the same period. The effectiveness of gully plugs and retaining dams in controlling sedimentation is presented in Table 10. Two research locations were in Pange Hamlet (built in 2016) and Padang Lampe Hamlet (built in 2017); both are in Lisu watershed.

Table 10. Structures’ capacity and volume of sediment

| SWC structures | Year of construction | Capacity (m³) | Sediment volume (m³) | Capacity remaining (m³) | Capacity remaining (%) |
|----------------|----------------------|---------------|----------------------|------------------------|------------------------|
| PADANG LAMPE   |                      |               |                      |                        |                        |
| RD 1           | 2017                 | 79.55         | 68.98                | 10.57                  | 13                     |
| RD 2           | 2017                 | 15.66         | 8.91                 | 6.75                   | 43                     |
| GP1            | 2017                 | 5.95          | 5.85                 | 0.1                    | 2                      |
| GP2            | 2017                 | 7.41          | 5.41                 | 2                       | 27                     |
| GP3            | 2017                 | 2.79          | 0.93                 | 1.86                   | 67                     |
| GP4            | 2017                 | 17.61         | 11.49                | 6.12                   | 37                     |
| PANGE          |                      |               |                      |                        |                        |
At the Padang Lampe Hamlet location, more than half of the capacity of the retaining dam and gully plug had been filled with sediment originating from the land on either side of the river channel in the catchment area of each structure. Based on the sedimentation that occurred previously, it was estimated that the retaining dam and gully plug would be full in the next five months (at the end of the 2019-2020 rainy season). Several gully plugs in the Padang Lampe and Pange Hamlets were filled with sediment only one year after being built. Generally, based on visual observation, this condition was caused by high sediment from erosion in the catchment area. Once full, these two buildings lost their function of controlling sediment and only functioned to slow the flow of water through the river channel due to changes in the river gradient. The reduced speed of water flow in the channel would ultimately reduce the potential for gully erosion.

3.3.2. Sheet erosion control structure. For SWC structures at the tillage level, the research was carried out using a rainfall simulator to examine the impact of silt pit in controlling sheet erosion, sedimentation, and nutrient loss. A silt pit is made to catch water and eroded soil to allow water to enter the soil and reduce erosion [19]. Using a silt pit, runoff velocity is slowed down, and the transported sediment containing nutrients can be retained. When the silt pit is full of sediment, the nutrient-containing sediment can then be taken and returned to the tillage field. Silt pit reduces overland flow and soil erosion effectively [20-22].

A rainfall simulator was made to simulate rainfall using a nozzle that could be adjusted to get a burst of water conditions resembling actual rainfall. The simulated rainfall was 150 mm for two hours. The potential of trapped sediment per hectare was calculated using 150 mm of rainfall and 3000 mm of average annual rainfall in the Gowa regency.

Table 1. The potential of sediment trapped in the silt pits

| PLOT | Slope class (%) | Sediment volume (m³) | Sediment potential /hectare | The total of potential sediment/ha/year |
|------|----------------|----------------------|-----------------------------|----------------------------------------|
| 1    | 8-15           | 0.0054               | 6.7                         | 100                                    |
| 2    | 15-25          | 0.0079               | 10                          | 150                                    |
| 3    | 25-45          | 0.0173               | 21                          | 315                                    |

From the data above, it appears that the total sedimentation that silt pits could control was 100, 150, and 315 tons per ha per year, respectively. In terms of erosion in the tillage field, although it was still above the allowed erosion rate, the silt pit quite effectively controlled the erosion rate. In the absence of conservation techniques, the erosion in horticultural cultivation on sloping land and the loss of nutrients were much greater. Previous studies have shown that erosion in the field with silt pit only ranged from 25 to 49% of the amount of erosion in the same field without any conservation treatment [23].

4. Conclusion

From the two study locations, it can be concluded that the high level of education was not directly related to the respondents’ high understanding of SWC structures. Meanwhile, respondents in the Jeneberang watershed with a large income from farming showed a better understanding of SWC techniques than respondents in the Lisu watershed, who, despite higher education, had lower income from farming. The
high level of understanding and high income from respondents' farming businesses in the Jeneberang watershed was closely related to the length of time the people knew and applied the SWC structures on their cultivated land. At the study site in the Lisu watershed, the research showed that the existing soil conservation structures effectively controlled sedimentation. However, due to the high erosion and sedimentation of the overlying area, more than half the capacity of the retaining dam and the existing gully plug was entirely filled with sediment only one year after construction and in the Pange Hamlet location. The researchers recommend that to slow down the reduced function of controlling dams, retaining dams, and gully plugs, it is necessary to carry out SWC massively on surrounding cultivated lands according to the field conditions with an incentive scheme for the land owners.

For the Jeneberang watershed, a silt pit is suitable to be applied, especially in horticultural areas. On horticultural lands, to maintain production levels, soil conservation techniques that need to be used are techniques that still accommodate the planting model commonly used by farmers (perpendicular to the contour) but can reduce the potential for erosion and its subsequent impact, namely loss of fertility and sedimentation.

Acknowledgment
This research is a collaborative research activity between the Makassar Environmental and Forestry Research and Development Center (BP2LHK Makassar) and the Jeneberang watershed and Protection Forest Management Center (BPDASHL Jeneberang) for the 2019 fiscal year.

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