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Original Research

Assessment of Land and Water Conservation Practices Against Runoff and Erosion

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Abstract

The Land converted in the form of road construction crossing protected forest areas has resulted in the loss of vegetation diversity and while surface flow and erosion are accelerated. This research aimed at determining the effectiveness of land and water conservation practices in controlling runoff and erosion. The research method adopted in this investigation uses a multislot divider measuring 10 m x 5 m with a slope of 25% on geogrid, geonet, and vegetation cover plots, where each plot comprises 3 pieces, accumulating to 9 units. The result showed the highest total runoff between June and November in the geogrid plot (531.61 m^3/ha). This was followed by the geonet (492.5 m^3/ha), while the lowest value was recorded in the vegetation cover plot (174.7 m^3/ha), with 1336 mm of rainfall. These outcomes collectively had a directly proportional relationship with the total land erosion, and similar rainfall at 94.17 tons/ha, 73.9 tons/ha, and 42.4 tons/ha for geogrid, geonet, and vegetation cover plots, respectively. The results demonstrated the effect of rainfall and slope on runoff as well as erosion and also provide valuable information on the negative impact of land conversion from vegetation cover to other uses.

Keywords: land and water conservation, runoff, erosion, watershed

Introduction

The existence of forest areas is currently being threatened by various development interests. These include road construction designed to cross a protected area and is capable of affecting the local ecosystem, through the destruction of biodiversity habitats and high rates of land erosion [1, 2]. There is also a higher incidence of land compaction, which affects water management conditions, reduces organic matter, function, and development of root crops, and consequently instigates plant death. Therefore, the particular area is unable to function as a surface flow controller and characterized by a low infiltration rate [3-6].

The construction of the coffee plantation axis road is one of the national strategic infrastructure projects in Central Sulawesi, Indonesia. In addition, a budget amounting to billions of rupiah is sourced annually from state budget funds and considered the most enduring project all year. The coffee plantation axis has been strategically positioned to support economic, social, and defence development. This 48 km long road

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is the main connection between the Trans Sulawesi East Coast and the West Coast of Sulawesi Island. Particularly, Trans Sulawesi on the East Coast links the provinces of Southeast, South, Central, as well as North Sulawesi, and Gorontalo, while South, West, Central as well as North Sulawesi, and Gorontalo are connected on the West Coast.

The main challenge with road construction is the floods caused by high rainfall during the rainy season, which inundates the road. These conditions are accompanied by erosion as well as landslides and are known to claim the lives of road users, due to the relatively high steep slope formed. Furthermore, there were changes in land cover from vegetated to non-vegetated. This is implicated in the increased volume of runoff and erosion [7-9], which are further influenced by the slope length and rainfall intensity [10, 11]. Consequently, the erosion is estimated to cause a release of land particles [12].

Currently, most research tends to focus on the relationship between the runoff processes and the type or quantity of vegetation [13, 14]. The plot scales were used to evaluate the impact of land cover and the correlation with topographic factors on erosion processes [15-18], and also the effect of spatial distribution on erosion [19, 20]. Furthermore, research on the impact of land and water conservation, specifically on the reconstruction and management of slope drainage required using geogrids to withstand rock loads. The geonet models as a plant growth media for erosion control and plays an important role in road construction planning and sustainable land management.

Some research was conducted relating to the impact of changes in land use and land cover types, including the response of hydrology and erosion [21, 22]. Others evaluated the influence of land-use change and climate variability on hydrology [23], as well as the effect of forest clearing/exploitation on erosion [24].

The ability to obtain an accurate estimation of runoff and land loss is key to successful erosion mitigation measures. This commonly involves using the single slot method to assess depreciation in a small fraction of discharged runoff, while a Multi-Slot Divisors (MSD) approach is reportedly more accurate for total measurements [25]. However, MSD estimates have not been sufficiently documented and disseminated, particularly in the Central Sulawesi region.

The reconstruction of slope drainage management using geogrids and geonets is one of the innovations in land and water conservation to secure coffee plantation roads. These materials, particularly in the form of a dark brown plastic net, serve to hold large rocks from being separated from the land layer. Furthermore, a bottom layer is added and is characterized by a bluish-green plastic net, termed "erosion mat", which functions as an erosion rate suppressor as well as a medium for plant growth.

Despite the safety engineering innovations carried out to date on several roads, the high tendency for erosion and potential casualties to road users simultaneously exists. Therefore, implementing an effective and efficient reconstruction plan requires research aimed at assessing the effectiveness of land and water conservation practices. These include the use of geogrid and geonet models in controlling runoff and erosion as a policy directed at managing steep slopes in a sustainable and environmentally friendly way.

Materials and Methods

Study Area

This research was conducted in the Toboli watershed by placing measuring plots along the road constructed with land and water conservation structures. These include geogrid and geonet models, characterized by a slope of 25%. Fig. 1 shows the experiment was conducted in the North Parigi District, Parigi Moutong Regency, administratively, which geographically located between 119°49'31.95" to 120°03'18.11" East Longitude and 01°11'20.23" to 01°35'25.83" Southern latitude. In addition, a priority scale was used to assess the location management and based on the results of a watershed boundary research by the Palu Poso Watershed and Protection Forest Management Center. The identification of eroded land samples was performed at the Soil Science Laboratory, Faculty of Agriculture and Forestry Laboratory, Tadulako University.

This research was carried out in several stages, including first, a field survey to determine the research location in March 2021. Second, research plots were made in April-May 2021, and third, data on rainfall, runoff, and erosion was collected from June-November 2021.

Research Procedure

Rainfall Measurement

The rainfall measurements were performed by installing an observatory-type rain gauge (ombrometer) in an open place. This was situated at a height of 1 m from the ground, and the rainwater volume was measured in units (mm).

Surface Flow and Erosion

The runoff and erosion were evaluated on a pilot scale, using the multi-slot divider method [26-28] measuring 10 m x 5 m at a slope of 25%. Fig. 2 shows the observations on vegetation cover, geogrid and geonet plots.

Zinc-aluminium plates were used as a barrier on the runoff and erosion plots. This approach was to prevent water from entering the measuring area, planted at about 10 cm long and 20 cm high. Fig. 2 shows 2 reservoirs in the form of plastic buckets placed at the base of

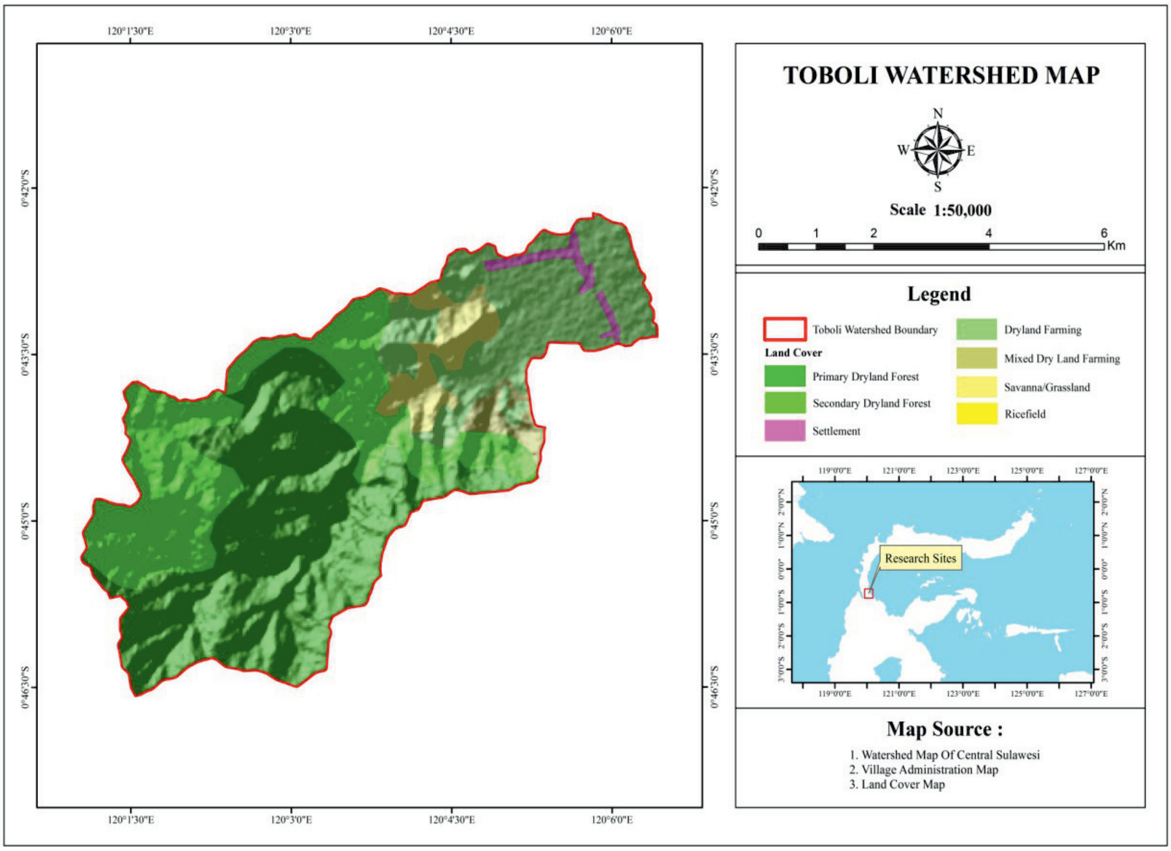

Fig. 1. Map of research location.

slopes of similar height. The outside was characterized by 7 drainage holes, and the one in the middle was connected to a plastic pipe which is directly connected to a water reservoir with a diameter of 35 cm and a height of 45 cm. In addition, the opening is avoided while the water drains, and the respective bucket is equipped with a cover and planted into the ground. This allows the surface to be in a slightly lower position than the terrain. Moreover, 3 plots of runoff and erosion measurements were made for the respective measuring plot, including geonet, geogrid, and vegetation cover, summing up to a total of 9 units.

Fig. 2. Location of plot placement; a) geonet, b) geogrid, c) vegetation cover, d) bucket observations surface flow and erosion; (1) bucket 1, (2) bucket 2

Data Analyst

Rainfall is calculated based on the equation [29].

$$CH = \frac{V}{A} \quad (1)$$

Description:
CH : Rainfall (mm)
V : Volume of water in ombrometer (cm^3)
A : The cross-sectional area of the mouth of the ombrometer funnel (cm^2)

Surface flow is calculated based on equation [30]:

$$Vlpi = \frac{Va+n(Vb)}{A} \quad (2)$$

$$Va = P \times l \times t \quad (3)$$

$$Va = 1/4\pi r^2 t \quad (4)$$

Description:
Vlpi : Surface runoff volume (m^3/ha)
Va : Bucket volume 1 (m^3)
Vb : Bucket volume 2 (m^3)
A : Area of observation plot/plot (ha)
n : Total of drain holes from bucket 2

Land erosion is calculated based on equation [30]:

$$Ei = \frac{(Va*Ca)+n(Vb*cb)}{1{,}000{,}000\ A} \quad (5)$$

$$ca \text{ or } cb = \frac{g\ (gram)}{v\ (liter)} \quad (6)$$

Description:
Ei : eroded land (tonnes/ha)
Va : Bucket volume 1 (liter)
Vb : Bucket volume 2 (liter)
A : Area of observation plot/plot (ha)
n : Total drain hole from bucket 2
ca : bucket sediment concentration 1 (gram/liter)
cb : sediment concentration bucket 2 (gram/liter)

Results and Discussion

Rainfall

Rainfall with specific characteristics, including high intensity, duration, and volume is among the determinants of high runoff and erosion [31]. The vulnerability of land to these conditions depends on the overall intensity. The results of classification and rainfall data processing at the Toboli watershed show the highest monthly precipitation occurs in November at 485 mm. Meanwhile, the lowest values were recorded in August, at 98 mm for 6 months, which span from June to November 2021. Table 1 highlighted the BMKG [32] classification of rainfall during the research period and was included in the low to high category.

Surface Flow

The incidence of high rainfall intensity over a relatively long period directly influences surface runoff [33, 34]. The outcome is imminent following a downpour volume which exceeds the land infiltration rate. Table 2 shows data indicating runoff variations in the land and water conservation model.

Table 1. Rainfall Classification.

Month	Rainfall (mm)	Criteria
June	137	Currently
July	118	Currently
August	98	Low
September	145	Currently
October	353	High
November	485	High

Based on the analysis of variance from the three surface flows in geonet, geogrid and vegetation cover (Table 2), Sig. = 0.160 is greater than the value of = 5%, it can be concluded that the three data have homogeneous variance.

Table 2 shows the existence of a direct correlation between rainfall and runoff rate. This is evidenced by the differences in rainfall between June and November. In addition, 485 mm of rainfall was observed in November, which resulted in bigger runoffs, with 111.65 m^3/ha, 100.74 m^3/ha, and 38.74 m^3/ha recorded in geogrid, geonet, and vegetation cover, respectively. The geogrid plot demonstrated the highest total runoff during the period from June to November, following a comparison with other types of land and water conservation practices. The value recorded was 531.61 m^3/ha, with a total rainfall of 1,336 mm, while the lowest was observed in the plot of vegetation cover, at 174.7. m^3/ha. Table 2 also showed this occurrence across all research intervals (June to November 2021). These results indicate that vegetation cover plots as more effective in the control of surface runoffs, which is in line with the opinion [35] of vertical vegetation structure, level of diversity, surface litter layer, and underground roots. In addition, changes driven by climate (rainfall) are known to instigate a 5.8%-12.9% increase in runoff compared to the total change observed during the base period [36].

Table 2 shows low runoff values in the vegetation cover plot, which was attributed to the factor of plant density. The land conditions generally demonstrated good aggregation, as the particles present tend to not decompose separate easily from bonds. This outcome is in line with the opinion of [37] where vegetation cover was widely recognized as an important factor in runoff inhibition. According to [38], the total overflow volume and erosion are reduced by the presence of litter cover from forested areas.

Rainfall is a prerequisite for surface runoffs, however, [39] recognized the impact of both intensity and quantity aspects, as well as land-use patterns. Furthermore, the vegetation's ability to withstand heavy downpours, reduce splash effects and ensure control results from the combined effects of leaves, stems, roots, and litter. These attributes are fundamental to land and water conservation functions [40-42].

Erosion

Table 3 presents the trend of erosion volume variability in rainfall intensity. Erosion was consistently higher in geogrid and geonet compared to the vegetation cover plots. This outcome was increased with higher rainfall intensity and duration. The sediment loading process was determined to show fluctuations along with runoffs, especially in the geogrid plots. Moreover,

Table 2. Surface Flow in Geonet, Geogrid, and Vegetation Cover Plots.

Month	Rainfall (mm)	Surface flow (m^3/ha)		
		Geonet	Geogrid	Vegetation cover
June	137	79.84	81.27	26.61
July	118	67.42	77.36	35.94
August	98	62.38	68.26	22.13
September	145	82.39	90.35	23.96
October	353	99.73	102.72	27.32
November	485	100.74	111.65	38.74
Total	1,336	492.5	531.61	174.7

sediment loads tend to increase significantly with overall prolonged rainfall duration, with different degrees of dependence on vegetation cover and rainfall intensity. Table 3 shows the resulting erosion to be significantly higher compared to the outcome in other plots under similar conditions.

The analysis of variance test from the three plot erosions in geonet, geogrid and vegetation cover (Table 3), the Sig. = 0.109 is greater than the value of = 5%, it can be concluded that the three data have the same variance (homogeneous).

Rainfall and runoff are indicators to measure land erosion on a slope. Furthermore, sedimentary material is carried at greater fall intensity than infiltration, which causes failure to seep into the soil. The tendency of variations in land erosion rate is largely determined by use, and vegetation cover [43-45].

The covered plot demonstrates an ability to intercept rainfall based on the presence of plant stems and leaves. These constituents reach a saturation point after the surface runoff initiation period and consequently cause direct rainfall to reach infiltration levels. Conversely, Table 3 shows this phenomenon is not the case in geonets and geogrid plots, which are known to demonstrate a directly proportional relationship between erosion and high rainfall in the research period.

Table 3 also showed the low erosion on vegetation cover was due to the plant density of undergrowth and seedlings, which is relatively high. These characteristics are assumed to be responsible for 90% of the canopy formed over the land surface and consequently affect the flow. In addition, direct exposure to the kinetic power of rainfall is limited, as well as potential damage to land particles, implying the tendency to protect the pore spaces is improved. The results show an indirect correlation between the growth and development of denser plants with the incidence of erosion [46-48]. This opinion is supported by [49-51], which identified ground cover as a key element in controlling land and water loss. Therefore, securing higher quantities, particularly comprising broadleaf trees is recommended. This approach is considered to be helpful in restoration efforts and conservation strategies.

Conclusion

Surface runoff and erosion in the geogrid and geonet plots were relatively higher compared to the results in the vegetation cover plots. The observations during the research period from June to November showed an over 100% increase in value, with a total rainfall of 1,336 mm.

Table 3. Erosion in Geonet, Geogrid, and Vegetation cover plots.

Month	Rainfall (mm)	Erosion (ton/ha)		
		Geonet	Geogrid	Vegetation cover
June	137	10.46	13.78	5.24
July	118	9.29	10.96	4.37
August	98	10.21	15.72	6.68
September	145	14.47	17.67	8.71
October	353	17.62	19.21	10.46
November	485	23.85	16.83	6.94
Total	1,336	85.9	94.17	42.4

The important protective role of vegetation cover instigates the need to conserve coffee plantations on roads in the Toboli watershed area. This is an attempt to ensure the location serves as a green line. These findings imply the ineffectiveness of the geogrid and geonet models built by the government to control erosion. Therefore, a combination of civil engineering land conservation methods and vegetative cover is needed as a form of environmentally sustainable development.

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Conflict of Interest

The authors declare that there is no conflict of interest.

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