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Predicting the impact of land-use changes on soil erosion rates in the three small sub-catchments of Larona Catchment

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Abstract. This study aims to predict the amount of soil erosion in the three sub-catchments of Larona Catchment, which are Larona, Balambano, and Karebbe sub-catchments. The USLE method is used to predict soil erosion rates in 2009 and 2015 by using rainfall data of 13 rainfall stations, soil maps, DEM data for generating LS factors, Landsat 8 Imageries, and land use maps create CP factors. Four thematic maps (R, K, LS, and CP) were overlaid and clustered using ArcGIS 10.4. The results show that soil erosion rates in the period of 6 years have changed in the three sub-catchments. The erosion rate in Larona and Karebbe sub-catchment slightly increased from 43,092 tons to 50,982 and 155,005 tons to 224,757 tons, respectively, from 2009 to 2015. In the Balambano sub-catchment, the value of erosion rate increased dramatically during the period. Total erosion this sub-catchment in 2015 became 5 to 7 times of the total erosion in 2009. The change of land use caused the increased sediment yields in the three cascade-reservoirs in Larona Catchment and land cover, mostly the result of increasing agricultural activities and not due to mining development.

1. Introduction

Land and water are the most vital natural resources and are under tremendous stress due to ever-increasing human pressure on the earth. The optimal management of these resources with minimum adverse environmental impact is essential for sustainable development and human survival. Soil degradation has already rendered arable land unsuitable for agricultural production every year. The Regency of Eastern Luwu has cascade dams facing land management problems in the three catchments of Larona, Balambano, and Karebbe Dams.

Soil erosion risk mapping and soil conservation planning are more accomplished by using erosion models. Soil erosion models are widely used to estimate the soil erosion rates by simple mathematical expressions to symbolize the relationships between different factors and processes occurring in the landscape. These factors generally include meteorological variables, soil properties, topography, land use, and land cover features [1]. The Universal Soil Loss Equation (USLE) model has been applied worldwide to predict soil loss. Although it is an empirical model, it predicts erosion rates of unguaged watersheds using knowledge of the watershed characteristics and local hydro-climatic conditions. It presents the spatial heterogeneity of soil use. It has been extensively used to estimate soil erosion loss to assess soil erosion risk and to guide development and conservation plans to control erosion under different land-cover conditions, climate, soil type, and topography [2,3,4,5]. The RUSLE model is based on the USLE erosion model, which was developed by Wischmeier and Smith (1978) and improved and modified by Renard *et al*. (1997) [6,7]. The integration of RUSLE and ArcGIS for estimating annual

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soil loss has been developed by Soo Huey Teh (2011) [8]. The RUSLE has been widely used for both agricultural and forest watersheds to predict the average annual soil loss by introducing improved means of computing the soil erosion factors.

Prediction annual soil erosion yield in the three sub-catchments in Larona during development in the Eastern Luwu is critical to figure the impact of land-use change during the last decade. The result would be helpful for soil conservation planning in the catchments to propose the best land management and sustain the dams in the future.

2. Methods

2.1. Catchment boundary

Sub-watershed boundaries were done by processing 30 m x 30 m resolution Digital Elevation Model (USGS DEM) data in ArcGIS software. The description of the Sub-watershed was carried out by the Automatic Watershed Delineation method so that the boundaries of the Sub-watershed and river network were mapped together for the three sub-catchments of Larona, Balambano, and Karebbe Dams.

2.2. Predicting soil erosion

Soil erosion was predicted using the USLE equation as a function of six factors. These factors were made in four thematic raster maps, which are rainfall erosivity (R), soil erodibility (K), slope length and steepness (LS), land cover, and management practice (CP). These factors vary over space and time and depend on other input variables. The rainfall erosivity factor indicates the erosive force of a specific rainfall. The relationship between rainfall erosivity and rainfall depth developed by Wischmeier and Smith (1978) is used to translate the rainfall depth to rainfall erosivity. It is likely to be associated with the ability of rain to erode the soil.

$$R_{annual} = \sum_{i=1}^{12} \quad 1.735 \ x \ 10^{l(1.5 log log \left(\frac{P_i^2}{P}\right) - 0.08188)} \tag{1}$$

where
R is rainfall erosivity factor in MJ mm/ha/h/year,
Pi is monthly rainfall in mm and,
P is annual rainfall in mm

The soil erodibility factor represents both susceptibility of soil to erosion and the rate of runoff. It depends on different biological and chemical soil characteristics such as its mineralogical composition, particle size, permeability, and the presence of organic matter [6].

$$100\,K = 10^{-4}\, 2.7M^{1.14}(12 - a) + 4.2(b - 2) + 3.23(c - 3) \tag{2}$$

where
K is K-factor (t m^2 h ha^{-1} h J^{-1} cm^{-1}),
M is texture from the first 15 cm of soil surface = [(100 – Ac) (L+Armf),
Ac is % of clay (<0.002 mm),
L is % of silt (0.002–0.05 mm),
Armf is % of very fine sand (0.05–0.1 mm),
a is % of organic matter content,
b is structure of soil (very fine granular: 1–2 mm; fine granular: 2–5 mm; med or coarse granular: 5–10 mm; blocky, platy and massive: >10 mm), and
c is permeability (c = 1, very rapid, c = 2, mod. to rapid, c = 3, moderate, c = 4, slow to mod., c = 5, slow, c = 6, very slow).

The topographic factor plays a decisive role in surface runoff. LS factor considers together the steepness (S), which increases the velocity of runoff, and the length (L) of a slope, which contributes to

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enlarging the ground surface area affected by runoff. This dimensionless factor was calculated using the equation slope gradient and slope length. Slope length and slope gradient, LS factor was computed by using the 30 m x 30 m resolution Digital Elevation Model (DEM) data in ArcMap based on flow accumulation and slope steepness using the relationship slope factor and gradient of slope factor [6] [9] [10].

$$LS = 1.4\left(\frac{As}{22.13}\right)^{0.4}\left(\frac{sinsin\,\beta}{0.0896}\right)^{1.3} \qquad (3)$$

where
As is specific catchment area (m^2/m) and
b is slope angle (degrees).

Cover management factor (C) represents the effect of vegetation and management on soil erosion rates—the coverage of a crop for the surface of the soil influences the soil erosion rate. The value of the cover management factor is equal to 1 when the land has continuous bare and has no coverage. The value of the cover management factor is lower when there is more coverage of a crop for the soil surface resulting in less soil erosion. The typical values are about 1 for bare soils, 1 to 0.9 for root crops and tuber crops, 0.01 on grasslands and cover plants, and 0.001 for forests [11]. The C-factor values were assigned to each corresponding land use/land cover class for the cover and management factors. Land cultivate or management practice factor (P) reflects the impact of support practices. The ratio of soil loss with a specific support practice on croplands to the corresponding loss with upslope and downslope tillage. This factor considers any method applied on a farm to reduce soil loss resulting from the water erosion process. It includes various agriculture management activities such as tillage and planting along contour lines, strip cropping, tree lines planted along with agricultural fields, and terracing [11].

Soil erosion was predicted using overlay procedures for all thematic maps, including R, K, LS, and CP maps in ArcGIS software version 10.4.

2.3. Predicting the impact of land used change

Land cover in the three Sub-watersheds was analyzed using the remote sensing method. The data used were Landsat 7 and 8 images data in the years 2009 and 2015. The images were corrected geometrically and, subsequently, radiometric correction. Analysis of land cover by using the image was carried out using the supervised classification method using the Arc GIS software in each of 2009 and 2015 for six categories of land use [1]. These maps were used for composing CP thematic maps. The changes were identified from 2009 to 2015 and analyzed altogether with erosion yield in the three sub-catchments.

3. Results and discussion

3.1. Rainfall

Rainfall is one of the variables that contribute to soil erosion yield in a catchment. Rainfall data used to determine the kinetic energy of raindrops to break soil particles. There are 12 rainfall stations in and around the catchment used to analyze rainfall areas using Polygon Thiessen Method. Annual rainfall data of 2009 and 2015 were employed consequently with the land-used and land-cover data. Maximum annual rainfall was 3,430 mm in 2009 and 4,182 mm in 2015 in Timampu rainfall station, while the minimum value was 1,814 mm in 2009 and 2,259 mm in 2015 in Larona rainfall station. Polygon Thiessen map of the three sub-catchments can be seen in figure 1.

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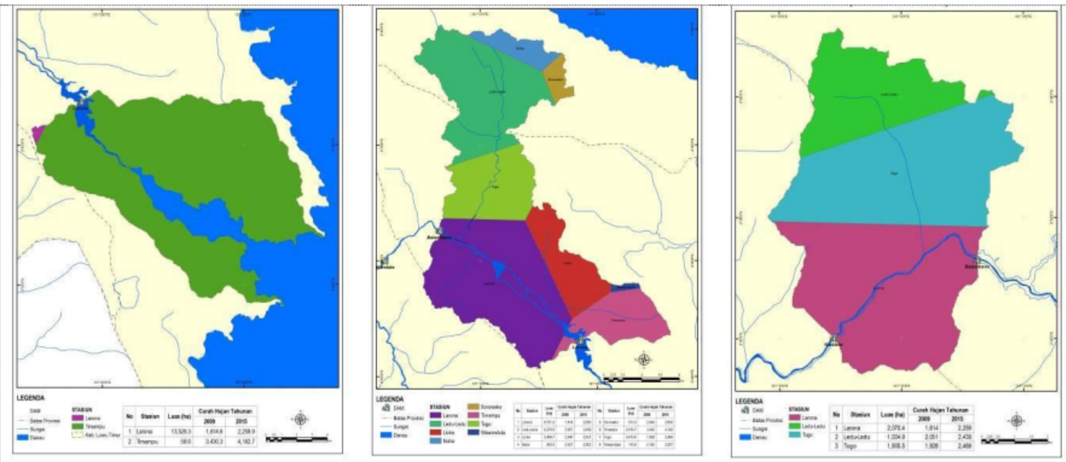
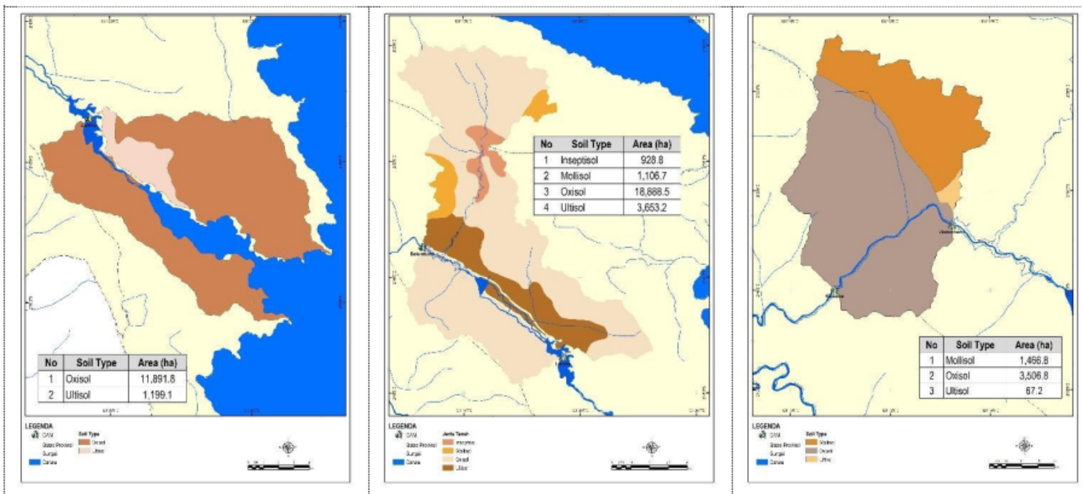


(a) Larona Sub-catchments (b) Balambano Sub-catchments (c) Karebbe Sub-catchments

Figure 1. Polygon Thiessen Maps of Larona, Balambano, and Karebbe Sub-catchments

3.2. Soil types

The main object of erosion is soil characteristics that influence the value of soil erodibility. A high value of soil erodibility indicates that soil is easy to erode. Soil erodibility is determined by soil texture, organic material concentration in the soil, soil structure, and level of soil permeability. Soil samples in this study were obtained from the surface layer as we assume that the layer is the object of the high potential of erosion. Soil types in the sub-catchments were Oxisol, Mollisol, Inseptisol, and Ultisol. These soil types are found mostly in Indonesia, tropical regions in particular. The area is dominated by Oxisol, where around 80-90% in Larona and Balambano sub-catchments and around 20% in Karebbe. The spatial distribution of soil types in the three sub-catchments was shown in figure 2.



(a) Larona (b) Balambano (c) Karebbe

Figure 2. Soil type maps in the Larona, Balambano, and Karebbe sub-catchments.

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3.3. Land slopes

The third factor of soil erosion is land topography. Components of topography in USLE are the slope and the length of flow (LS). Land slope classes did the determination of LS value in this study. Land slope classes are divided into seven classes. They are (i) Plane (0-3%), Mild (3-8%), Low sloping (8-15%), Sloping (15-30%), Low Steep (30-45%), Steep (45-65&) and Very steep (>65%). Plane land or flat area have small potential surface flow or overland flow compared to the sloping and steep area. The three sub-catchments dominated by the area of very steep have a high potential of soil erosion. Eroded land has a high contribution to the sediment in the three dams. So, the steep land should be considered the focused area of controlling erosion rate into the dams.

All sub-catchments showed that topography is situated in the mountainous area where the land slope is dominated by very steep and sloping land. The area with dominant sloping and steep should be managed using soil conservation practices, including terracing. However, it is rarely found in the location. The area of each land slope class in all sub-catchments is presented in table 1.

Table 1. Detail Area of Land-slope Classes at Larona, Balambano, and Karebbe.

No	Land slope (%)	Area (ha)		
		Larona	Balambano	Karebbe
1	0 - 3 (Plane)	1,661.1	396.1	-
2	3 - 8 (Mild)	2,148.3	1,735.8	-
3	8 - 15 (Low sloping)	77.5	488.7	-
4	15 - 30 (Sloping)	3,674.1	7,818.1	127.2
5	30 - 45 (Low steep)	1,307.0	531.6	29.2
6	45 - 65 (Steep)	431.0	41.7	101.7
7	> 65 (Very steep)	4,288.7	13,970.0	4,782.8

3.4. Land use change in the Larona, Balambano and Karebbe sub-watersheds

Land use and land cover are the fourth factors of soil erosion rate. Bare land will be easy to erode compare to forest or other covered lands. Land cover of 2009 and 2015 for all sub-catchments in this study was processed spatially to capture the change over the period of 2009 to 2015. Larona sub-catchment did not show the change during the period. Dominant land use is a secondary forest with a good land cover. Even there were found small parts of savanna, wildland, and bare land that mostly located along the levee of Malili river. Detailed land use of the Larona sub-catchment can be seen in figure 3 and table 2.

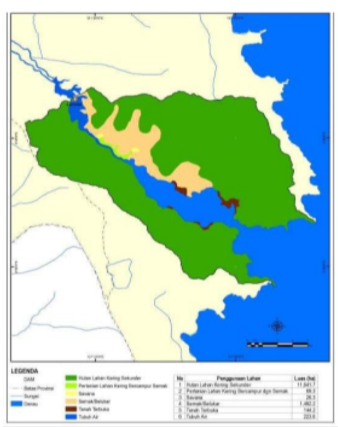
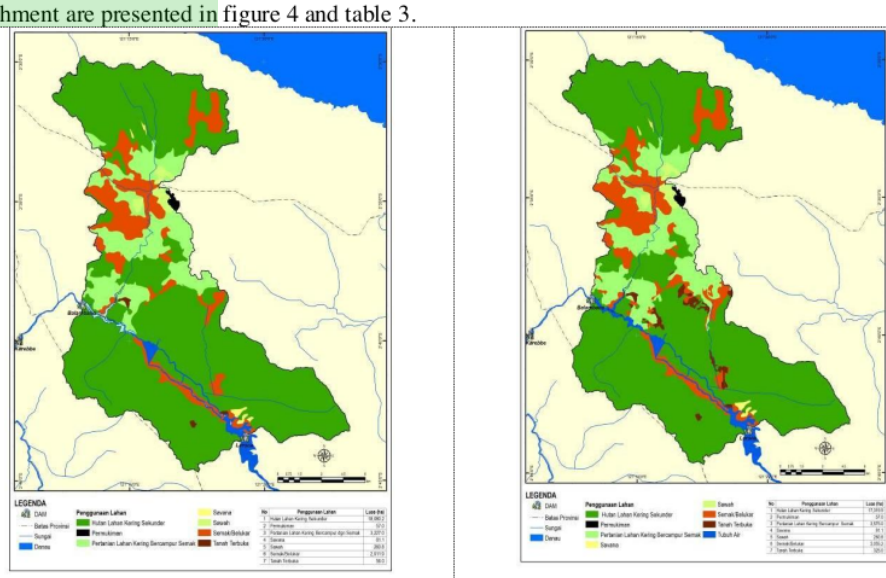


Figure 3. Land use of Larona Sub-catchment.

Table 2. Land-used Area of Larona Sub-catchment.

No	Land uses	Area (ha)
1	Secondary forest	11,641.7
2	Mix agricultural land	69.3
3	Savanna	26.3
4	Shrubs	1,482.2
5	Uncovered land	144.2

Balambano is the largest sub-catchment along Malili river. Human activities in the catchment such as agricultural development and settlement area, have contributed widely to soil erosion if the agricultural practices without conservation planning. Based on the land-used change in the years 2009 and 2015, it is clear that the forest area has decreased by around 760 ha, while agricultural land and shrubs have increased in the catchment. The change could be the impact of agricultural development, where the secondary forest became agricultural land. Detailed land-use changes in the Balambano sub-catchment are presented in figure 4 and table 3.



(a) 2009 (b) 2015

Figure 4. Land-used maps of Balambano in the year of 2009 & 2015.

Table 3. Land use of Balambano Sub-catchment in the year of 2009 and 2015.

No	Land-uses	Area (in ha)	
		2009	2015
1	Secondary forest	18,080.2	17,319.9
2	Settlement	57.0	57.0
3	Mix agricultural lands	3,227.0	3,575.0
4	Savanna	81.1	81.1
5	Rice field	260.8	260.8
6	Shrubs	2,911.9	3,055.2
7	Uncovered land	56.0	325.0

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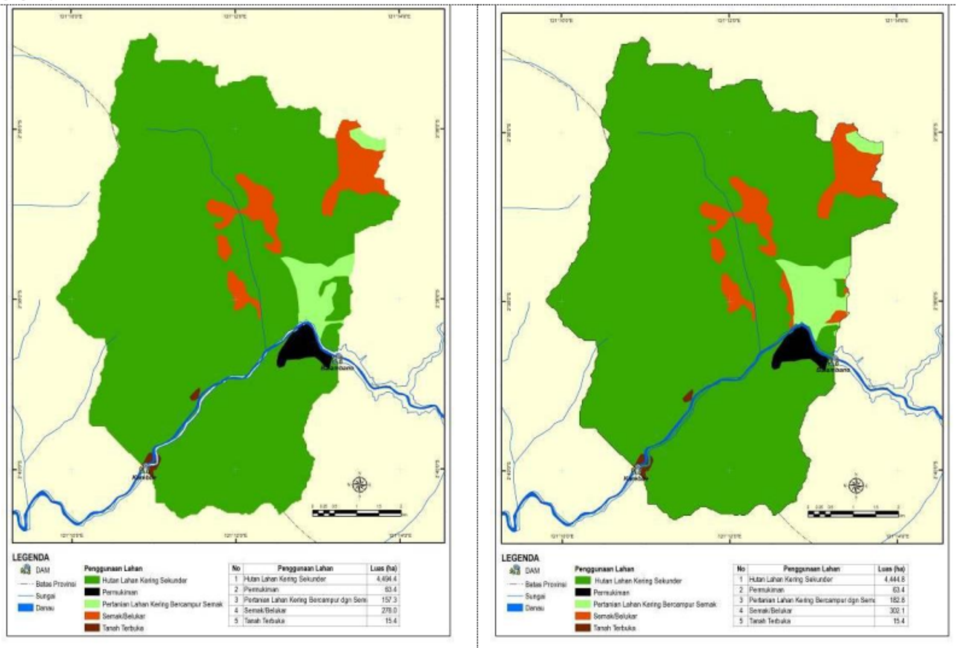
Land uses in the Karebbe sub-catchment are dominated by secondary forest. There were no significant changes during the period of 2009-2015. The local government has committed to maintaining the forest in the Karebbe sub-catchment for conservation to reduce the soil erosion rate. The distribution of land-used area in the Karebbe sub-catchment is presented spatially in figure 5 with detailed data in table 4.



(a) 2009 (b) 2015

Figure 5. Land-used Maps of Karebbe in The Year of 2009 & 2015.

Table 4. Land-used Area of Karebbe Sub-catchment.

No	Land uses	Area (ha)	
		2009	**2015**
1	Secondary forest	4,494.4	4,444.8
2	Settlement	63.4	63.4
3	Mix agricultural lands	157.3	182.8
4	Shrubs	278.0	302.1
5	Uncovered land	15.4	15.4

3.5. Potential erosion in the Larona, Balambano and Karebbe sub-watersheds

Based on the maps resulting by overlying four thematic maps using the USLE algorithm, the prediction of annual soil erosion rate for all sub-catchments was found. The land unit resulted have been analyzed to indicate the level of erosion hazards. Erosion hazards in the Larona sub-catchment were categorized as very light level in both the year of 2009 and 2015. The increase of annual soil erosion yield from 43,092 tons in 2009 to 50,982 tons in 2015 was caused by the change of erosivity level due to the rise of total rainfall events during the period. These soil erosion yields were classified into a very light, where average thick soil losses were 0.03 cm in 2009 and 0.04 cm in 2015. A detail of erosion hazard level in the sub-catchment can be seen in table 5.

Table 5. Erosion hazard level in the Larona sub-catchment.

No	Level of erosion hazards	Area (ha)	
		2009	2015
1	Very light	13,226.4	13,229.6
2	Light	257.7	212.1
3	Medium	103.2	146.1
4	Heavy	-	-
5	Very heavy	-	-

Balambano sub-catchment had indicated that the erosion hazard level increase from 2009 to 2015. The changes of level occurred at medium and heavy levels. Based on spatial analyses, the spreads of heavy levels have been found in the area where human activities intensively grow up in the settlement and agricultural land. This was indicated by the increase of sediment level at Patingku river, a river flowing into the Malili river. Results of USLE shown that total soil erosion in the year of 2009 was 197,005 tons. Then the erosion increased dramatically to 960,310 tons in the year of 2015. The thick of soil loss was about 0.1 cm and 0.5 cm in 2009 and 2015, respectively. The dam authority has prevented more land degradation in the catchment to reduce sediment rate flow into Balambano dam.

Table 6. The area of erosion hazard levels in Balambano sub-catchment.

No	Level of erosion hazards	Area (ha)	
		2009	2015
1	Very light	21,965	18,630
2	Light	2,071	1,822
3	Medium	254	2,026
4	Heavy	383	2,198
5	Very heavy	-	-

The value of annual erosion in Karebbe sub-catchment grows from year to year during 2009 and 2015. The level of erosion hazards became very heavy in several areas as a combination of land slope and increased human activities. A large sub-catchment area was categorized as very steep, which is no allow to develop agricultural activities. The annual erosion rate indicated that 155,005 tons of soil eroded in 2009 and increased to 224,757 tons in the year of 2015. It was predicted that 0.4 cm thick of soil eroded in 2009 and about 0.58 cm thick of soil in 2015. Controlling soil conservation in the catchment should be taken into account to prevent more soil flow into the Karebbe dam. The distribution of erosion hazard levels in 2009 and 2015 can be seen in table 7.

Table 7. The level of erosion hazard in Karebbe sub-catchment.

No	Level of erosion hazards	Area (ha)	
		2009	2015
1	Very light	3,827	3,269
2	Light	668	1,177
3	Medium	314	149
4	Heavy	200	214
5	Very heavy	-	200

4. Conclusion

The three sub-catchments in Larona Catchment showed an increased level of erosion hazard during 2009 and 2015. Land-used changes in the catchment were dominated by the development of agricultural land and settlement. The annual erosion has folded five times in the period of six years. Conservation strategies should be focused on the sloping land with intensive development activities to reduce the occurrence of soil erosion in the three sub-catchments

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References

[1] Achmad M; Samsuar, and Mubarak H 2020 Predicting the impact of land-use change on soil erosion rate in Ussu sub-catchment area and sedimentation yield in Malili River *IOP Conf. Ser.: Earth Environ. Sci.* **486** 012061
[2] Renard K G, Foster G R, Weesies G A, and Porter J P 1991 RUSLE Revised Universal Soil Loss Equation. Soil and Water Conservation Society *Journal of Soil and Water Conservation* **46** (1) 30-33
[3] Kouli M, Soupios P and Vallianatos F 2008 Soil erosion prediction using the Revised Universal Soil Loss Equation (RUSLE) in a GIS framework, Chania, Northwestern Crete, Greece. *Environ. Geol.* **57** 483-497
[4] Boggs G, Devonport C, Evans K and Puig P 2001 GIS-based rapid assessment of erosion risk in a small catchment in the wet/dry tropics of Australia *Land Degradation & Development* **12** 417 - 434
[5] Angima S, Stott D, O'Neill M, Ong C K & Weesies G A 2003 Soil Erosion Prediction Using RUSLE for Central Kenya Highland Conditions *Agriculture, Ecosystems & Environment* **97** 295-308
[6] Wischmeier W, and Smith D 1978 *Predicting Rainfall Erosion Losses*- A Guide to Conservation Planning. U.S. Department of Agriculture Handbook No.**537**
[7] Renard K G, Foster G R, Weesies G A, McCool D K anf Yoder D C 1997 Predicting soil erosion by water: a guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE) *Agriculture Handbook* No. **703** USDA-ARS
[8] Teh S H 2011 *Soil Erosion Modelling Using RUSLE and GIS on Cameron Highland, Malaysia for Hydropower Development*. Master Thesis University of Iceland & University of Akureyri **15**
[9] Alewell C, Borrelli P, Meusburger K and Panagos P 2019 Using the USLE: Chances, challenges and limitations of soil erosion modelling *International Soil and Water Conservation Research* **7** (3) 203-225
[10] Morgan R P C 2005 *Soil Erosion and Conservation*, 3rd Edn (Australian: Blackwell Publishing Company)
[11] Arsyad S 1989 *Konservasi Tanah dan Air* (Bogor: IPB Press)

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