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Surface erosion hazard and sediment yield for Keuliling Reservoir in Indonesia

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Abstract: The construction of the Keuliling Reservoir aims to accommodate and utilise water for agricultural purposes. In this research, soil erosion modelling using the USLE method showed that the level of erosion hazard for each Keuliling Reservoir sub-watershed was classified into low-moderate. Land erosion occurred in the area around the reservoir inundation is the most significant contribution to the magnitude of erosion (38.62 Mg·ha^{-1}·y^{-1}. Based on the point of sediment sampling in the Keuliling reservoir, the sediment volume was 1.43 Mg·m^{-3}. So, the volumetric sediment input from the Keuliling reservoir watershed is 20.918,32 m^3·y^{-1}. The degradation of reservoir function due to sedimentation can affect reservoir services. The ability to estimate the rate of watershed surface erosion and sediment deposition in the reservoir is vital for reservoir sustainability. Besides the land erosion in the Keuliling Reservoir, there are also other potential sources of erosion that can reduce the capacity of the reservoir, i.e. the rate of sedimentation from a reservoir cliff landslide. The USLE estimation results show that the soil erosion analysis provides important and systematic information about nature, intensity and spatial distribution in the watershed and sediment volume in the Keuliling Reservoir. This finding allows the identification of the most vulnerable areas and the type of erosion dominant for long-term land management.

Keywords: erosion hazard, Keuliling Reservoir, sediment yield, soil erosion

INTRODUCTION

Soil erosion is a complex dynamic process, through the process of productive soil, the particles are released, transported and subsequently accumulated in different places [ADEDIJI *et al.* 2010; ALEXAKIS *et al.* 2013]. Soil erosion can reduce watershed productivity, such as reducing soil quality resulting in reduced agricultural efficiency, deteriorating water quality, and flooding [PARK *et al.* 2011]. The condition is getting worse when there is a significant reduction in reservoir capacity due to sedimentation in the reservoir [ALEXAKIS *et al.* 2013]. Therefore, soil erosion is an important issue to consider in watershed management.

The information related to the spatial and temporal distribution of erosion is the first step in effective erosion control. Planning effective soil conservation measures on the watershed scale can be applied after there is clarity of spatial information about the dynamics of erosion and its quantity. It is crucial to identify areas for which soil erosion is planned, mainly a priority area for conservation actions [UDDIN *et al.* 2016].

Many models have been developed to estimate the rate of soil erosion. LAL [2001] and MERRITT *et al.* [2003] have summarised the soil erosion models namely Universal Soil Loss Equation (USLE) and its derivatives of Revised Universal Soil Loss Equation (RUSLE) and Modified the Universal Soil Loss Equation (MUSLE). The simplicity and accuracy of the USLE model make this empirical model most widely used [Alexakis *et al.* 2013; Azmeri *et al.* 2016; Chatterjee *et al.* 2014; Kourgialas *et al.* 2016; Lal 2001; Lim *et al.* 2005; Merritt *et al.* 2003; Perović *et al.* 2013; Xu *et al.* 2008; Zhang *et al.* 2008]. The USLE and RUSLE models estimate the average annual gross erosion as a function of rainfall energy. The difference in the MUSLE is that the rainfall energy factor is replaced by a runoff factor for sediment mapping [Wiliams 1975].

The use of GIS has been widely used to characterise soil erosion over large areas [Benzer 2010; Biswas 2012; Dabral *et al.* 2008; Meusburger *et al.* 2010; Pandey *et al.* 2007; Rahman *et al.* 2009; Sheikh *et al.* 2011]. In various countries, the mapping of erosion hazard zones using GIS has been done [Kothyari, Jain 1997]. The results of the study provide information on soil erosion rates with good accuracy. GIS allows users to analyse spatial data more efficiently. It also helps users to identify locations that are vulnerable to soil erosion [Kamuju 2016]. Spatial field survey collection is required, which affects the rate of erosion through a modelling approach with validation, although the type of validation needed is different for each category [Ionuş *et al.* 2013].

Reservoir development is one of the water resources management in terms of water conservation. Reservoirs are expected to meet the needs of downstream. Likewise, the existence of the Keuliling Reservoir in Bak Sukon Village, Kuta Cot Glie District, Aceh Besar Regency, Aceh Province has a huge role in meeting the needs of rice fields covering an area of 1,716 ha [Armido *et al.* 2020; BWS 2018].

The reservoir is expected to be able to suffice the needs following the operational service life plan. One of the factors that affect the operational service life of the reservoir is the increase in dead load storage due to the accumulation of sediments [Zarfl, Lucia 2018]. Sources of sedimentation rates that fill reservoirs can come from watersheds and reservoir cliffs [Legowo *et al.* 2009]. Sediment entry into reservoirs will result in sedimentation and siltation, which affect reservoir capacity [Tatipata *et al.* 2015]. A study in Morocco showed that significant siltation of reservoirs occurs annually. The reduction in storage capacity reached 75 Mm^3, which represented 0.005% of annual water mobilisation with a total shortfall of USD1 bln per year due to severe water erosion [Namr, Mrabet 2004].

Land erosion in the Keuliling Reservoir has the potential to cause sedimentation in the reservoir. All flowing rivers carry sediment, which is then trapped in the reservoir [Duta 2016]. The sediment at the bottom and valleys of the Keuliling Reservoir results in the reduction of the reservoir's effective storage. It is feared that the planned service life of the reservoir for the vulnerable 50 years is not achieved. Sedimentation is an unavoidable natural phenomenon. The high rate of sedimentation filling the reservoir can be slowed down. However, it is inevitable because erosion and sedimentation are the natural phenomena from the balance of energy elements [Legowo *et al.* 2009]. Because of the severe problem of soil and sediment erosion, this study aims to highlight the relationship between hydrological and biophysical conditions of watersheds that control erosion and sediment accumulation in Keuliling Reservoirs. Keuliling Reservoir is a reservoir playing an essential role in fulfilling the irrigation water needs in Aceh Besar District and is a promising irrigation area in Indonesia [BWS 2018].

MATERIALS AND METHODS

STUDY AREA

This research was conducted in the Keuliling Reservoir, Aceh Besar, Aceh Province, Indonesia. The Keuliling Reservoir has water sources from five sub-watersheds, namely: Glee Leumah Flow, Kang Flow, Keunikie Flow, Paku Kanan Flow and Paku Kiri Flow (Fig. 1).

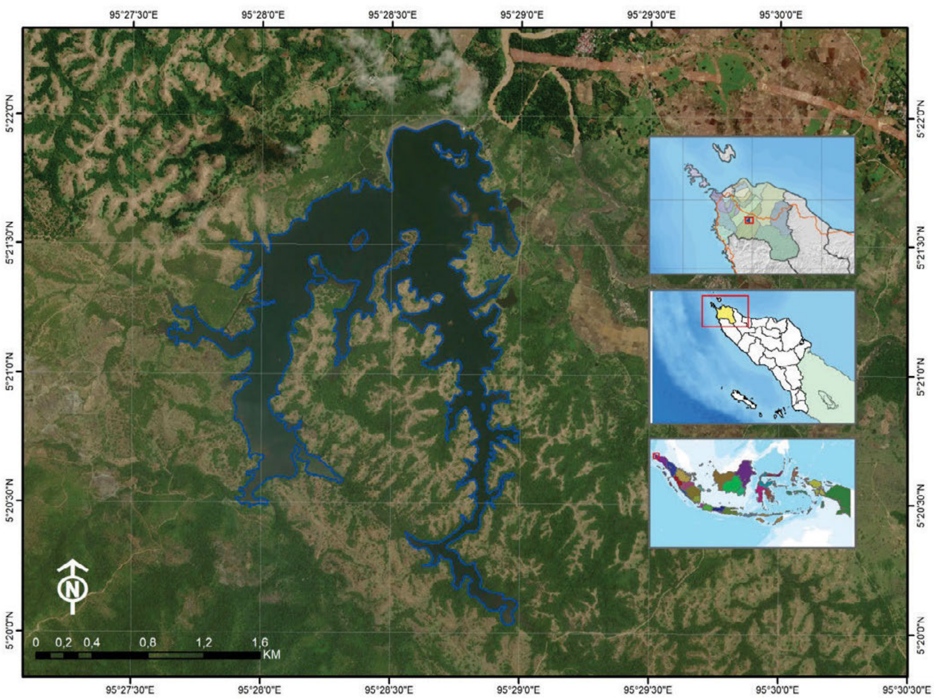

Fig. 1. The study area – Keuliling Reservoir; own elaboration

Table 1. Watershed components used to calculate the USLE factors

Factor	Input data	Source	Equation used and table reference
Rainfall erosivity factor (R)	rainfall data (2000–2015)	Blang Bintang Station	$R = 2.21P^{1.36}$ P = the amount of monthly rainfall (cm)
Soil erodibility factor (K)	land type map (2010)	Krueng Aceh BPDAS	soil type and erodibility value as in Tab. 2
Crop management and support practice factor (CP)	vegetation and land use map (2016)	Krueng Aceh BPDAS	classification erodibility value as in Tab. 3
Slope length and steepness factor (LS)	slope length and steepness map (2010)	Krueng Aceh BPDAS	$LS = \sqrt{\frac{l}{22}}(0.065 + 0.045s + 0.0065s^2)$ l = slope length (m) s = percent slope
Watershed boundaries and outlets	watershed map (2016)	Krueng Aceh BPDAS	–

Source: own elaboration based on literature.

DATA COLLECTION AND PROCESSES

All data in this study are given in Table 1 in the form of data input, sources, and equations used to calculate the USLE factors. Watershed factors are categorised into rainfall, soil type, land use, slope and slope length, and watershed boundaries.

METHODS

The modelling process was carried out using ArcGIS 10.1 through spatial conversion to a data format that is suitable for the application. The Universal Transverse Mercator (UTM) coordinate system (UTM zone 36N, ellipsoid WGS-84) is a geographic reference for the Digital Elevation Model (DEM) compatibility used. DEM is used to define the physical characteristics of the Keuliling Reservoir. The watershed components were classified into rainfall, soil type, length and slope steepness, and then landuse. The USLE model estimated the erosion hazard map and the average annual soil loss rate [Wischmeier, Smith 1978]. According to Azmeri *et al.* [2020], the modelling of soil erosion hazard map required the calculation of six input factors of the USLE model to control the soil erosion. The factors R, K, CP, and LS were generated in the data layers distributed using ArcGIS 10.1. (Eq. 1, Fig. 2):

$$A = R \cdot K \cdot LS \cdot CP \tag{1}$$

where: A = the amount of soil loss per unit area (Mg·ha^{-1}·y^{-1}), R = rainfall erosivity factor, K = soil erodibility index, LS = slope length factor, C = crop management factor, P = soil conservation factor.

Rainfall erosivity factor (R) quantifies the amount of rain and erosive strength of a particular rainfall [Prasannakumar *et al.* 2012; Xu 2008]. The ability of rainwater as a cause of erosion originates from the rate and distribution of raindrops, both of which affect the amount of rainwater kinetic energy (EI_{30}). In most cases in some countries, it is challenging to obtain rainfall intensity data. As a result, efforts have been made to determine erosivity from monthly rainfall data [Asdak 2004; Sahu *et al.* 2017].

Erodibility (K) is a function of soil texture, profile structure, permeability, and organic substance. K is defined as a measure of the soil particle's vulnerability toward discharge and transportation by rainfall and water runoff [Hoyos 2005; Panagos *et al.* 2014]. The chemical and physical properties of the soil are needed

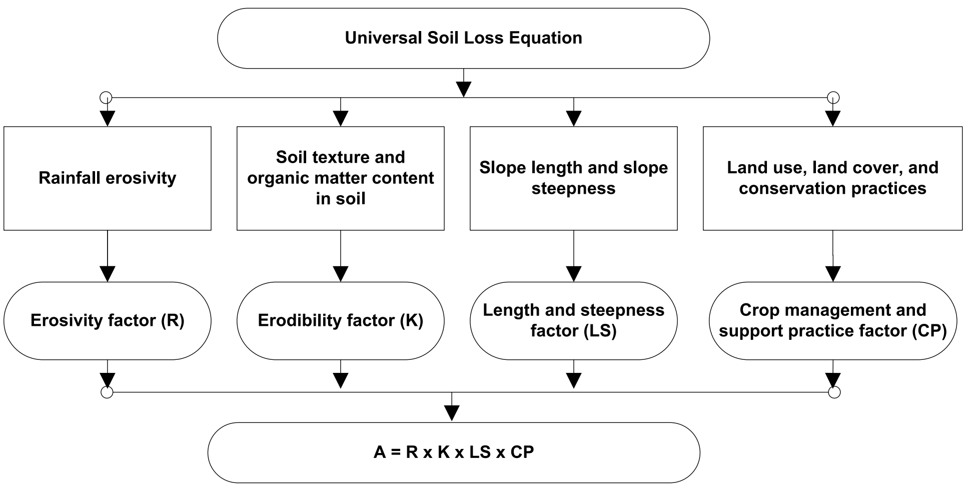

Fig. 2. Methodology flowchart; A as in Equation (1); source: Azmeri *et al.* [2020]

to determine soil erodibility in the form of soil structure and texture, organic matter content, and permeability. These properties indicate the type of soil and erodibility value (*K*), which is the sensitivity of the soil to the erosion hazard (Tab. 2). The erodibility classification is given in Table 3.

Table 2. Soil type and erodibility value (*K*)

Soil type	*K* value
Yellow-red Latosol	0.560
Grumusol	0.200
Alluvial	0.470
Regosol	0.400
Yellow Podzolic	0.107
Yellow-Red Podzolic (Tropudults)	0.320
Latosol (Epiaquic tropodult)	0.310
Rensing and Litosol Complex	0.220

Source: own elaboration based on literature (Kironoto [2000], Arsyad [2010], Asdak [2014]).

Table 3. Classification erodibility value (*K*)

K value	Grade
0.00–0.10	very low
0.11–0.21	low
0.22–0.32	moderate
0.33–0.44	moderate-high
0.45–0.55	high
0.56–0.64	very high

Source: Arsyad [2010].

The topographic factor is a combination of the length factor and the steepness factor of the slope. This factor affects the rate of erosion. The effect of the terrain on erosion reflects the fact that erosion increases with slope angles and slope length [Fu *et al.* 2005]. One of the essential elements for analysing physical characteristics that determine the suitability of various zones is a slope map. The DEM map is used to calculate *LS* factors.

In the USLE, crop management factor (*C*) is the ratio of the amount of erosion on land planted with specific management and the magnitude of erosion on the land not planted without special management. Whereas the soil conservation action factor (*P*) is soil conservation carried out as an action to reduce soil erosion. This can be in the form of mechanical or physical soil conservation techniques. As a reference, the *CP* value can be seen in Table 4.

The USLE parameters were calculated using separate equations with input generated from a DEM. The input data, their sources, and the equations used are listed in Table 1. The calculation of the individual factors is described in more detail in the next sections.

Table 4. The crop management and support practice factor (*CP* values) of various types of land use

Type of land use	*CP* value
Shrubs/meadows	0.300
Open land	1.000
Dryland agriculture	0.500
Secondary dryland forest	0.030
Residential area	0.500
Mixed dryland agriculture	0.013

Source: own elaboration based on literature (Asdak [2004]; Peraturan ... nomor: P. 61 /Menhut-II/2014; Kalsum [2017]).

VALIDATION OF SPATIAL EROSION HAZARD

The accuracy assessment of the mapping results classification is based on information overlay from the topographic base map and Google Earth. Validation of erosion models is done through field observations of randomly selected locations on the erosion hazard map. Table 5 displays the erosion hazard classes, which can be identified based on the magnitude of the actual erosion.

Table 5. The erosion erosion hazard classes

Class	Soil erosion hazard ($Mg \cdot ha^{-1} \cdot y^{-1}$)	Classification
I	<15	low
II	15–60	low-moderate
III	60–180	moderate
IV	180–480	high-moderate
V	>480	high

Source: Peraturan ... nomor: P. 3/V-SET/2013.

SEDIMENT YIELD ASSESSMENT

Eroded material in the watershed is transported in the form of sediment particles in various phases and locations. There is a relationship between soil erosion and sediment yield, represented using Sediment Delivery Ratio (*SDR*), i.e. sediment yield in the outlet catchment/dirty erosion in the water catchment [Duta 2016]. The determination of *SDR* needed to predict sediment yield in the catchment outlets [Asdak 2014]. It is shown in Table 6. In this study, the term sediment yield refers to the total sediment flow from a watershed with the output is the Keuliling reservoir for a specified period.

RESULTS AND DISCUSSION

SUBWATERSHED OF KEULILING RESERVOIR

This research was conducted in five sub-watersheds, including the areas around the reservoir inundation, upstream to downstream of the reservoir. The area of each sub-watershed can be seen in Table 7. All the USLE factors are derived as raster geographic

Table 6. Relationship between area and Sediment Delivery Ratio (*SDR*)

Watershed area (ha)	*SDR*
10	0.53
50	0.39
100	0.35
500	0.27
1000	0.24
5000	0.15
10000	0.13
20000	0.11
50000	0.85
2600000	0.49

Source: Arsyad [2012].

Table 7. Sub-watershed of the Keuliling Reservoir

Sub-watershed	Area (ha)	Percentage
Glee Meumah	942.1	26.3
Kang	166.6	4.7
Keunikie	62.7	1.8
Paku Kanan	679.1	18.8
Paku Kiri	1,066.0	29.7
The areas around inundation	669.9	18.7
Total	**3,586.4**	**100.0**

Source: own study.

layers after the original data processing. Maps of various erosion factors in the Keuliling Reservoir have been converted into layers. There is an attribute table that contains map data and the erosion parameters of the Keuliling Reservoir watershed. The processing of the database was performed with the professional software ArcGIS 10.1. (maps digitalisation).

RAINFALL EROSIVITY

The location of this study has limited distribution of automatic rain stations in the field. Wischmeier and Smith [1978] and modified by Arnoldus [1980] have also developed a relationship between rainfall erosivity and rainfall depth which is given in Table 1. Based on the monthly rainfall amount data of Blang Bintang Station, the results of rainfall erosivity of Keuliling Reservoir watershed are 1,185 mm.

SLOPE LENGTH AND STEEPNESS FACTOR (*LS*)

Based on the *LS* factor map data, it has the same value of <8% in each sub-watershed. This data indicates that slopes that tend to be similar in each sub-watershed have a little risk in influencing the magnitude of land erosion. The results of this study are in accordance with Fu *et al.* [2005], the effect of the terrain on erosion reflects the fact that erosion increases with slope angles and slope length.

CROP MANAGEMENT AND SUPPORT PRACTICE (*CP*) FACTOR

In this study, the verification was carried out between the crop management and support practice factor map through the field observations. The *CP*-factor values are in line with those available in the literature [Asdak 2004; Issa *et al.* 2016]. *CP*-factor values are given for each land-use land cover class (Tab. 8).

Table 8. Crop management and support practice factor (*CP*) distribution

Sub-watershed	Land-use	*CP* value	Area (ha)	Percentage
Glee Leumah	secondary dry land forest	0.03	2.4	0.3
	meadow	0.30	638.5	67.7
	shrubs	0.30	301.2	32.0
	total		**942.1**	**100.0**
Kang	meadow	0.30	166.1	99.7
	shrubs	0.30	0.5	0.3
	total		**166.6**	**100.0**
Keunikie	meadow	0.30	62.7	100.0
	total		**62.7**	**100.0**
Paku Kanan	secondary dry land forest	0.30	83.8	12.3
	meadow	0.30	132.4	19.5
	shrubs	0.30	462.9	68.2
	total		**679.1**	**100.0**
Paku Kiri	secondary dry land forest	0.03	325.3	30.5
	meadow	0.30	427.9	40.2
	shrubs	0.30	308.3	28.9
	open land	1.00	4.5	0.4
	total		**1,066.0**	**100.0**
The areas around inun-dation	dryland farming	0.50	68. 9	10.3
	meadow	0.30	434.0	64.8
	shrubs	0.30	167.0	24.9
	total		**669.9**	**100.0**

Source: own elaboration based on: Qanun … nomor 4/2013.

Based on the land-use map, the Keuliling Reservoir watershed is mostly covered by grasslands with the largest area of 638.5 ha which located in the Glee Leumah sub-watershed. Besides grasslands, it is also dominated by shrubs with the largest area of 462.9 ha in the Paku Kanan sub-watershed. Both of these *CP* factors have a large factor value of 0.3 and have an impact on the magnitude of land erosion [Alexakis *et al.* 2013]. While the *CP* factor value will affect the reduction in land erosion rates, namely secondary dryland forests and it is only a small part covered in other sub-watersheds. The map of *CP* factor can be seen in Figure 3.

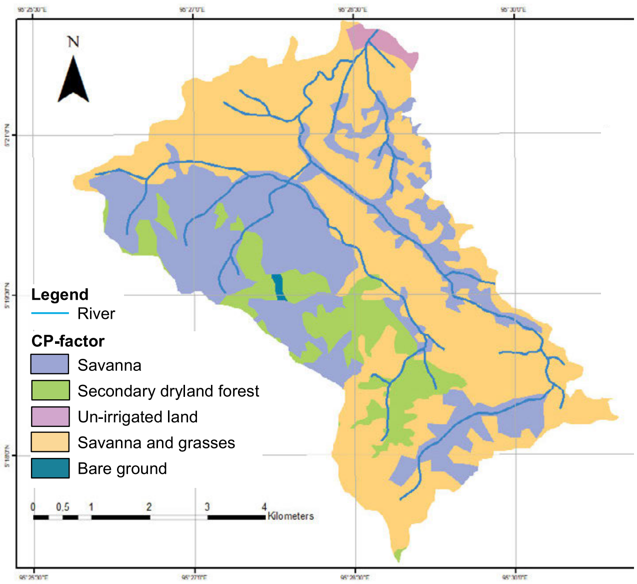

Fig. 3. Crop management and support practice factor (*CP*) map; source: own study

SOIL ERODIBILITY

In this study, a land map sourced from Krueng Aceh BPDAS (Fig. 4) and Table 2 as a basis for assessing soil erodibility. The Keuliling Reservoir watershed is covered by three types of soil, namely Red-Yellow Podzolic, Latosol, Rensing Complex and Litosol (Tab. 9). According Jiang [2013] higher the *K* value, the more soil is eroded.

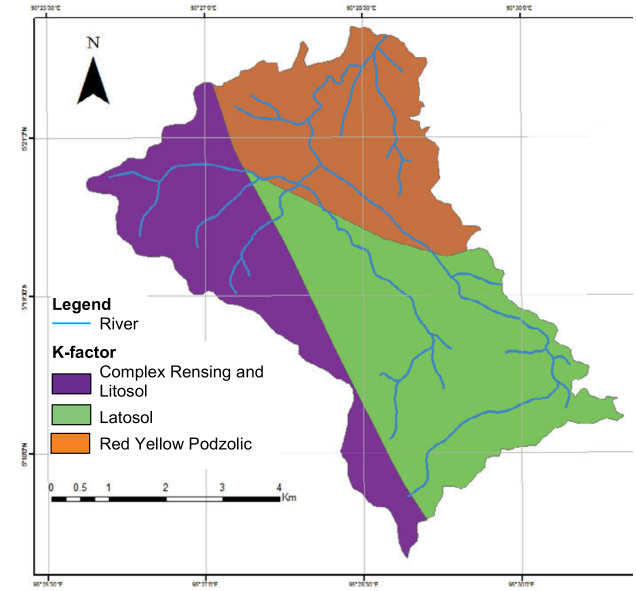

Fig. 4. Soil erodibility map; source: own study

Table 9 presents the percentage of area based on each soil type in the study area. The soil erodibility map was produced to show the spatial distribution of erodibility in the Keuliling Reservoir watershed between 0.22 and 0.32 $Mg·h^{-1}·MJ^{-1}·mm^{-1}$. This variation in erodibility is influenced by various land factors, including slope and land use. Soil types that develop on varied

Table 9. Soil erodibility (*K*) factor distribution

Sub-watershed	Landuse	*K*	Area (ha)	Percentage
Glee Leumah	Red-Yellow Podzolic	0.32	68.9	7.3
	Latosol	0.31	120.9	12.8
	Rensing complex and Litosol	0.22	752.4	79.9
	total		**942.2**	**100.0**
Kang	Red-Yellow Podzolic	0.32	77.9	46.8
	Rensing complex and Litosol	0.22	88.7	53.2
	total		**166.6**	**100.0**
Keunikie	Red-Yellow Podzolic	0.32	62.7	100.0
	total		**62.7**	**100.0**
Paku Kanan	Red-Yellow Podzolic	0.32	50.5	7.4
	Latosol	0.31	47.8	7.0
	Rensing complex and Litosol	0.22	580.9	85.6
	total		**679.2**	**100.0**
Paku Kiri	Red-Yellow Podzolic	0.32	31.0	2.9
	Latosol	0.31	782.7	73.4
	Rensing complex and Litosol	0.22	252.3	23.7
	total		**1,066.0**	**100.0**
The areas around inundation	Red-Yellow Podzolic	0.32	669.9	100.0
	total		**669.9**	**100.0**

Source: own elaboration based on: Qanun ... nomor 4/2013.

Table 10. Erosion risk and soil loss classifications in sub-watersheds of the Keuliling Reservoir

Sub-watershed	Area		Soil loss ($Mg \cdot ha^{-1} \cdot y^{-1}$)	Class	*SDR* (%)	Sediment yield ($Mg \cdot y^{-1}$)
	ha	%				
Glee Meumah	942.1	26.3	33.9	low-moderate	22.4	7,133.9
Kang	166.6	4.7	37.9	low-moderate	33.3	2,106.9
Keunikie	62.7	1.8	45.5	low-moderate	38.0	1,083.3
Paku Kanan	679.1	18.9	29.5	low-moderate	23.3	4,800.6
Paku Kiri	1,066.0	29.72	30.2	low-moderate	21.9	7,048.5
The areas around inundation	669.9	18.7	48.6	low-moderate	24.0	7,809.9
Total	**3,586.4**	**100.0**				**29,982.9**

Source: own study.

land conditions tend to have varying degrees of erodibility [ARIF 2013]. At the research location, soil conditions were dominated by the soil types of the Rensing complex and Litosol, covering 46.7% of the Keuliling Reservoir watershed. Furthermore, the soil condition is dominated by the Red-Yellow Podzolic soil type (26.8%). The types of soil in the Keuliling Reservoir are the soils that have a layer of solum. This type of soil has good resistance to soil erosion. When it related to the physical properties of the soil and soil organic matter content, due to stable soil aggregates, the erodibility value is low [ARSYAD 2010].

ANNUAL SOIL EROSION ESTIMATION

All the USLE factors are defined as the raster geographic layer after the original data is processed. These factor layers are then overlapped and multiplied together according to Equation (1). In overlay analysis, all four layers are combined to obtain maps and attributes that have the data for all four layers. Furthermore, the USLE model produces a spatial distribution of soil erosion hazards for the Keuliling Reservoir watershed (Tab. 10) and surface erosion hazard map (Fig. 5).

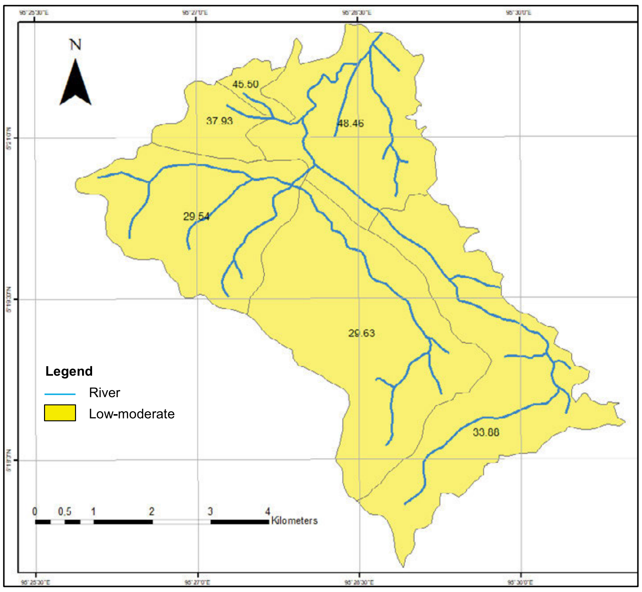

Fig. 5. Soil erosion hazard map; source: own study

Based on the results in Table 10 and Figure 7, the erosion hazard level for each Keuliling Reservoir sub-watershed is classified into low-moderate. However, the land erosion that occurred in the area around the reservoir inundation was among the most significant contribution to the amount of erosion in the inundation area (38.6 $Mg \cdot ha^{-1} \cdot y^{-1}$). The area around the reservoir inundation is dominantly open land. This condition gives a *CP* value of 1, providing the maximum impact on land erosion [ASDAK 2004; KALSUM 2017; Peraturan ... nomor: P. 61 /Menhut-II/2014]. Based on the *SDR* for each sub-watershed, it will deliver erosion to the outlet (Keuliling Reservoir). The total sediment yield accumulated in the Keuliling Reservoir was 29,982.9 $Mg \cdot y^{-1}$.

To find out the amount of sediment volume delivered to the Keuliling Reservoir, information on soil type with volume weight is needed. The nine samples of basic sediment were collected in Keuliling Reservoir inundation areas. Based on the test results of the sediment samples, the data obtained in Table 11.

Based on nine points of sediment sampling in the Keuliling reservoir, a sediment volume weight of 1.43 $Mg \cdot m^{-3}$ was obtained. Therefore, the volumetric sediment input from the Keuliling reservoir watershed is 20,918.32 $m^3 \cdot y^{-1}$. The USLE estimation results shows that the soil erosion analysis provides

Table 11. The results of Keuliling Reservoir sediment samples characteristics

Sample	Sand	Silt	Clay	Soil type	Volume weight ($Mg \cdot m^{-3}$)
	%				
1	21.15	46.42	32.43	clay loam	1.45
2	15.34	42.33	42.33	silty clay	1.50
3	18.87	41.45	39.68	silty clay loam	1.50
4	11.81	39.59	48.60	clay	1.35
5	11.80	44.09	44.11	silty clay	1.45
6	17.70	35.78	46.52	clay	1.35
7	16.08	44.12	39.80	silty clay loam	1.50
8	14.95	34.87	50.18	clay	1.35
9	3.44	46.56	50.00	silty clay	1.45
Average					**1.43**

Source: own study.

important and systematic information about nature, intensity and spatial distribution in the watershed and sediment volume in the Keuliling Reservoir. This finding allows the identification of the most vulnerable areas and the type of erosion dominant for long-term land management [ALEXAKIS *et al.* 2013]. This erosion hazard map can be an important tool as soil management integrated with land-use changes.

The results of field observations found that the five sub-watersheds of the Keuliling Reservoir were clear both in the dry and rainy seasons (Photo 1). This finding shows that the sedimentation coming from the sub-watershed into the Keuliling reservoir is not too significant. Although erosion that occurred in the Keuliling watershed occurred in several locations, it did not cause a high surge of sedimentation into the reservoir. This condition is adequate in terms of the low potential of sedimentation only. However, this condition is problematic when it is examined based on the land erosion and the ability to store rainwater [ZARFL, LUCIA 2018]. For this purpose, land erosion studies need to be monitored continuously, so that the capacity of the Keuliling reservoir during the dry season does not shrink dramatically.

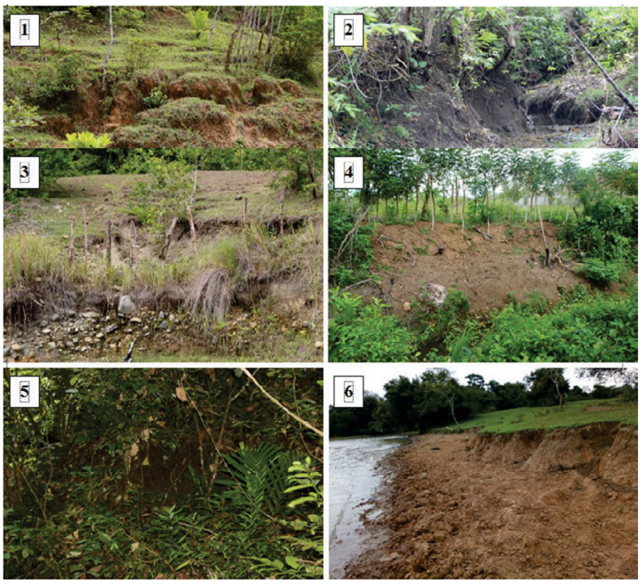

Photo 1. Land erosion in each Keuliling Reservoir sub-watershed; 1 – Alue Glee Leumah, 2 – Alue Keunikie, 3 – Alue Kang, 4 – Paku Kanan, 5 – Paku Kiri, 6 – the areas around reservoir inundation (phot. *A. Azmeri*)

Photo 1 visually shows the results of erosion have occurred in the form of a pile of sediment in the left and right grooves located in the Alue Glee Leumah sub-watershed. Even though these sediments are still accumulating along the channel, the potential to be transported and enter the reservoir is quite large when the channel discharge increases. Another source of erosion in this sub-watershed is sourced from the hill cliffs which are generally grasslands with sparse vegetation and land for community livestock release [ALEXAKIS *et al.* 2013]. Soil type is dominated by Red-Yellow Podzolic soil, Latosol, and Rensing complex and Litosol, which is a type of soil that is susceptible to erosion in the event of rain.

Red-Yellow Podzolic, Rensing Complexes, Latosol soils are the main soil types in the Alue Kang sub-watershed, and the land use are mainly grasslands and shrubs. Photo 1 shows the condition of the eroded hill cliffs, and it shows that erosion occurred in nearly all parts covered by less plant. In Alue Kang sub-watershed erosion also occurred along the roads in this sub-watershed. Road erosion will go directly into the channel and will settle in several places along the channel.

Erosion also occurs on the cliffs of the Alue Keunikie sub-watershed. Sediment material both originating from the cliff itself and from the flat terrain which is transported and retained in the furrows, and it will later enter the Keuliling reservoir as sediments. Landslide inventory was made by the analysis of the topographical maps. The landslide triggering factors are considered to be slope angle, slope aspect, slope curvature, slope length, distance from drainage, distance from lineaments, lithology, land use and geomorphology [VIJITH, MADHU 2008]. This sub-watershed is dominated by Red-Yellow Podzolic soil, although in some locations found gravel and sand material. The common types of plants are grasslands.

The condition of Alue Paku Kanan sub-watershed is not much different from the sub-watershed mentioned above, the type of land and land use are the same. The soil types are Red-Yellow Podzolic, Latosol, Rensing complex and Litosol. The forest is a dry land forest, shrubs, and meadows that are used for cattle herding.

The Alue Paku Kiri sub-watershed also provides criteria and conditions that are not much different from the Alue Paku Kanan sub-watershed. The largest channel that is the largest source of water to the Keuliling reservoir is from this channel. Along the left and right sides of the stove are overgrown with shrubs and sediments originating from the erosion of land held in the channel.

Land cover around the inundation area is dominated by grassland and Red-Yellow Podzolic soil type. Both, when viewed from the value of factors, have a high risk so that it has a large effect on the rate of erosion. This analysis is also supported by the discovery of several landslide points around the reservoir inundation.

The sediment accumulation into the reservoir within a certain period of its operation needs to be assessed. The capacity change tracking of the Keuliling Reservoir was carried out by BWS [2018], using data from bathymetric measurement results in 2013 and 2018. The volume of reservoir capacity reduction for five years was 1,206 Mm^3. This means that sedimentation has already occurred of that magnitude.

Land erosion in the watershed has the potential to cause sedimentation in the Keuliling Reservoir. The calculation of the sedimentation rate in this study is only in terms of land erosion in the five sub-watersheds. Comparison of USLE land erosion estimation results and the influences the magnitude of land erosion in the Keuliling reservoir watershed with the sediment volume from the bathymetric has a small value. The comparison between land erosion and effective storage provides information that sub-watershed land erosion does not play a major role in reservoir sediment volume. The slope of the land in the watershed area, which is relatively flat (<8%) and also the small flow of the channel into the reservoir inflow, may cause this condition. Therefore, it is concluded that there are other sources of erosion that reduce the reservoir capacity of the reservoir namely the rate of sedimentation from erosion or avalanche of reservoir cliffs, according to LEGOWO *et al.* [2009]. For this reason, it is necessary to comprehensively examine the potential for accumulation that comes from the erosion of the reservoir cliffs.

CONCLUSIONS

The results of soil erosion modelling using GIS techniques show that the level of erosion hazard for each Keuliling Reservoir sub-watershed is classified into low-moderate. Land erosion occurred in the area around the reservoir inundation is the largest contribution to the magnitude of erosion in the inundation area of 348.6 $Mg \cdot ha^{-1} \cdot y^{-1}$ and sediment yield of 7,809.9 $Mg \cdot y^{-1}$. Crop management and support practice factor (*CP*) value in this sub-watershed is the influencing factor for the magnitude of land erosion rate. It is seen that the area is dominated by land cover and soil conditions which have a low ability to prevent land erosion. In the Keuliling Reservoir, there is another potential source of erosion that reduces the reservoir capacity of the reservoir, namely the sedimentation rate of the reservoir cliffs. Overall, a comparison between land erosion and reservoir provides information that sub-watershed land erosion does not play a major role in reservoir sediment volume. The slope of the land in the watershed area, which is relatively flat (<8%), and the small flow of the channel into the reservoir inflow, may contribute to this. Although it is classified into low-moderate, this study shows that land erosion in the Keuliling Reservoir should have been handled because the reservoir is a reliable source of irrigation water in the study location. The USLE estimation results show that the soil erosion analysis provides important and systematic information about nature, intensity and spatial distribution in the watershed and sediment volume in the Keuliling Reservoir. This finding allows the identification of the most vulnerable areas and the type of erosion dominant for long-term land management.

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