Spatial Modeling of Sediment Export Rate with Rainfall Variability Scenario in Peusangan Watershed, Aceh Province

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Abstract. The rainfall affects the environmental interaction of watersheds and coastal areas. The high intensity of rain and water runoff will lift and carry particles in the watershed environment in the erosion process. This study estimates the total exports of sediment in Peusangan Watershed in the period 1995, 2005, 2015, and 2018 with rainfall variability scenarios. Total sediment exports are calculated from the erosion rate and sediment delivery ratio (SDR). Erosion rate modeling uses the RUSLE (Revised Universal Soil Loss Equation) that takes into account erosivity of rainfall, soil erodibility, topography, land cover, and land-use practices. While SDR is calculated based on its function as watershed area so that homogeneous value that causes the value of sediment export rate is directly proportional to the erosion rate value. The correlation between rainfall variability and sediment export rates is calculated based on rainfall variability correlation to erosion rate change. There is a direct relationship between rainfall variability and sediment export rates because the correlation coefficient is close to one. The rate of erosion in Peusangan watersheds falls into the light category based on the classification of erosion hazard levels according to the Ministry of Forestry in 1998. Based on the estimated rate of erosion and SDR, the total annual number of sediment exports obtained in the Peusangan watershed in 1995, 2005, 2015, and 2018 amounted to 1,066,027,426 tons, 909,914,623 tons, 1,075,759,133 tons, and 1,085,490,841 tons, respectively. Based on the spatial distribution of sediment export, Peusangan Watershed falls into the category of normal erosion.

1. Introduction
The interaction of watersheds and coastal areas is influenced by climate change [1]. Climate change is characterized by rising air temperatures, changes in rain times and patterns, and sea level rise [2]. In 2007, The Intergovernmental Panel on Climate Change (IPCC) published a 4th Assessment Report (AR4) stating that coastal areas are particularly vulnerable to erosion and sea level rise as a result of climate change [3].

Rainfall is one of the climatic elements that can cause erosion. Falling rainwater will erode soil particles at a certain slope, thus generating erosion [4]. Falling raindrops pounding the ground will cause soil particles to detach from the surface and be carried away by surface water runoff. The higher the rainfall will cause the potential for erosion to be higher, and vice versa.
Meanwhile, watershed and coastal sedimentation is causing changes in environmental appearance. The United Nations Convention on the Law of the Sea (UNCLOS) does not explicitly mention changes in normal baselines and maritime boundaries resulting from watershed sedimentation, coastal erosion, and sea level rise. UNCLOS allows if there is a change in the baseline due to watershed sedimentation, coastal erosion, and sea level rise can claim the maritime zone [5]. Sediment from watersheds to coastal areas can change the coastline and dynamics of the coastal environment. In addition, the change of coastline has the possibility to change the normal baseline, which will then change the maritime boundary zone. What's more, negotiations on maritime boundaries in local and international areas should be conducted with extreme caution [6]. Changes in maritime boundaries caused by environmental changes in adjacent administrative areas can lead to conflicts in various aspects.

In the study will be analyzed the impact of rainfall variability scenario which is one of the elements of the climate on watershed sedimentation and coastal dynamics. The results of the analysis in the form of interaction of watershed and coastal dynamics caused by the intensity of rainfall and runoff of surface water flow caused by the variability of rainfall to be a recommendation tool in making the right decision to evaluate environmental changes in the dynamics of watersheds and coastal.

This research was conducted in Peusangan Watershed, Aceh Province as shown in Figure 1. The determination of the research area is based on the criteria by which there is a cross between the land and the normal baseline along the coast of the region to be conducted research. The areas that meet these criteria are Peusangan Watershed and the coastal along the estuary of Peusangan River, Aceh Province. The Watershed area is in the coordinate range of 4°30'00" N to 5°17'30" N and 96°27'00" E to 96°27'00" E.

Peusangan watershed has upstream rivers located in mountainous areas and crosses five districts / cities until finally reached the Bireuen Sea. The upstream river is located in Lake Lut Tawar, Central Aceh Regency, while the river network flows through the administrative areas of Bener Meriah, North Aceh, Bireuen, and Lhokseumawe. The area of Peusangan watershed reaches 238,550 hectares. The length of the main river from Lake Lut Tawar to the Bireuen Sea coast reaches 128 kilometers. The area around Peusangan watershed is dominated by dense forests. The main upstream of Peusangan watershed is in Gayo Plateau in Takengon City while the estuary is in the Strait of Malacca in Biruen Regency [7].
2. Materials and Methods

The watershed is a land area that has a unitary river network that serves for catchment area, water storage and distribution water. Water derived from rainfall is flowed to the point of production or outlet of watersheds that are usually located in the lake or in the sea. Between one watershed and another on land is limited by topographical differences, while the boundary of the watershed with the water area is influenced by the activity that occurs on the mainland. The watershed boundary is delineated from the highest points of the ridge/mountain.

Figure 1. Peusangan watershed boundary map
2.1. Erosion and Sedimentation Process

One of the land activities in the watershed is erosion. Erosion naturally occurs due to the generation factor that causes the soil to peel off and lift from the surface which will then be transported by surface flow until it will eventually be deposited in the river network and watershed outlets. The event of particle transport by surface flow is called sediment transport. In general, the number of particles that are carried during the process of transporting sediment to watershed outlets is less than the number of particles that are peeled off the ground. Particles deposited up to the watershed outlet are called total sediment exports.

In general, erosion is a natural event that occurs due to the influence of several factors such as climate (rainfall), surface flow, soil type, slope, soil cover, population, and soil conservation action factors [8].

The most dominant climate factor causing erosion is rainfall. Rain that falls to the ground will cause soil particles to be destroyed in small grains that detach from the ground and then will be carried by the presence of surface flow caused by the amount and length of rain that occurs [9].

The erodibility factor states the degree of soil sensitivity to erosion is related to whether or not a soil is raised and carried away in an erosion event. Some soil properties such as texture, structure, organic content, depth, and soil fertility provide different responses to water behavior such as when falling pounding the soil during rain, seeping into the soil, and surface flow [10].

The dominant topographic factors affecting erosion events are the length and slope of the slope. Splashes of soil particles due to rainfall collisions occur more in areas with higher slope slopes. In addition, the slope of the slope will increase the discharge of surface flow so that more soil particles are exported. Generally the surface flow speed for the lower part of the slope is greater than the top of the slope, therefore at the bottom of the slope there will be more soil particles exported. While the length of the slope has a response that is affected by the intensity of the rain. At high rainfall intensity will cause erosion to increase, and vice versa [10].

Land cover factors also affect the erosion process that occurs. The speed of rain falling on areas with vegetation cover will be reduced so that the particles of loose soil will be less. This is due to reduced erosion generation force [10]. Changes in land cover will cause erosion behavior to change, changes in land cover from forests to open land will increase the rate of erosion [11].

In an effort to reduce erosion so that it is not too large, humans can give special treatment in soil conservation practices such as soil management based on soil capability [10].

2.2. Erosion Hazard Level Classification

The level of danger according to the Ministry of Forestry in 1998 is a calculation to compare the level of erosion in a land unit and the effective soil depth of the land unit. Erosion level analysis aims to determine the rate of erosion in a watershed area. The classification of erosion hazard levels based on the Indonesian Ministry of Forestry (1998) is classified into 5 classes as shown in Table 1.

| Classification | Loss of soil (tons/Ha/year) | Information |
|----------------|----------------------------|-------------|
| I              | < 15                       | Very light  |
| II             | 16 - 60                    | Light       |
| III            | 60 - 180                   | Medium      |
| IV             | 180 - 400                  | Weight      |
| V              | > 400                      | Very heavy  |

Source: the Indonesian Ministry of Forestry (1998)
To find out the increase in erosion rate can be done by determining the value of sediment export rate produced in watershed outlets. Determination of erosion rate based on sediment value exported to watershed outlets is classified as [12]:

a. Erosion rates are normal, with the average sediment export rate between 0–3000 tons/km²/year
b. Critical erosion rate, with an average sediment export rate between 3000–10000 tons/km²/year
c. The erosion rate is super critical, with the average sediment export rate above 10000 tons/km²/year.

2.3. Erosion Rate Equation Mathematical Model

This research will focus on geospatial modeling to determine the rate of sediment export \( Y \) occurring in the Peusangan watershed, Aceh Province. Sediment export rate is obtained from the calculation value of erosion rate \( A \) and sediment delivery ratio \( SDR \). A is the mass of soil particles raised from their source during the erosion process. A is calculated based on the common equation of soil particle loss RUSLE (Revised universal soil loss equation) used for soil loss simulation in watersheds (Renard, 1997). RUSLE is an empirical model that has been widely used around the world to calculate lost land. The RUSLE model takes into account erosiveness of rainfall, soil erodibility, topography (slope length and slope), land cover, and land use practices prepared in a Geographic Information System (GIS) environment. SDR is a calculation of sediment transport efficiency that is actually transported from the source of erosion so that it is exported out of a watershed compared to the mass of soil particles eroded in the watershed. SDR by calculated based on watershed area function. SDR values range from 0 to 1. The closer the value of 1, then all the eroded soil particles are carried to the watershed outlet, and vice versa. The calculation of the SDR value as a watershed area function is described in the equation \( SDR = 0.4724A^{-0.125} \) obtained from the processing of 300 watersheds [13].

In this study will be focused on rainfall variability scenarios. Calculation of erosion rate \( A \) amount and value of sediment export rate \( Y \) was done in time step in 1995, 2005, 2015, and 2018. The scenario of rainfall variability is done by making global climate data in the form of average rainfall every month as a free variable in the study. While the control variable is the amount of sediment export rate is done in time step in 1995, 2005, 2015, and 2018. The scenario of rainfall variability is done by making global climate data in the form of average rainfall every month as a free variable in the study. While the control variables in the form of land cover data, DEM data, and soil type data, land cover data, DEM data, and soil type data.

Rainfall variability scenarios using global climate data as free variables have a much smaller limited resolution compared to other data resolutions in erosion rate calculations. But the global climate data is one of the best climate modeling data in the world obtained from the results of measurement and modeling. Santa Clara University conducts climate observations in the form of rainfall and temperature at several stations in different countries to model. The evaluation of global climate data was conducted by comparing between global rainfall data from the official page of Santa Clara University and daily climate observation data from Malikussaleh Meteorological Station of the Bureau of Meteorology, Climatology, and Geophysics (BMKG) in 2015 and 2018 located at a geographic location of 5,22869°N dan 96,94749°E. Malikussaleh Meteorological Station was chosen based on its location close to the Peusangan watershed area and is located in a global climate data pixel with a resolution of 0.5×0.5 degrees containing the Peusangan watershed area. Observational data that has many data gaps is not used as a comparison for the evaluation of global climate data models. Data voids are caused by station maintenance periods, station damage due to natural events, and instrument failures. The steps of the research conducted can be seen in Figure 2.
The model of erosion rate calculation with RUSLE equation has adapted the USLE (Universal Soil Loss Equation) method introduced by Wischmeier & Smith (1978) by replacing the rainfall energy factor with the erosive factor of precipitation in lifting soil particles due to collisions with rain grains and surface flows that transport soil particles as a runoff factor as a function of surface flow volume and peak rate of surface erosion (peak runoff rate) (William, 1975; Onstad and Foster et al., 1977; Foster et al., 1980) in [14]. Here is the RUSLE equation in (1) [15]:

\[
A = R \times K \times C \times LS \times P
\]  

With \( A \) = average amount of soil lost each year (ton/ha/year), \( R \) = erosivity factor of rainfall, \( K \) = soil erodibility factor, \( C \) = land cover factor, \( LS \) = slope and length factor, and \( P \) = conservation factor.
2.3.1. Erosivity factor of rainfall. R factor states the physical influence of rain resulting in erosion. Erosiveness of rain occurs from the grain of rain that falls pounding the soil will make soil particles peel off and be carried away by the flow of water at the surface of the soil. Erosiveness of rainfall in Indonesia was stated by Bols in 1978 (2) [16]:

\[
R = \frac{2.5P^2}{100(0.073P + 0.73)}
\]  

where \( P \) is annual precipitation in millimeters.

2.3.2. Soil erodibility factor. Erodibility factor (K) owned by soil properties include influencing infiltration, permeability, and soil capacity in holding water. These properties are used in soil in terms of structural resistance at the time of receiving the influence of erosion of rain grains and surface flow [17]. Wishmeier and Smith (1960) in Arsyad, (2010) explained that the erodibility factor is the rate of erosion per unit of soil erosion index on a homogeneous plot of standard experiments with a length of 72.6 feet (22 meters) located on a slope with a slope of 9% without plants.

Based on the results of the research that has been conducted, Clay soils are more resistant to the release of soil grains so that it has a low K value that ranges from 0.05 to 0.15, sandy soils are also resistant to the release of soil grains with a value of K that ranges from 0.05 to 0.20, while muddy soils have a greater K value that ranges from 0.25 to 0.40 so that it is easily detached and carried by surface flow. Soils containing organic matter can increase soil resistance to soil grain release and reduce the impact of surface flow by increasing soil infiltration so that the erosion process can be reduced [14].

Table 2 is the determination of soil erodibility value according to (Kartasapoetra et al., 1991):

| Soil Type                                      | K  |
|-----------------------------------------------|----|
| Alluvial, Planosol, Gray hydromorf, Lateric, Gley | 0.2 |
| Latosol                                       | 0.23 |
| Mediteran                                     | 0.24 |
| Andosol, Grumosol, Podsol, Podsolic            | 0.26 |
| Regosol, Litosol, Organosol, Renzina           | 0.31 |

Source: Kartasapoetra (1991)

2.3.3. Land cover factor. C factor is the value of plant factors in the form of a ratio between the amount of soil eroded on land cover covered by certain plants with erosion that occurs on land that is not covered by plants [14]. Land cover data is influenced by crop factors and soil management to determine the vulnerable or less susceptible soil to erosion. Land cover is a watershed defense against energy generation erosion as well as determining the capacity of water at ground level (Julian, 2008).

Land without vegetation cover will be easier to erode When raindrops fall pounding soil particles and surface flow brings the particles to the watershed outlet. Land with dense vegetation cover will have protection so that the kinetic energy of rainwater when pounding the soil will be reduced so that the potential for erosion can be reduced. C values range from 0 to 1. The higher the value of C indicates that the more easily eroded the soil is with the barren surface. While the smaller the value of C indicates that the soil is difficult to erode due to vegetation factors that cover the soil so that the soil has a strong defense against erosion. Table 3 indicates the value of land cover factor in erosion process [20]:
Table 3. The value of the land cover factor

| Id | Land Cover Classification                              | C     |
|----|--------------------------------------------------------|-------|
| 10 | Cropland, rainfed                                      | 0.005 |
| 11 | Herbaceous cover                                       | 0.002 |
| 12 | Tree or shrub cover                                    | 0.003 |
| 20 | Cropland, irrigated or post-flooding                   | 0.005 |
| 30 | Mosaic cropland (>50%) / natural vegetation (tree, shrub, herbaceous cover) (<50%) | 0.002 |
| 40 | Mosaic natural vegetation (tree, shrub, herbaceous cover) (>50%) / cropland (<50%) | 0.002 |
| 50 | Tree cover, broadleaved, evergreen, closed to open (>15%) | 0.003 |
| 100| Mosaic tree and shrub (>50%) / herbaceous cover (<50%) | 0.003 |
| 110| Mosaic herbaceous cover (>50%) / tree and shrub (<50%)  | 0.002 |
| 120| Shrubland                                              | 0.003 |
| 150| Sparse vegetation (tree, shrub, herbaceous cover) (<15%) | 0.005 |
| 160| Tree cover, flooded, fresh or brakish water            | 0.001 |
| 170| Tree cover, flooded, saline water                      | 0.001 |
| 190| Urban areas                                            | 0.0007|
| 210| Water bodies                                           | 0.0001|

Source: Trahan (2003)

2.3.4. Slope and length factor. LS factor consists of components of topographic length and topographic slope. The length of the topography represents its effect on erosion measured from where the water flow at ground level begins to the sediment deposition site.

The slope of the topography represents its effect on erosion expressed in degrees of topographic angle or percent [10]. LS calculation comes from DEM data that has been done the process of patching holes/sinks. Mathematical equations in LS calculations use the following equations (3) [9]:

\[ L_S = \left( \frac{L}{K} \right)^m (k_1 \sin^2 s + k_2 \sin s + k_3) \]

with description,
- \( m = 0.2 \) for \( 0 \leq s < 1 \)
- \( m = 0.3 \) for \( 1 \leq s < 3 \)
- \( m = 0.4 \) for \( 3 \leq s < 4.5 \)
- \( m = 0.5 \) for \( s \geq 4.5 \)

With \( L \) = slope topographic length on dem surfaces with a value greater than 122m, it is an empirical value obtained from research from various countries over the years (Renard et al., 1997), \( m \) = slope index, \( s \) = percent slope, and \( k \) = empirical constants.

2.3.5. Conservation factor. P factor is a factor of human action in soil conservation. P is the ratio between the amount of land eroded on a land that is the same as the conservation action on the land and the absence of conservation measures on the land [14]. P can be derived from the slope or slope value of a land (Sharma et al., 2011). The steeper the slope will cause the soil particles to be more easily lifted up the surface flow. Table 4 is a classification of the value of conservation practices based on slope level:
Table 4. Value of Conservation Practices

| Slope (%) | P   |
|-----------|-----|
| 9-12      | 0.6 |
| 13–16     | 0.7 |
| 17–20     | 0.8 |
| 21–25     | 0.9 |
| >25       | 0.95|

Source: Sharma (2011)

2.4. Calculation of SDR and Total Sediment Exports

The predicted erosion rate generally has a higher value than the actual conditions in watershed outlets. Sediment Delivery Ratio (SDR) is the ratio between the number of sediments exported in watershed outlets with the mass of eroded sediment. The value of SDR are used to assess the efficiency of sediment transport. The value of SDR have a range of values from 0 to 1. The higher the SDR value indicates the more sediment that is carried up to the WATERSHED outlet. This has the sense that when the SDR value is close to one, then almost all eroded soil is transported to the outlet.

The variability of the SDR value of a watershed is influenced by: Sediment source, sediment count, transport system, texture of eroded soil particles, sediment deposition location and watershed characteristics [23]. The amount of SDR value in general is inversely proportional to the area of the watershed, the wider the watershed, the smaller the SDR value. Calculation of SDR value as a watershed area function is described in the equation $(4)$ obtained from the processing of 300 WATERSHED [13]:

$$ SDR = 0.4724A^{-0.125} $$  

(4)

with,

$A$ = watershed in km$^2$

To calculate the number of sediment particles reaching the outlet of a WATERSHED system can be done by calculating the total yield of erosion rate and SDR value. $(5)$ is the equation used to calculate the total number of sediment exports:

$$ Y = A \times SDR $$  

(5)

with,

$Y$ = Total Sediment Exports

$A$ = Erosion Rate

2.5. Research Data

The data used in this study comes from global secondary data that is freely available on the internet.

2.5.1. Rainfall Data

Rainfall data obtained from the official page of Santa Clara University with a spatial resolution of 0.5×0.5 degrees. This rainfall data has netCDF data format. The data presented is in the form of average monthly rainfall data from 1950 to 2099. The data is presented globally so it needs to be done clip against the boundary of the Peusangan watershed. The data can be accessed through the following links: [https://www.engr.scu.edu/~emaurer/global_data/](https://www.engr.scu.edu/~emaurer/global_data/).

2.5.2. Malikussaleh Meteorological Station Observation Data

The observation data is in the form of daily climate observation data obtained from the Bureau of Meteorology, Climatology, and
Geophysics with geographical location: 5.22869° N and 96.94749° E. The data is used to evaluate global climate data used in modeling.

2.5.3. DEM Hydrosheds. DEM SRTM (Shuttle Radar Topography Mission). Hydrosheds provides hydrographic information in a consistent and comprehensive format for regional and global scale applications. Here is the quality of Hydrosheds data according to (Lehner, 2013):

Hydrosheds demonstrate much better accuracy than other global river network representations derived from elevation data. In particular, due to its superior underlying digital elevation model, Hydrosheds represents a clear improvement over HYDRO1K which is an earlier global hydrographic data set and is widely used at a resolution of 1 km.

Hydrosheds in general tend to show better accuracy than 1:1 million DCW (VMAP-0) mapping products. However, the accuracy of both data sets varies by location. In some areas suggesting that Hydrosheds is particularly prone to faults, such as floodplain vegetation, DCW quality can be superior to Hydrosheds. In DEM Hydrosheds data development, accuracy levels have not been systematically evaluated. DEM Hydrosheds can be accessed through the following link: https://hydrosheds.org/downloads

2.5.4. Soil Type Data. Soil type data obtained from Soil Grids refers to the classification of land World Reference Base for Soil Resources 2006 (WRB 2006) which has a spatial resolution of 250 meters with overall accuracy of 70% (Sousa et al., 2020). This data is obtained through the following links: https://soilgrids.org/

2.5.5. Land Cover Data. Land cover data using classification from The Land Cover Classification System (LCCS). The classification was developed by the United Nations (UN) Food and Agriculture Organization (FAO). LCCS classifications follow standard qualifications to produce globally consistent land cover maps. This land cover data has a spatial resolution of 300 meters. The cover-up data used is 2018 data with overall accuracy of 70.82% (Copernicus, 2020). The data is obtained from Copernicus official page with the following link: https://cds.climate.copernicus.eu/cdsapp#!/dataset/satellite-land-cover?tab=form.

3. Results

3.1. Rainfall Variability Scenario
Rainfall data from Santa Clara University's official courtyard with a spatial resolution of 0.5×0.5 degrees is used to determine the force of the plant in releasing soil particles at the time of falling ground level. The scenario of calculation of rainfall of Pesangan watershed is done in each rainy season (October – March) and dry season (April – September) in 1995, 2005, 2015, and 2018 with the average rainfall in each season presented in Table 5.

| Table 5. The average rainfall in each season |
|---------------------------------------------|
| Season | Period | Average rainfall (mm/6 months) |
|--------|--------|-------------------------------|
| Dry    | 1995   | 850,897                       |
|        | 2005   | 592,925                       |
|        | 2015   | 674,154                       |
|        | 2018   | 563,415                       |
| Rain   | 1995   | 977,072                       |
|        | 2005   | 970,900                       |
|        | 2015   | 1164,575                      |
|        | 2018   | 1309,455                      |
Based on the table, characteristics of rainfall variability that occurs in the Peusangan watershed can be observed by making 1995 as a baseline observation. From the global climate modeling data obtained information that in the rainfall of the dry season will decrease while in the rainy season will increase, but not in the period of 2005 which has the least annual rainfall.

In the process of data processing, the spatial resolution of rainfall data is adjusted to conform to the spatial resolution of DEM HydroSheds data. Statistics of annual rainfall data in Peusangan watersheds in 1995, 2005, 2015, and 2018 are shown in Table 6. Erosive factor of rain in releasing and transporting soil particles through the surface flow at the time of erosion is calculated based on kinetic energy and annual rainfall intensity maximum 30 minutes. Spatial map of rainfall on each observation year shown in Figure 3.

| Period | Minimum | Average | Maximum |
|--------|---------|---------|---------|
| 1995   | 1.587,293 | 1.827,969 | 2.852,890 |
| 2005   | 1.377,208 | 1.563,825 | 2.381,019 |
| 2015   | 1.530,991 | 1.838,729 | 2.828,998 |
| 2018   | 1.734,346 | 1.871,310 | 2.786,888 |

Figure 3. Spatial map of rainfall
3.2. Global Climate Data Evaluation
In general, global climate data has less accumulated rainfall than the Malikussaleh Meteorological Station. This is because the calculation of rainfall from Malikussaleh Meteorological Station is done by calculating the average daily rainfall data for the months that are not too much data gap or gap by multiplying the average by the number of days in the month concerned. In 2015 and 2018 has a percentage rate of difference between global climate data and Malikussaleh Meteorological Station of 26,140% and 17,483% respectively, the global climate data from the official page of Santa Clara University can be used as data for erosion rate modeling by RUSLE method as a calculation of rainfall erosive factors that require annual rainfall data in peusangan watershed as a research site.

Comparison of global climate data to Malikussaleh Meteorological Station observation data is presented in Table 7 and Table 8. While the graph to visualize the comparison in each month is presented in Figure 4 and Figure 5. The percentage level of difference between global climate data and Malikussaleh Meteorological Station is presented for three periods including dry season, rainy season, and annual presented in Table 9 and Table 10. Observational data that has a lot of data gaps are not used as a comparison for the evaluation of global climate data models. The existence of data gaps is due to the maintenance period of the station, damage to the station due to natural events, and instrument failure.

| Month     | Malikussaleh Meteorological Station | Santa Clara University Global Climate Data |
|-----------|------------------------------------|-------------------------------------------|
| January   | 151,776                            | 110,963                                   |
| February  | 78,800                             | 101,582                                   |
| March     | -                                  | -                                         |
| April     | 65,870                             | 102,326                                   |
| May       | 54,012                             | 159,355                                   |
| June      | 103,889                            | 80,264                                    |
| July      | 96,774                             | 50,019                                    |
| August    | 165,568                            | 65,778                                    |
| September | 269,870                            | 119,529                                   |
| October   | 119,908                            | 112,593                                   |
| November  | 487,200                            | 221,807                                   |
| December  | 207,700                            | 303,853                                   |
| Total     | 1,801,366                          | 1,428,069                                 |

Table 7. Comparison of Total Rainfall in 2015
Table 8. Comparison of Total Rainfall in 2018

| Month  | Malikussaleh Meteorological Station | Santa Clara University Global Climate Data |
|--------|-------------------------------------|-------------------------------------------|
| January | -                                   | -                                         |
| February| 84,667                              | 135,845                                   |
| March   | -                                   | -                                         |
| April   | 116,192                             | 139,995                                   |
| May     | 218,938                             | 133,973                                   |
| June    | 65,586                              | 47,693                                    |
| July    | 225,636                             | 73,131                                    |
| August  | 92,885                              | 40,796                                    |
| September| 77,875                             | 84,439                                    |
| October | 306,423                             | 176,709                                   |
| November| 338,423                             | 209,528                                   |
| December| 67,741                              | 314,998                                   |
| Total   | 1,594,365                           | 1,357,107                                 |

Figure 4. The graph to visualize the comparison of total rainfall in 2015
Figure 5. The graph to visualize the comparison of total rainfall in 2018

Table 9. The percentage level of difference between global climate data and Malikussaleh Meteorological Station in 2015

| Period   | Amount of Rainfall in 2015 (mm) | Percentage Level of Difference (%) |
|----------|--------------------------------|-----------------------------------|
|          | Malikussaleh Meteorological Station | Santa Clara University Global Climate Data |
| Dry      | 755,982                         | 577,271                           | 30,958 |
| Rain     | 1,045,384                       | 850,798                           | 22,871 |
| Annual   | 1,801,366                       | 1,428,069                         | 26,140 |

Table 10. The percentage level of difference between global climate data and Malikussaleh Meteorological Station in 2018

| Period   | Amount of Rainfall in 2018 (mm) | Percentage Level of Difference (%) |
|----------|--------------------------------|-----------------------------------|
|          | Malikussaleh Meteorological Station | Santa Clara University Global Climate Data |
| Dry      | 797,112                         | 520,027                           | 53,283 |
| Rain     | 797,254                         | 837,080                           | 4,758  |
| Annual   | 1,594,365                       | 1,357,107                         | 17,483 |
3.3. Erosion Rate

Of all the parameter inputs in the erosion rate calculation model (A) using rusle approach obtained erosion rate value in 1995 in Peusangan watershed, Aceh which ranges from 0 to 2.172,390 tons/ha/year with an average of 26,290 tons/ha/year. In 2005, erosion rate ranged from 0 to 1.855,720 tons/ha/year with an average of 22,440 tons/ha/year. In 2015, erosion rate ranged from 0 to 2.202,925 tons/ha/year with an average of 26,530 tons/ha/year. While in 2018 obtained erosion rate value ranging from 0 to 2.203,413 tons / ha / year with an average of 26,770 tons / ha / year.

High erosion rate values are generally located in areas with steep topography with a slope of more than 25%, soil types dominated by andosols in erosion-sensitive Peusangan watersheds, and rainfall ranging from 2.381,020 mm/year to 2.852,890 mm/year during the modeling year range used. The majority of land cover in Peusangan Watershed in the form of tree cover with leaf cover that is tight to open. In general, areas with slope levels of less than 9% do not experience erosion events. Based on the level of danger according to the Indonesian Ministry of Forestry in 1998 in Table 2. 1 Classification of Erosion Hazard Level based on the Ministry of Forestry (1998), in general Peusangan Watershed has the potential for mild erosion with the average rate of erosion occurring in the range of 15 to 60 tons/ha/year in 1995, 2005, 2015, and 2018.

3.4. Correlation of Relationship Between Rainfall Variability to Erosion Rate

The correlation between rainfall variability and erosion rate was done by assuming the period of 1995 as the baseline in calculating changes in the periods 2005, 2015, and 2018. The calculation of the percentage difference between rainfall and erosion rate refers to the equations (6) and (7) to determine the percentage difference in rainfall and erosion rate in general can be done by looking for the average of each result of calculation of the percentage difference in rainfall and erosion rate of each pixel of raster data.

$$\% p = \frac{p_i - p_{95}}{p_{95}}$$  \hspace{1cm} (6) $$\% A = \frac{A_i - A_{95}}{A_{95}}$$  \hspace{1cm} (7)

with,

\%p = Difference in rainfall percentage (%)
\%A = Difference in erosion rate percentage (%)
p_{95} = rainfall in 1995 in every pixel of annual 1995 raster rainfall data
p_i = rainfall in the i-th year in each pixel of annual precipitation raster data in the i-th year
A_{95} = rate of erosion in 1995 in each pixel of raster data erosion rate in 1995
A_i = rate of erosion in the i-th year in each pixel of raster data erosion rate in the i-th year

i = 2005, 2015, atau 2018

In determining the relationship of rainfall variability to erosion rate is done by statistical calculation of correlation with precipitation variability as an independent variable that affects the rate of erosion. Calculation values range from -1 to 1. If it is positive then it shows the direct relationship of the variable. Whereas when negative is opposite direction. Correlation calculation refers to equations (8). The guidelines for assessing the interpretation of correlation levels refer to [26] in Table 11.

$$r = \frac{\Sigma xy}{\sqrt{(\Sigma x^2)(\Sigma y^2)}}$$  \hspace{1cm} (8)

with,

r = correlation coefficient
x = percentage change in rainfall in general
y = percentage change in erosion rate in general
Table 11. The guidelines for assessing the interpretation of correlation levels

| Coefficient Interval | Relationship Level |
|----------------------|--------------------|
| 0.000 – 0.199        | Very Weak          |
| 0.200 – 0.399        | Weak               |
| 0.400 – 0.599        | Intermediate       |
| 0.600 – 0.799        | Strong             |
| 0.800 – 1.000        | Very Strong        |

From the calculation of correlation coefficient based on the percentage of changes in rainfall to erosion rate by assuming the period of 1995 as a baseline against other periods of the year obtained information that rainfall has a very strong level of direct relationship to changes in erosion rate with the value of correlation coefficient close to one. The percentage information of precipitation changes that affect the erosion rate value is presented in Table 12.

Table 12. The percentage information of precipitation changes that affect the erosion rate value

| Year   | Difference % | Correlation Coefficient |
|--------|--------------|-------------------------|
|        | Rainfall     | Erosion Rate           |
| 1995-2005 | -14,395      | -6,453                   | 1.000 |
| 1995-2015 | 0,501        | 0,304                    |
| 1995-2018 | 2,592        | 0,982                    |

3.5. Sediment Delivery Ratio
Soil particles eroded in the Peusangan watershed in 1995 amounted to 5,922,374,590 tons, in 2005 amounted to 5,055,081,240 tons, in 2015 amounted to 5,976,439,630 tons, and in 2018 amounted to 6,030,504,670 tons. However, the total sediment found in watershed outlets is less than soil particles eroded in the Peusangan watershed. A portion of the sedimentary mass will be deposited on the slopes or watershed flow network so that the sediment that is successfully exported out of the watershed becomes less. In the calculation of the amount of sediment that is eroded to reach the watershed outlet requires the value of SDR and the total mass of sediment eroded in the watershed system. SDR states a comparison between the amount of sediment exported out of a watershed and the mass of sediment eroded in the watershed.

Research on the calculation of SDR value as a watershed area function has been done a lot. Based on Boyce's "Upland Theory" (1975), the SDR value is inversely proportional to the watershed area. The larger the watershed will cause more sediment to be deposited along the river flow or watershed before it reaches the outlet causing a decrease in the value of SDR. An example of SDR and watershed area relationships is shown in Figure 6.
3.6. Total Sediment Exports

The distribution of sediment export rate \( Y \) in Peusangan watershed, Aceh is determined by the estimated erosion rate \( A \) and the amount of SDR in the watershed. The distribution of sediment export rate is proportional to the rate of erosion. This is because the SDR value in the modeling is homogeneous so that it applies as a constant of pixel value multiplier factor in raster erosion rate. Figure 7 describing the level of erosion based on (Mulyanto, 2006) in each year of observation.

The calculation of total sediment exports from soil particles eroded in the Peusangan watershed area with an area of 2.252,710 km\(^2\) and SDR values as in the equation (9) obtained the results of total sediment found in watershed outlets as in Table 13. Distribution of sediment export suppliers in the Peusangan watershed in 1995 has an average of 4,732 tons/ha/year, in 2005 of 4,039 tons/ha/year, in 2015 of 4,775 tons/ha/year, and in 2018 of 4,819 tons/ha/year.

**Table 13.** The results of total sediment found in watershed outlets

| Year   | Erosion Rate (tons/year) | SDR | Total sediment exports (ton/year) |
|--------|--------------------------|-----|----------------------------------|
| 1995   | 5.922,374,590            | 0,180 | 1.066,027,426                     |
| 2005   | 5.055,081,240            | 0,180 | 909,914,623                       |
| 2015   | 5.976,439,630            | 0,180 | 1.075,759,133                     |
| 2018   | 6.030,504,670            | 0,180 | 1.085,490,841                     |
3.7. Comparison of Modeling Results With Previous Research

The modeling results in this study compared with the annual data on the total number of sediment exports in some watersheds that have been validated in the field. This model comparison aims to know the quality of modeling data that has been done.

Based on Figure 8, it can be seen that Peusangan watershed has a low annual total total sediment exports when compared to other watersheds with a relatively similar area. The area of the watershed does not have a significant influence on the number of soil particles carried by surface flow in the erosion process until it reaches the watershed outlet. Based on the data comparing the total exports of sediment between peusangan watershed and other watersheds obtained information that the modeling results are said to be quite good because it is still in the same order range with a range of between one to ten million tons per year.
One of the causes of low erosion levels in this study was the low level of rainfall in the Peusangan watershed in the epoch of the selected modeling year. In addition topographic differences, soil types and land cover also have an influence on erosion rate. Slope level above 25% in Peusangan watershed is only 38.370% of the watershed area, soil dominated by soil type that is not very sensitive to erosion in the form of latosol and andosol, and land cover is dominated by dense leafy tree vegetation that reduces kinetic energy collision of rainwater when falling to ground level causes peusangan watershed to have a mild erosion rate based on the Indonesian Ministry of Forestry (1998) and classified as normal erosion based on the amount of sediment item on the Watershed outlet.

4. Conclusion
This study examined the scenario of rainfall variability to the rate of sediment export in Peusangan watershed, Aceh Province. Sediment export rate is obtained from the calculation value of erosion rate (A) and sediment delivery ratio (SDR). A is calculated based on the common equation of loss of soil particles rusle used for simulation of soil loss in watersheds [15]. An SDR calculated based on the watershed area function using the equation \( SDR = 0.4724A^{-0.125} \). obtained from the processing of 300 watersheds [13].

Peusangan watersheds are located in regions with climate characteristics with annual rainfall that tends to increase. The characteristics of rainfall variability were observed by making 1995 as a baseline observation. In peusangan watershed, the rainfall of the dry season will decrease while in the rainy season will increase, but in the global climate modeling data, the trend does not apply in the period of 2005 which has the least annual rainfall. Annual rainfall in the Peusangan watershed during the modeling period ranged from 1,377,208 mm/year to 2,852,890 mm/year which was not very high. Validation of annual rainfall data is done by comparing global climate data against daily climate observation data from Malikussaleh Meteorological Station from BMKG in 2015 and 2018. In general, the global climate data used in modeling in this study had rainfall under observation data from malikussaleh Meteorological Station with a difference of 17.483%.

The environmental characteristics of Peusangan watershed are areas with varying slope levels from fairly ramped to steep, but most areas have very steep slopes and very ramps. Most of the soil in...
Peusangan watershed is latosol and andosol which are not very sensitive to erosion. Land cover in Peusangan watershed is dominated by tree cover with dense green leaves throughout the year so that it has a defense against erosion.

In general, Peusangan watershed has a mild erosion rate based on the Ministry of Forestry (1998) with the rate of erosion in 1995 in Peusangan watershed, Aceh which ranges from 0 to 2,172,390 tons/ha/year with an average of 26,290 tons/ha/year. In 2005, erosion rate ranged from 0 to 1,855,720 tons/ha/year with an average of 22,440 tons/ha/year. In 2015, erosion rate ranged from 0 to 2,202,925 tons/ha/year with an average of 26,530 tons/ha/year. While in 2018 obtained erosion rate value ranging from 0 to 2,203,413 tons/ha/year with an average of 26,770 tons/ha/year.

SDR calculation is done referring to the equation of SDR as a watershed area function obtained SDR value of 0.180. Homogeneous SDR values cause the calculation of sediment export rate proportional to erosion rate. So to see the effect of rainfall variability on the rate of sediment exports can be by correlating annual rainfall data to the value of erosion rate by assuming the period of 1995 as a baseline to calculate the difference between changes in rainfall and erosion rate in other years. From the calculation obtained a correlation coefficient of value one that indicates a strong unidirectional relationship between rainfall variability to changes in erosion rate in the modeling performed.

Based on the estimated rate of erosion and SDR, the total annual number of sediment exports in the Peusangan watershed in 1995 amounted to 1,066,027,426 tons, in 2005 amounted to 909,914,623 tons, in 2015 amounted to 1,075,759,133 tons, and in 2018 amounted to 1,085,490,841 tons. Based on the spatial distribution of sediment export rate, in general Peusangan Watershed falls into the category of normal erosion based on [12]. The amount of sediment value eroded to the watershed outlet is not affected by the area of the watershed, but from various erosion generation factors such as rainfall, soil type, and land cover in the watershed.

This final task research has a useful output as a consideration for the government in the development of adaptation strategies that take into account rainfall variability as well as watershed and coastal dynamics. For example, local government input in watershed management and spatial planning. This should be considered because if there is an error in spatial planning will lead to an increase in the rate of erosion, shallowing of rivers and estuary areas that cause flooding due to the volume of water that can not be accommodated by the river flow network. While in the academic field, this research can be used as knowledge to support further research to analyze the impact of coastal dynamics on regional boundaries. This is in accordance with the selection of study areas with criteria of river estuary areas that offend the baseline which will then be used as the basis for the withdrawal of the Indonesian boundary line.

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