The effect of dem resolution on calculation of erosion in Batang Kuranji watershed

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Abstract. Batang Kuranji Watershed with a total area of Watershed 224.7 km² comprises Batang Sungai Sapiah Sub-watershed, Batang Danau Limau Manih Sub-watershed, Batang Sungkai Sub-watershed, Batang Bukik Tindawan Sub-watershed and Batang Padang Janiah Sub-watershed. Batang Kuranji flows from upstream of the Bukit Barisan with the highest elevation of 1,605 meters above sea level at the peak of Bukit Tinjau Laut and empties into the Padang beach with a main river length of ± 32.41 km. DEM has an influence on the results of land erosion by affecting the slope accuracy. The higher the DEM resolution, the more precise the results of the soil erosion simulation. With the MUSLE method the rate of erosion occurs in the Batang Kuranji watershed, with DEM data of 8m and land cover in 2017, an erosion rate of 23.91 tons / hectare / year is classified in hazard class II (light), DEM data of 30m erosion rate is 7.70 tons / hectare / year are classified in hazard class I (very mild), with DEM data of 90m erosion rate of 4.54 tons / hectare / year classified in hazard I class (very light). It can be seen that the higher the DEM resolution, the more accurate the erosion rate calculation in the watershed.

1. Introduction

Batang Kuranji Watershed is one of the region river at Indragiri - Akuaman with a total area of Watershed 224.7 km², consisting of Batang Sungai Sapiah Sub-watershed, Batang Danau Limau Manih Sub-watershed, Batang Sungkai Sub-watershed, Batang Bukik Tindawan Sub-watershed and Batang Padang Janiah Sub-watershed. The main river, Batang Kuranji, flows from upstream of the Bukit Barisan at the highest elevation of 1,605 meters above sea level at the peak of Bukit Tinjau Laut through to the Padang beach with a main river length of 32.41 km [1]. The upper catchment has a highest annual rainfall in Sumatera with an average of above 3000 mm. The upstream catchment is dominated by natural forest and plantations, comprising approximately 20 percent of catchment area. On the other hand, the middle and lower catchment are dominated by housing, farms and plantations. Housing and plantations expanded to the upper catchment since mid 1980’s and is still progressing.

Due to steep topography in the upper catchment, coupled with high rainfall, land erosion has been imminent. Some studies have been conducted to estimate erosion rate of the watershed in an attempt to anticipate environmental impacts. [2] explains that erosion is a process in which land is destroyed (detached) and then transported to another place by water, wind, river or gravity. This phenomenon may result in damage to ecosystems along the watershed, especially the reduction in forest area. Decreasing vegetation area is a serious problem in watershed ecosystems. Land cover in the form of vegetation...
functions as a watershed defense against erosion [3]. However, the estimation of erosion at a large scale at Batang Kuranji watershed is hampered by data availability for topography and land use functions as two main parameters. As an alternative, the use of Digital Elevation Model (DEM) is promising due to better DEM resolution that is available at free of charge. Yet, there is no agreement on DEM resolution that results in optimum erosion yield. The use of fine resolution will cost computational time and resources, while coarse resolution is fast in computation but ignore variations in land topography.

Previous studies using varied DEM resolution suggested different conclusions. [4], [5], [6] and [7] found that the choice of DEM input resolution depends on the response of the watershed. These studies highlighted that if only a runoff response will be modeled, a DEM resolution of up to 500 m will produce less than 1% Relative Error (RE) in the model predictions. If sediment is the desired result, then an input resolution of less than 50 m is needed to achieve the same level of accuracy in the SWAT prediction [8]. This study also found that DEM resolution has an influence on runoff and sediment yield by affecting slope accuracy. The higher the DEM resolution, the more precise the results of runoff and sediment simulations. Since the acquisition of high-precision DEM data and the accuracy of other parameters are limited, the use of right DEM resolution in SWAT model is very pertinent [9].

The purpose of this study is to seek for optimum DEM resolution for the accuracy of erosion calculations in the Batang Kuranji watershed. We use the MUSLE (Modify Universal Soil Loss Equation) formula as governing equation. The method is a modification of the USLE (Universal Soil Loss Equation) method, which is to replace the rain erosivity factor (R) with a flow factor or runoff surface (Run Off). The MUSLE method takes into account both erosion and sediment movement in the watershed based on a single rain event [10], [11], [12], with the following equation:

\[ SY = R \cdot K \cdot LS \cdot CP \]  

(1)

where:

\[ R = a \cdot (Vq \cdot Qp)^b \]  

(2)

Information:

- \( SY \) = Amount of eroded land (ton / year)
- \( R \) = runoff
- \( K \) = Soil erodibility factor
- \( LS \) = Slope factor
- \( CP \) = Land use factors and Tillage
- \( Vq \) = Surface Flow Volume (m³)
- \( Qp \) = Peak Flow (m³/s)
- \( a \) = 11.8 (constant)
- \( b \) = 0.56 (constant)

2. Research methods

The study was conducted using a survey method for collecting primary data, and secondary data from the internet. Primary data comprises test of soil permeability, soil water content, soil density and soil content in Padang State Polytechnic Laboratory. Secondary data comprises land use maps from Landsat, 90m DEM from SRTM (Shuttle Radar Topographic Mission), 30m DEM from ASTER GDEM (Advanced Spaceborne Thermal Emission and reflection Radiometer-Global Digital Elevation Model), and 8m DEM from DEMNAS. Land use were acquired from BAPPEDA Kota Padang. Daily rainfall data from Koto Tuo Station, Gunung Nago Station and Batu Busuk Station from Year 1992 to 2017 were acquired from BWS V Sumatra and Provincial Body for Water Resources Management.
Rainfall analysis were conducted by applying Thiessen area weighted method from 3 stations. Rainfall Frequency Analysis were calculated using the Gumbel, Normal, Log Normal, and Log Person Type III Methods. The four methods were examined using Chi-Square for best-fitted function. Rainfall intensity were calculated using Mononobe method. Land use changes were estimated using Landsat 8 OLI (Operational Land Imager) data from the USGS for Year 1994, 1999, 2004, 2012 and 2017 due minimum cloud cover. Landsat 8 OLI multispectral images consist of 9 bands. For land use analysis, Landsat bands were combined using Image Analysis in Windows. Then after the bands have been combined, the next step is to seek for the color of the specified land cover. The color of the projected area depends on the order of the band used, namely band 4, 5, 6 (red, infrared, and short-wave infrared-SWIR, respectively). Land cover classification were conducted using QGIS package. Peak discharge calculation utilizes the Hydrological 7 Sub-watershed distributed model, using the SCS Curve Number method with the HEC-HMS software. River slope data uses 3 types of DEM, i.e. 90m, 30m, and 8m DEM.

Erosion Rate were calculated using MUSLE equation with input of surface flow (R) taken from the results of the SCS Curve Number method in the form of runoff volume (Vq) data and peak flow (Qp). For K value input, the type of soil in the watershed is needed. Due to predominant type of soil in the Kuranji watershed being latosol, the K value is 0.31. LS factors used 3 types of DEM with pixel resolutions of 8m, 30m and 90m. The type of slope was grouped into 5 classes for each Sub-watershed. From the mapping results, the LS value for each Kuranji sub-watershed was obtained. The CP value affects the type of land cover. The value of land erosion calculated for each sub-watershed is obtained by knowing the values of R, K, LS and CP. The use of R, K, LS and CP values were revealed in [13]. Research methods is described in a flow chart as follow:
3. Results and Discussion

Table 1. Erosion Rate for 2017 land cover with 8m DEM.

| Watershed Name | Area of watershed (ha) | Q (m³) | Qn (m³/s) | K | LS | CP | R | Erosion Tons/Year | Erosion Tons/ha/Year |
|----------------|------------------------|--------|-----------|---|----|----|---|-------------------|---------------------|
| sub 1          | 3,225.51               | 5,085,000 | 157.8    | 0.300 | 3.4250979 | 0.072293 | 1143786.227 | 91,415             | 28.34               |
| sub 2          | 2,133.84               | 3,268,200 | 101.5    | 0.300 | 2.8352454 | 0.059289 | 697454.407 | 35,173             | 16.48               |
| sub 3          | 4,680.80               | 7,162,000 | 222.5    | 0.300 | 2.9958794 | 0.05409  | 1679600.647 | 91,014             | 19.44               |
| sub 4          | 1,467.92               | 3,218,800 | 99.6     | 0.300 | 1.9574632 | 0.079635 | 684251.6805 | 37,871             | 25.80               |
| sub 5          | 1,381.24               | 3,077,200 | 119.3    | 0.300 | 0.5679433 | 0.118896 | 738189.4959 | 14,954             | 10.83               |
| sub 6          | 7,673.39               | 14,744,400 | 492.8   | 0.300 | 1.3429172 | 0.135962 | 3928337.36  | 245,871            | 32.04               |
| sub 7          | 1,289.58               | 3,075,800 | 123.1    | 0.300 | 0.3602558 | 0.076215 | 751074.554 | 6,187              | 4.80                |

Amount of erosion Tons/Year: 522,484
Amount of erosion Tons/ha/Year: 23.91
Kuranji watershed were divided into 7 sub-watersheds. This method has found to be an optimum division for discharged computation with varied DEM resolution [14]. Each sub-watershed has one tributary flowing to the main river. An example of erosion rate calculation is presented in Table 1 using 8m DEM and land cover data of year 2017. Among the 7-sub-watershed, sub-watershed 6 is the largest area by more than 7 thousand hectares, followed by sub-watershed 4. The smallest one is sub-watershed 7. However, Table 2 reveals that annual erosion rate is not linear with sub-watershed area. While sub-watershed 6 results in highest erosion rate per year, the second largest is found in sub-watershed 1 with area of less than half of sub-watershed 6.

Table 2. Sum of Kuranji watershed erosion rate with 8m DEM.

| Watershed | Erosion Recapitulation (Tons/ha/Year) |
|-----------|--------------------------------------|
| Sub       | 1994 | 1999 | 2004 | 2012 | 2017 |
| sub 1     | 19.17 | 23.99 | 19.76 | 26.46 | 28.34 |
| sub 2     | 9.16  | 9.70  | 9.19  | 10.09 | 16.48 |
| sub 3     | 23.43 | 23.92 | 23.50 | 29.27 | 19.44 |
| sub 4     | 8.42  | 22.73 | 14.17 | 27.15 | 25.80 |
| sub 5     | 2.49  | 6.67  | 4.02  | 5.22  | 10.83 |
| sub 6     | 27.42 | 78.94 | 58.44 | 35.90 | 32.04 |
| sub 7     | 0.02  | 3.13  | 2.60  | 1.75  | 4.80  |
| Amount    | 19.10 | 39.46 | 30.73 | 26.02 | 23.91 |

Table 2 and figure 4 exhibit Kuranji watershed erosion using 8m DEM data and land cover from the year 1994, 1999, 2004, 2012 and 2017 were 19.10, 39.46, 30.73, 26.02 and 23.91 tons/ha/year, respectively. These values were classified in hazard class II (mild), ranges from 15-60 ton/ha/year. However, within the watershed, the trends are not the same. Sub-catchment 3, 4 and 6 show a downward trend through 2017, while other sub-catchments exhibit upward trend. Overall, during 1994 to 2017 period, sub-watershed 6 exhibited the largest erosion rate with 8m DEM The highest rate is shown in Year 1999. In other sub-watersheds, however, the figure is different with up and down trend.

Figure 4. Sub-watershed Erosion Rate with 8m DEM.
Table 3. Sum erosion rate with 30m DEM.

| Watershed | Erosion Recapitulation (Tons/ha/Year) |
|-----------|-------------------------------------|
|           | 1994  | 1999  | 2004  | 2012  | 2017  |
| sub 1     | 6.91  | 8.64  | 7.12  | 9.53  | 9.49  |
| sub 2     | 3.24  | 3.43  | 3.25  | 3.57  | 5.82  |
| sub 3     | 5.81  | 5.93  | 5.83  | 7.26  | 4.33  |
| sub 4     | 2.34  | 6.40  | 3.99  | 7.64  | 6.14  |
| sub 5     | 1.30  | 3.50  | 2.11  | 2.74  | 5.68  |
| sub 6     | 10.93 | 31.02 | 22.96 | 14.11 | 11.02 |
| sub 7     | 0.65  | 2.21  | 1.85  | 0.99  | 3.40  |
| Amount    | 6.61  | 14.39 | 11.04 | 8.98  | 7.70  |

Figure 5. Sub-watershed Erosion Rate with 30m DEM.

Table 4. Sum of erosion rate with 90m DEM.

| Watershed | Erosion Recapitulation (Tons/ha/Year) |
|-----------|-------------------------------------|
|           | 1994  | 1999  | 2004  | 2012  | 2017  |
| sub 1     | 3.20  | 4.01  | 3.30  | 4.42  | 4.40  |
| sub 2     | 1.36  | 1.44  | 1.36  | 1.49  | 2.44  |
| sub 3     | 3.62  | 3.70  | 3.64  | 4.53  | 2.70  |
| sub 4     | 0.97  | 2.65  | 1.65  | 3.16  | 2.54  |
| sub 5     | 1.11  | 2.98  | 1.80  | 2.33  | 4.83  |
| sub 6     | 6.89  | 19.56 | 14.48 | 8.90  | 6.95  |
| sub 7     | 0.64  | 2.16  | 1.81  | 0.97  | 3.33  |
| Amount    | 3.91  | 8.76  | 6.71  | 5.26  | 4.54  |
Table 3 and Figure 5 show that using 30m DEM and land cover from the year 1994, 2004, 2012 and 2017, the average annual erosion was 6.61, 14.39, 11.04, 8.98 and 7.70 ton/hectare/year, respectively. This is categorized as hazard class I (very light), ranges from <15 ton/hectare/year. Similar to that of the 8m DEM, sub-watershed 6 exhibits the highest rate, peaked in year 1999. Yet, there are some variations in trend among the 7 sub-catchments. Sub-catchment 3, 4 and 6 show a downward trend through 2017, while other sub-catchments exhibit upward trend. This figure is similar to the 8m DEM.

Figure 6. Sub-watershed erosion rate with 90m DEM.

Figure 7. Erosion rates with variations in DEM resolution.
Table 4 and Figure 6 reveals that using 90m DEM resolution and land cover from 1994, 2004, 2012 and 2017, erosion rate was 3.91, 8.76, 6.71, 5.26 and 4.54 ton/ha/year, respectively. This is classified in hazard class I (very light), range from less than 15 tons/ha/year. However, the figure clearly shows that among the sub-watersheds, the trends are not the same. Sub-catchment 3, 4 and 6 show a downward trend through to 2017, while other sub-catchments exhibit upward trend.

Figure 7 describes that total erosion from 8m, 30m, and 90m DEM exhibits the same pattern, in that it peaked in 1999 and continued to decrease to 2017. It is very obvious that the finest resolution DEM of 8m results in highest erosion rate with the number of approximately 2.5 times and 5 times higher than that of the 30m DEM and 90m DEM, respectively. The most contributor of total erosion came from sub-watershed 6. In this catchment, almost 80 percent of the area are paddy farms and housing. The reason for the 1999 peak was the massive land conversion from farms into houses that significantly alter land cover type, and thus resulted land erosion. The MUSLE equation explicitly reveals that land use type greatly affect erosion rate. From 1999 onward, land conversion began to decline steadily.

These three DEM resolutions show a striking pattern, in that the higher the resolution, the higher the erosion rate (Figure 7). This finding agrees with [15] and [16]. Both studies recognized the effect of DEM resolution on finding topographic parameter better with finer resolution. [15] explained the mechanisms that by using finer resolution grids, more rills were defined and sediment erosion and deposition in rills were counted. The effect of DEM resolution was explained by [16] that in coarser DEM resolution, the accuracy of elevation and computation of soil erosion decreases.

4. Conclusions

Using the MUSLE method, the rate of erosion in the Batang Kuranji watershed was calculated using with DEM resolutions of 8m, 30m, and 90m, and land cover in 1994, 1999, 2004, 2012, and 2017 from Landsat 8 OLI. The study shows that the higher the DEM resolution, the higher the erosion rate calculation. The trend shows that the highest erosion occurred in 1999 due to extensive land conversion from paddy farms into houses. This study agrees with previous studies that highest DEM resolution results in higher erosion rate. However, the 8m resolution is not sufficient for calculation of erosion in relatively flat area, since at this resolution, some important topographic parameters such as drainage length and slope may be averaged by coarse DEM.

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