Assessment of LULC Change and Its Impact on Soil Erosion Using GIS and Revised Universal Soil Loss Equation Model

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Abstract. Land use is one of the vital factors in estimating soil erosion over an area. Significant changes in spatio-temporal land use distribution might lead to water runoff which causes soil erosion events. It is important to assess the soil erosion risk for hydropower reservoir as part of sediment management activities. This study aims to assess the impact of land use and land cover (LULC) changes on soil erosion risk at Chenderoh catchment in Perak. LULC distribution within the study area was mapped for 2008, 2010 and 2015 by using land use maps obtained from Department of Agriculture, Malaysia. The soil loss rate was measured using the Revised Universal Soil Loss Equation (RUSLE) utilizing spatial data of rainfall factor, soil erodibility, topographical factor, conservation factor, and support practice factor. Average soil loss was calculated according to sub-catchment of Chenderoh, and it is found that the soil loss trend marginally increases from year 2008 to 2015. Based on soil erosion risk map results, it is found that conversion of forest land to agriculture is the main contributor to soil loss, which might be due to land clearance and agriculture practice activities.

Keywords: LULC change, soil loss estimation, GIS, RUSLE

1. Introduction

Chenderoh hydropower is the oldest hydropower in Peninsular Malaysia, which was constructed in the 1920s during British administration. Hence, along with the increasing population and changes of local economic activities, utilization of land use and land cover (LULC) over the catchment area has changed. Changes of the LULC especially on the expansion of the agriculture land has driven the changes of LULC spatial distribution. Conversion of forest area to agriculture and urban land in a large scale area will consequently lead to soil erosion problems which trigger dangerous natural phenomena [1], water quality degradation [2] and reservoir sedimentation [3].

Soil erosion is a natural process mainly accelerated by factors of wind and water and involves three main processes, which are soil loosening, soil transport and deposition [4-5]. Several factors such as soil types, slope length and steepness are considered in evaluating the soil erosion rate by using the soil loss model. However, it is found that vital factors influencing the soil erosion rate are the rainfall and land use types [6]. Previous studies have highlighted LULC influence on sediment yield especially with soil disturbance from human activities and conversion of forest to agriculture [7-9].
Therefore, it is crucial to evaluate the LULC relation with soil loss due to its impact on soil erosion to help the authorities and power plant owner in monitoring, managing, and planning activities of the hydropower plant efficiently. Remote sensing and GIS has been widely adopted as a tool to estimate soil erosion using soil loss models such as USLE and RUSLE [10-12]. In the Revised Universal Soil Loss Equation (RUSLE), integration of RUSLE method with GIS helps in mapping the spatial distribution of erosion location and intensity. This study aims to assess LULC changes from year 2008 to 2015 to analyse soil erosion of past scenarios in Chenderoh catchment. The relation of the land use changes to soil erosion will be investigated to describe the impact of land use changes towards soil erosion problems, which may lead to sedimentation issues in hydropower plants.

2. Study Area

![Study area map](image)

Figure 1. Study area

Study area is located at Chenderoh hydropower catchment in Perak state. The coordinate of the Chenderoh dam is approximately at latitude 4°57’ 38” North and longitude 10° 58’ 38” East. Chenderoh Reservoir is approximately 50 km inland from the coast or 210 km upstream from Sg Perak river mouth. Chenderoh Dam commands 6,688 km2 which is about 46% of the Sg Perak Basin (15,000 km2), the second largest basin in Peninsular Malaysia. Based on land use map obtained from Deptment of Agriculture, Malaysia (DOA), main economic activities in Chenderoh catchment are oil palm and rubber plantation. Figure 1 shows the location map of the Chenderoh Reservoir catchment in Sungai Perak Hydroelectric Scheme.

3. Data and Methodology

Soil loss prediction for the study area was carried out using the RUSLE model. Five parameters influencing the soil loss prediction amount were used which comprises parameter of rainfall erosivity factor (R), soil erodibility factor (K), slope length and steepness factor (LS), land canopy cover factor (C) and conservation practice factor (P). All the input data was rasterized and resampled to 90 meter. List of the data used and data sources are described in Table 1 below. Land use data obtained from
DOA for year 2008, 2010 and 2015 were used to compute soil loss estimation in GIS environment to calculate erosion map for past scenarios. The land use data were used to describe the conservation practise and land cover of the study area (C and P factor). While, rainfall data from three rainfall stations available within the catchment area were used to describe the rainfall erosivity factor by interpolating the data in GIS-based software. SRTM data was also used in this study to determine the LS factor. Soil map and soil erodibility table acquired from DOA were used to derive K parameter during model set-up using GIS-based software. Computation of soil loss will be generated using equation (1).

\[ A = R \times K \times L \times S \times C \times P \]  

Where:
- \( A \): Soil loss in t/ha/yr
- \( R \): Rainfall erosivity factor, R-Factor
- \( K \): Soil erodibility factor, K-Factor
- \( L \) and \( S \): Topographic factor where L is the length and S is slope steepness
- \( C \): Crop management factor (represent the degree of soil erosion under crop cover compared to bare earth)
- \( P \): Conservation practice factor (represent mitigation and conservation measures taken compared to no measures taken)

Table 1. List of the data sets

| No. | Data Type          | Data Usage                                      | Sources                                      |
|-----|--------------------|------------------------------------------------|----------------------------------------------|
| 1.  | Soil Map           | Soil types distribution                         | Department of Agriculture, Malaysia (DOA)    |
| 2.  | Soil erodibility (K) | Soil properties and soil profile characteristics | Department of Agriculture, Malaysia (DOA)    |
| 3.  | Terrain (LS)       | Topographic map describing slope steepness and slope length | Shuttle Radar Terrain Mission (SRTM)        |
| 4.  | Rainfall (R)       | Monthly precipitation and mean annual rainfall  | Department of Irrigation and Drainage (DID) Malaysia and Tenaga National Berhad (TNB) |
| 5.  | Land use (C and P) | Crop management and practise support            | Department of Agriculture, Malaysia (DOA)    |

The overall methodology is described in Figure 2, explaining the four stages of methodology consist of data collection, derivation of parameter, GIS processing, and computation of soil loss and analysis.

4. Results and Discussion
The results comprise the LULC dynamic change from year 2008 to 2015 and soil erosion risk map using RUSLE in Chenderoh catchment.

4.1 LULC changes
Comparative assessment of Land Use change from 2008 to 2015 is shown in Table 1. All the land use listed from DOA were simplified to five main categories which are forest, agriculture, built up, water bodies and other area. Based on the result in Table 3, the forest area reduces about 2.5% respectively from 2008 to 2015. Meanwhile, land use changes result for agriculture area shows inconsistent changes. From 2008 to 2010 the agriculture area is reduce by 3.3%, while from 2010 to 2015, the area increase by 1.5%. In addition to that, the result also shows that built-up areas are not significantly
increased within seven years period with only 0.1% to 0.3% increment. Referring to satellite image, it is found that other land use area in Chenderoh catchment are including the sandy or cleared land area. From year 2008 to 2015, other land use area has increased by 1.9%. However, the number is reduced by 3.5% in 2015. Considering the comparison of land use 2008, 2010 and 2015, it seems to have no abrupt change in land use. Chenderoh Reservoir is also identified as part of the water bodies in 2008 land use. Land use change map from year 2008 to 2015 is shown in Figure 3.

Table 2. LULC area and percentage for year 2008, 2010 and 2015

| Category                              | LULC 2008 |   %  | LULC 2010 |   %  | LULC 2015 |   %  |
|---------------------------------------|-----------|------|-----------|------|-----------|------|
| Total Forest                          | 64847.85  | 66.50| 63982.04  | 63.90| 62425.0   | 64.00|
| Industrial plantation (rubber and oil palm) | 24803.79  | 25.44| 26595.44  | 27.30| 26596.0   | 27.30|
| Agriculture other than rubber and oil palm | 2946.17   | 3.20 | 2894.37   | 2.70 | 3107.1    | 3.20 |
| Total Agriculture                     | 27749.96  | 30.20| 29489.80  | 26.90| 29703.1   | 28.40|
| Total Built Up                        | 1548.97   | 1.20 | 1501.29   | 1.50 | 1605.7    | 1.60 |
| Total Water Bodies                    | 1578.39   | 0.10 | 2363.32   | 0.80 | 2326.9    | 1.60 |
| Total Other Area                      | 149.73    | 2.40 | 175.01    | 4.30 | 145.6     | 0.80 |
| GRAND TOTAL                           | 97,511    | 100.0| 97,511    | 100.0| 97,511    | 100.0|
4.2 Soil Erosion Analysis

RUSLE model was used to compute the soil erosion risk map. Soil erosion risk map was classified according to guideline from DOA as shown in Table 3. Red spot in the map represents very high soil erosion, while orange represents high soil erosion. Light green and dark green represent low and moderate soil erosion, while yellow colour in the map is moderately high erosion. The soil erosion risk map was constructed for the whole Chenderoh catchment and annual average soil loss rate in tan/ha/year unit was computed for each sub-catchment in Chenderoh catchment. Overall, there is a total of 19 sub-catchment in Chenderoh basin.

Table 3. Soil Erosion Rankings

| Ranking | Low  | Moderate | Moderately High | High  | Very High |
|---------|------|----------|-----------------|-------|-----------|
| Soil Erosion (t/ha/yr) | 0-10 | 10-50    | 50-100          | 100-150 | >150      |

Figure 4 shows the soil erosion map generated based on land use for the year 2008, range from nearly 0 up to 1606 ton/ha/year. Based on DOA soil loss classification (as in Table 3), it is noted that soil loss rate within Chenderoh Catchment is low risk because the average is less than 10 ton/ha/year. However, based on result in Table 3, certain sub-catchment has moderate erosion rate between 10 – 50 ton/ha/year. Sg Beng has the highest erosion rate of 15.97 ton/ha/year followed by Sg Nerok (14.6 ton/ha/year), Sg Tampan (12.77 ton/ha/year). Dominant land use within this area is industrial agriculture such as rubber and oil palm plantation that are located within close vicinity to the river banks. Sg Tampan and Sg Nerok are also located close to urbanised and residential areas.
Figure 4. Soil erosion risk map for year 2008

Figure 5. Soil erosion risk map for Chenderoh catchment in year 2010
Figure 5 shows the soil erosion map computed based on land use for the year 2010, range from nearly 0 up to 2985 ton/ha/year. There is an increase of soil loss rate as compared to 2008, contributed mainly by the conversion of forest to industrial agriculture such as rubber and oil palm from 2008 to 2010. Again, Sg Beng has the highest erosion rate of 15.5 ton/ha/year followed by Sg Nerok (14.85 to/ha/year), Sg Tampan (14.09 ton/ha/year) as presented in Table 3. Dominant land use within this area is industrial agriculture such as rubber and oil palm plantation that are located within close vicinity to the river banks. Sg Tampan and Sg Nerok are also located close to urbanised and residential areas.

Figure 6 shows the soil erosion map computed based on land use for the year 2015, range from nearly 0 up to 2990 ton/ha/year. There is a slight increase of soil loss rate as compared to 2010, contributed mainly by the conversion of forest to agriculture. Again, Sg Beng has the highest erosion rate of 15.85 ton/ha/year followed by Sg Nerok (15.3 to/ha/year), Sg Tampan (14.83 ton/ha/year). Dominant land use within this area is industrial agriculture such as rubber and oil palm plantation that are located within close vicinity to the river banks. Sg Tampan and Sg Nerok are also located close to urbanised and residential areas.

4.3 Discussion.
Soil loss estimation within Chenderoh sub-catchment shows a marginal increase from year 2008 to 2015. Although the average erosion rate is low (less than 10 ton/ha/year), certain sub-catchments show moderate soil loss especially for Sg Beng and Sg Chegar that is located within industrial plantation land use such as rubber and oil palm. Certain sub-catchment also show moderate soil loss rate for being located in an active urbanisation and commercials areas such as Sg Nerok and Sg Tampan. Based on soil erosion comparison chart in Figure 7, it is noted that sub-catchment of Sungai Karah, Sungai Kala, Sungai Bebalek have also recorded significant increase of soil erosion in 2015. Referring
to the land use change map, it is found that patches of high and very high soil erosion at that sub-
catchment were located at agriculture land use which is previously is forest area (Figure 8). Therefore,
it shows that the increase of soil loss rate might be driven by the land conversion from forest to
agriculture area, which is in line with previous finding by [13].

Table 4. Soil Erosion Result for Chenderoh Catchment based on Land use 2008, 2010 and 2015

| Sub-catchment | Area (km²) | Soil Loss From RUSLE |
|---------------|-----------|----------------------|
|               |           | 2008 Average (Tan/Ha/Year) | 2010 Average (Tan/Ha/Year) | 2015 Average (Tan/Ha/Year) |
| Sg Nerok      | 34.6      | 14.6                  | 14.85                  | 15.34                  |
| Sg Pauh       | 4.1       | 1.88                  | 1.76                   | 2.04                   |
| Sg Perah      | 61        | 9.68                  | 9.8                    | 9.57                   |
| Sg Satu       | 25.5      | 2.68                  | 2.5                    | 2.72                   |
| Sg Sawa       | 4         | 2.32                  | 2.15                   | 2.51                   |
| Sg Soh        | 49        | 7.55                  | 8.3                    | 8.84                   |
| Sg Tampan     | 20.6      | 12.77                 | 14.09                  | 14.83                  |
| Sg Temelong   | 151.7     | 10.72                 | 12.80                  | 13.16                  |
| Kg Lapit      | 9.4       | 1.42                  | 1.2                    | 1.4                    |
| Sg Ashar      | 4.7       | 4.56                  | 4.06                   | 6.84                   |
| Sg Bebalek    | 8.2       | 11.13                 | 10.06                  | 10.62                  |
| Sg Beng       | 63.5      | 15.97                 | 15.48                  | 15.85                  |
| Sg Chegar     | 67.4      | 11.61                 | 11.38                  | 12.08                  |
| Sg Chepor     | 31.4      | 3.07                  | 3.02                   | 3.06                   |
| Sg Gerus      | 7.2       | 0.34                  | 0.70                   | 0.75                   |
| Sg Kala       | 26.3      | 6.8                   | 7.79                   | 8.72                   |
| Sg Karah      | 21.8      | 5.35                  | 6.45                   | 6.03                   |
| Sg Kenering   | 342.1     | 6.21                  | 6.29                   | 7.18                   |
| Sg Luat       | 42.9      | 7.00                  | 6.96                   | 6.90                   |

5. Conclusion
Study reveals that soil erosion rate at the rural area with low built up density is still of low risk. However, it is shown that land use conversion of forest to agriculture and built up area has contributed to the increase of soil erosion risk due to human activities of land clearing and construction. Overall, result from this study shows that total soil loss from entire Chenderoh Subcatchment range from 818,164 ton/year to 910,625 ton/year. However, not all this eroded soil can be transferred to sediment, which requires detail analysis in the future to determine the sediment yield for comprehensive analysis.
Figure 7. Comparison of soil erosion rate from year 2008 to 2015 for Chenderoh sub-catchment

Figure 8. Comparison of soil erosion risk map (2015) with land use change map

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