Investigating the Impact of Land Use Change on Sediment Yield for Hydropower Reservoirs through GIS Application

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Abstract. Reservoir sedimentation is one of the most common lakes and reservoirs degradation. With land use change and more development in the catchment area, soil loss becomes more imminent causing more sediment yield into the reservoir. With this uprising trend, it is important to predict sediment yield using soil loss (RUSLE) and sediment delivery ratio (SDR). This modelling is simplified in GIS. This paper compiles prediction of sediment yield for reservoirs in Malaysia based on soil loss model (RUSLE) calculated in GIS for Cameron Highlands and Chenderoh (Perak). The analysis show that land use change increases sediment yield. Sediment yield rate for reservoirs in Cameron Highlands is higher than the sediment yield rate for Chenderoh.

Keywords: reservoir sedimentation, sediment yield, GIS, soil loss, reservoir, hydropower,

1. Introduction
Prediction of reservoir sedimentation rate is important for the reservoir operator and manager to develop the suitable sediment management plan. The sediment management strategies or plan must evolution of land use in catchment and its impact on hydrological process, erosion and sediment transport and water quality [1]. Reservoir sediment yield is best estimated using bathymetric survey, of which annual sediment yield rate is determined by calculating the storage differences based on interval of surveys [2-4]. However, the use of Universal Soil Loss Equation (USLE), Modified Revised Universal Soil Loss (MUSLE) and sediment delivery ratio (SDR) have gained interest as method for prediction of reservoir sediment inflow in many areas worldwide and in Malaysia, as studied in Bukit Merah [5], Bengoh in Sarawak [6], Cameron Highlands [7-8], Chenderoh and Kenyir [9]. As the rainfall distribution and land use activities change over the years, related parameters such as rainfall erosivity, land cover factor and erosion management factor are also altered. This allows investigation on the impact of land use change to soil loss and sediment yield to be calculated.

In the advancement of computer technology coupled and emergence of GPS technology and GIS-based software, computation of soil loss is made easier allowing spatial presentation of the results across the study area. Remote Sensing (RS) has been used to classify, identify and analyse land cover and land use changes with different techniques and data sets. Processing of satellite image and radar information enables identification and verification of the land use changes on spatial and temporal variability.
Application of RUSLE in GIS platform also allow for larger application of the results such as identification of high erosion risk area, scenario assessment and development of best management practice to reduce soil erosion. This research therefore discusses the method, calculation of sedimentation rate and identification of high sediment yield area for selected hydropower reservoirs in Ringlet (Cameron Highlands) and Chenderoh (Perak) based on change in land use map, using RUSLE method that is modelled in GIS.

2. Study area

Ringlet Reservoir is part of Cameron Highlands Batang Padang Hydroelectric Scheme, with main function for hydropower generation and flood control. The sub-catchments drain into the Ringlet Reservoir Upper Bertam, Lower Bertam, Habu, Ringlet, Middle Bertam, Telom, Kial - Kodol and Plau’ur. The catchment area in 183km$^2$, with 26% of the area is steeper than 25º. Dominant soil type for Cameron Highlands is steepland. Average annual rainfall is 2800mm. As of year 2015, major land use within the area is forest (71%), followed by agricultural activities (17%) and urbanised area (5%).

Chenderoh Reservoir is part of Sg Perak Hydroelectric Scheme located 20 km north of Kuala Kangsar. Chenderoh reservoir is the downstream most reservoir of the four cascading reservoirs straddled along Sg Perak. Chenderoh direct catchment is approximately 975 km$^2$ as delineated from Kenering Dam to Chenderoh Dam, comprising 19 major sub-catchments. Mean annual rainfall for the catchment is about 1,930 mm. The area is of flat undulating terrain, where 27% of the area is between 12º - 20º and only 12% of the area is steeper than 25º. Major soil type is steepland representing 69% of the area, followed by Rengam – Kala (RGM-KLA), Rengam – Bukit Temiang (RGM-BTG), Telemong-Akob-Local Alluvium (TMNG-ADB-LAA) and Chenian (CHN). Land use information from 2015 shows that forest dominates the catchment (64%), followed by industrial plantation such as rubber and oil palm (27.3%), built up (1.6%) and water bodies (1.6%). Residential area accounts for 25% of the total built-up area. Unlike Cameron Highlands, Chenderoh catchment is less steep and less developed. Figure 1 illustrates the location of Ringlet and Chenderoh Reservoir.

Figure 1. Study area: Chenderoh and Cameron Highlands
3. Methodology

Sediment yield defines the amount of sediment delivered from a catchment up to an outlet. As reservoir acts as a catchment outlet, sediment yield is used to predict reservoir sediment inflow rate. Soil loss in the reservoir’s catchment is calculated using universal soil loss formula (RUSLE), based on the rainfall intensity map, soil map, topography and land use map. Sediment yield is determined by multiplying the calculated soil loss with Sediment Delivery Ratio (SDR). There are many factors controlling SDR, mainly catchment area, slope length to relief ratio and drainage network. However, the most common SDR empirical formula relates sediment yield to size of catchment area as studied by [10-14]. Equations used in RUSLE and Sediment yield are shown below, where R represents rainfall factor, K denotes soil erodibility factor, LS denotes slope length and steepness factor and CP are land cover and support practice factors that depend on land use activities.

\[
A = RKLSCP \\
SY = A \times SDR
\]

Computation of R-factor requires high temporal rainfall resolution data with maximum of 30-minutes intensities for at least 20 years [15]. For Malaysia, rainfall erosivity factor is available from Manual for Saliran Mesra Alam 2nd Edition (MSMA 2nd Edition) [16] and it was derived from selected rainfall stations that record short duration rainfall in Peninsular Malaysia. For example, Cameron Highlands area is only represented by 1 rainfall station which might not sufficient to represent the entire area. Due to lack of this short interval rainfall data in Malaysia as well as many parts of the world, various simplified models have been proposed for estimating R-factor using precipitation either monthly or yearly data instead of intensity. That is why for this study, R-Factor is computed based on the formula by Bols [17] that utilises average annual rainfall, obtained from rainfall data available within the study area.

Soil erodibility, or K-factor depends mainly on the texture, structure, permeability and organic carbon content of the specified soil. It can be measured based on the soil data if a quantitative relationship between soil erodibility and soil properties has been established. For Malaysia, K-factor for 289 soil series has been determined by the Department of Agriculture Malaysia through experimental studies and observation [18] but there is lack of data for steepland soils. List of K-values used in this study is shown in Table 1 below. Length and steepness factor (LS-factor) represent the topographical variation of the catchment that affects sediment distribution and runoff characteristics along the path. In this study, the LS factor was estimated based on MSMA 2nd Edition [16].

**Table 1.** Soil erodibility factor (K-factor) used in this study.

| Soil type                              | K-factor |
|----------------------------------------|----------|
| Chenian                                | 0.0032   |
| Rengam-Bukit Temiang                   | 0.0025   |
| Rengam-Kala                            | 0.0018   |
| Serdang-Bungor-Munchong                | 0.0025   |
| Steepland                              | 0.11     |
| Telemong-Akob-Lanar Tempatan           | 0.0129   |
| Chenian                                | 0.0032   |

Crop Management factor, C-factor and Conservation practice, P Factor are determined based on MSMA 2nd Edition [16] in reference to land use map 2008, 2010 and 2015 produced by Department of Agriculture. Figure 2 and Figure 3 show the variation of factors used in RUSLE for Cameron Highlands and Chenderoh respectively.
4. Results and discussion

4.1. Land use change
Land use map for Cameron Highlands catchment are analysed and tabulated as shown in Table 2 below. It shows significant increase of bareland from 2006 to 2015, with marginal increase in forest cover and urban area. This would lead to substantial in soil loss as bareland has the highest C and P factor. Table 3 illustrates percentage land use change for Chenderoh catchment, which shows marginal increase of agricultural activities and built up areas. This would lead to marginal change in erosion rate and sediment yield.

Table 2. Percentage of land use change in Cameron Highlands.

| Land use       | 2006 | 2010 | 2015 |
|----------------|------|------|------|
| Bareland       | 0.4  | 0.1  | 5.0  |
| Urban          | 3.6  | 4.4  | 4.9  |
| Grassland      | 0.2  | 0.2  | 0.0  |
| Forest         | 62.5 | 65.0 | 71.5 |
| Orchard        | 18.6 | 23.7 | 17.1 |
| Scrub Forest   | 6.9  | 0.2  | 0.0  |
| Tea            | 7.3  | 6.0  | 1.1  |
| Water Body     | 0.5  | 0.4  | 0.4  |
Table 3. Percentage of land use change in Chenderoh catchment

| Category                                  | 2008  | 2010  | 2015  |
|-------------------------------------------|-------|-------|-------|
| Total Forest                              | 66.50 | 63.9  | 64.0  |
| Industrial Plantation                     | 25.44 | 27.3  | 27.3  |
| Agriculture other than rubber and oil palm| 3.2   | 2.7   | 3.2   |
| Total Agriculture                         | 30.2  | 26.9  | 28.4  |
| Total Built-up                            | 1.2   | 1.5   | 1.6   |
| Water bodies                              | 0.1   | 0.8   | 1.6   |
| Total Other area                          | 2.4   | 4.3   | 0.8   |

4.2. Soil loss and Sediment yield for Cameron Highlands

Using annual rainfall data from 2007 to 2017 and interpolation in GIS, rainfall erosivity in Cameron Highlands range from 730 to 870 MJ mm/ha/year, with K-factor of 0.0659. LS factor varies depending on the data used to generate Digital Elevation Model (DEM). Using topography map from Department of Survey and Mapping Malaysia (JUPEM), LS factor is calculated in the range of 0 to 2232. As modelled in GIS, soil loss for Cameron Highlands is on increasing trend based on land use map 2006, 2010 and 2015. Average soil loss increases dramatically from 30.9 ton/ha/year (in 2006) and 27.9 ton/ha/year (in 2010) to 86.4 ton/ha/year in 2015. This shows that average erosion rate in Cameron Highlands is moderately high (50 – 100 ton/ha/year) with certain area is extremely high erosion rate exceeding 150 ton/ha/year. This dramatic increase is mainly due to urbanisation land use activities that increase from 3.6% (in 2006) to 4.4% (in 2010) and 4.9% (in 2015), bareland area (0.4% in 2006 to 5% in 2015) and increase of agricultural activities 18.5% to 23.7 to 17.1% for year 2006, 2010 and 2015 respectively. To convert soil loss (ton/ha/year) to sediment yield (m³/year), soil loss rate is multiplied by SDR that range from 0.32 to 0.49 and conversion factor 1.62 ton/m³ sediment density. Results of soil loss and sediment yield in Cameron Highlands is shown in Table 4.

Table 4. Soil loss and sediment yield rate for Ringlet Reservoir Catchment, Cameron Highlands

| Sub-Catchment   | Area (km²) | SDR  | Soil Loss (tons/ha/yr) | Sediment yield (m³/yr) |
|-----------------|------------|------|------------------------|------------------------|
|                 |            |      | 2006  | 2010  | 2015 | 2006  | 2010  | 2015 |
| Upper Bertam    | 21         | 0.38 | 19    | 21.9  | 42.9 | 9,267 | 10,681| 20,937|
| Middle Bertam   | 13.4       | 0.40 | 34    | 27.5  | 197.7| 10,581| 8,558 | 65,298|
| Lower Bertam    | 4.3        | 0.46 | 15    | 36    | 6.1  | 1,498 | 3,595 | 747   |
| Habu            | 19.1       | 0.38 | 44    | 20.3  | 415.1| 19,518| 9,005 | 186,442|
| Ringlet         | 9.7        | 0.42 | 86    | 80.6  | 17.7 | 19,374| 18,157| 4,423 |
| Reservoir       | 2.8        | 0.49 | 12    | 6.4   | 57.3 | 780   | 416   | 4,865 |
| Plau’ur         | 9.7        | 0.42 | 5.2   | 2.4   | 3.9  | 1,171 | 541   | 970   |
| Kial and Kodol  | 22.8       | 0.46 | 46    | 46.3  | 24.9 | 24,358| 24,517| 16,056|
| Telom           | 77.8       | 0.32 | 24    | 23    | 40.6 | 43,364| 41,558| 61,799|
Prior to developing any sedimentation strategies for any reservoir, it is important to determine its sedimentation rate. The most common method that offers highest accuracy is using bathymetry survey, or hydrographic survey which utilises sonar for underwater and topographic or on-land survey along the reservoir perimeter. However, estimated sedimentation rate is related to sediment yield, which is calculated from the potential soil loss in the catchment drains into the reservoir. Using GIS, soil loss rate in Cameron Highlands range from moderate to extremely high while for rate for Chenderoh

4.3. Soil loss and Sediment yield for Chenderoh
Using annual rainfall records in Chenderoh direct catchment, R-factor range from 700 to 800 MJ mm/ha/year. Soil erodibility factor ranges from 0.0018 to 0.11 where the maximum K-factor represents steepland. Maximum LS factor is 1683 while maximum CP factor is up to 0.4 based on the land use map. From the RUSLE model, average erosion rate in Chenderoh range from 9.64 to 11.45 ton/ha/year, without too significant increase from 2008 to 2015. This is categorised as low erosion risk as per DoA classification. Sg Beng has the highest erosion rate followed by Sg Nerok and Sg Tampan. Industrial agriculture such as rubber and oil palm plantation that are located within close vicinity to the river banks might have contributed to higher erosion rate while Sg Tampan and Sg Nerok are also closer to urbanised and residential areas. Table 5 summarises the results of soil loss and sediment yield for Chenderoh, while Figure 4 shows comparison of sediment yield and soil loss rate for each sub-catchments in Chenderoh.

From the analysis, it is clear that sediment yield has increased at both catchment areas, but more significant increase is recorded in Cameron Highlands. This leads to increase of sediment load into both Ringlet and Chenderoh Reservoirs, although more prominent increase is observed in Ringlet, Cameron Highlands. Total sediment yield that Ringlet Reservoir increased from 129,911 m³/year to 361,537 m³/year based on land use of year 2006, 2010 and 2015 while sediment yield at Chenderoh Reservoir range from 268,342 m³/year to 297, 200 m³/year based on land use map from 2008, 2010 and 2015.

5. Conclusion
Prior to developing any sedimentation strategies for any reservoir, it is important to determine its sedimentation rate. The most common method that offers highest accuracy is using bathymetry survey, or hydrographic survey which utilises sonar for underwater and topographic or on-land survey along the reservoir perimeter. However, estimated sedimentation rate is related to sediment yield, which is calculated from the potential soil loss in the catchment drains into the reservoir. Using GIS, soil loss rate in Cameron Highlands range from moderate to extremely high while for rate for Chenderoh

### Table 5. Soil loss and sediment yield rate for Chenderoh Reservoir Catchment, Perak

| Sub-catchment | Area (km²) | SDR | Average Soil Loss From RUSLE (ton/ha/year) | Sediment Yield (m³/year) |
|---------------|------------|-----|------------------------------------------|--------------------------|
|               |            |     | 2015 | 2010 | 2008 | 2015 | 2010 | 2008 |
| Sg Nerok      | 34.6       | 0.38 | 20.03 | 19.42 | 19.01 | 17,368 | 16,839 | 16,484 |
| Sg Pauh       | 4.1        | 0.51 | 2.81  | 2.43  | 2.59  | 391   | 338   | 360   |
| Sg Perah      | 61.0       | 0.35 | 12.19 | 12.43 | 12.26 | 17,194 | 17,533 | 17,293 |
| Sg Satu       | 25.5       | 0.39 | 3.54  | 3.25  | 3.49  | 2,362  | 2,169  | 2,329  |
| Sg Sawa       | 4.0        | 0.51 | 2.94  | 2.52  | 2.73  | 400   | 343   | 372   |
| Sg Soh        | 49.0       | 0.36 | 11.19 | 10.54 | 9.63  | 13,079 | 12,319 | 11,256 |
| Sg Tampan     | 20.6       | 0.40 | 18.33 | 17.45 | 15.87 | 10,186 | 9,697  | 8,819  |
| Sg Temelang   | 151.7      | 0.30 | 19.53 | 19.03 | 15.97 | 60,200 | 58,658 | 49,226 |
| Kg Lapit      | 9.4        | 0.45 | 1.8   | 1.54  | 1.82  | 510   | 436   | 516   |
| Sg Ashar      | 4.7        | 0.50 | 7.1   | 4.22  | 4.73  | 1,110  | 660   | 740   |
| Sg Bebalek    | 8.2        | 0.46 | 14.41 | 13.73 | 15.07 | 3,633  | 3,461  | 3,799  |
| Sg Beng       | 63.5       | 0.34 | 17.79 | 17.37 | 17.91 | 25,973 | 25,360 | 26,148 |
| Sg Chegar     | 67.4       | 0.34 | 14.55 | 13.72 | 13.98 | 22,358 | 21,082 | 21,482 |
| Sg Chepor     | 31.4       | 0.38 | 4.01  | 3.96  | 4.02  | 3,199  | 3,159  | 3,207  |
| Sg Gerus      | 7.2        | 0.47 | 1.01  | 0.95  | 0.47  | 228   | 214   | 106   |
| Sg Kala       | 26.3       | 0.39 | 11.54 | 10.33 | 9.05  | 7,908  | 7,079  | 6,167  |
| Sg Karah      | 21.8       | 0.40 | 6.86  | 7.19  | 6.05  | 4,002  | 4,194  | 3,529  |
| Sg Kenering   | 342.1      | 0.27 | 15.78 | 13.98 | 14.05 | 97,734 | 86,586 | 87,019 |
| Sg Luat       | 42.9       | 0.36 | 8.98  | 9.05  | 9.1   | 9,364  | 9,437  | 9,490  |

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catchment is still relatively low. Sedimentation rate calculated from soil loss and SDR for Ringlet Reservoir is on drastic increment, ranging from 129,911 m$^3$/year to 361,537 m$^3$/year due to significant land use change from 2006 to 2015. However, marginal increase in land use change in Chenderoh catchments has resulted in marginal increase of sediment yield from 268,342 m$^3$/year to 297,200 m$^3$/year, based on land use 2008 to 2015.

Figure 4. Sediment yield and soil loss rate according to sub-catchment in Chenderoh.
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