Recent Trends in Civil Engineering and Built Environment Vol. 3 No. 1 (2022) 872-883

RTCEBE

Homepage: http://publisher.uthm.edu.my/periodicals/index.php/rtcebe
e-ISSN :2773-5184

Application of HEC-RAS to Estimate the Sediment Transport in Cameron Highlands, Pahang, Malaysia

Dahlia Mohamad Noor[1], Siti Hidayah Abu Talib[1]*

[1]Department of Civil Engineering, Faculty of Civil Engineering and Built Environment,
Universiti Tun Hussein Onn Malaysia, Batu Pahat, 86400, MALAYSIA

*Corresponding Author Designation

DOI: https://doi.org/10.30880/rtcebe.2022.03.01.101
Received 4 July 2021; Accepted 13 December 2021; Available online 15 July 2022

Abstract: Sediment deposition which involved the sediment transport is a key factor in limiting the river development and management, affecting in river morphology and river channel stability. Rivers in Cameron Highlands, Pahang are subjected to rapid deforestation and construction development that bring high impact on the process of sediment transport, becoming the main cause for serious flooding in areas. This study was carried out to simulate the sediment transport concentration at Sg. Bertam, Cameron Highlands by using one-dimensional (1D) quasi-unsteady flow HEC-RAS. Some information such as hydrological data, geometric data and sediment data are needed to run the simulation. The analysis is done by using Laursen-Copeland method as it performs in the very fine sand and very coarse silt range. The result shows the location of erosion and deposition occurs. The maximum depth of erosion in these reaches is about -0.773 m which happens in STN 1537 river stations and the maximum deposition is about 0.794 m in downstream STN 636 reach of the river having wide cross section. It is seen that Sg. Bertam experiences sequentially both erosion and deposition. It shows that these sediments are in continuous, downstream transport and have led to shallowing of the channel. The maximum sediment concentration along Sg. Bertam is obtained to be 54008.60 mg/L. HEC-RAS results indicate that the Sg. Bertam has majorly experienced sedimentation and the bed level increase has been widely observed during the simulation period.

Keywords: Sediment, Sediment Transport, Sediment Deposition, Erosion, Cameron Highlands, HEC-RAS

1. Introduction

Rivers are one of the strong agents of erosion that move material out of their beds and banks. Rivers can move a wide range of sediment sizes from clay-sized particles to large boulders. Sediment is anything carried by a stream of water and settles under it such as loose sand, clay, silt, and other soil [1]. The movement of organic and inorganic particles through water is referred to as sediment

*Corresponding author: hidayaht@uthm.edu.my

transport [2]. The sediment transported may include mineral matter, chemicals, pollutants and organic materials. A multitude of variables impacts sediment movement, including river flow, harsh weather, water level and human activity. When the velocity of water increases, therefore the larger the particle size that may be moved. This is often the reason why the beds of fast-moving shallow streams are relatively clear of sediment with only large rocks or boulders, while those in slow-moving streams have more sediment.

There are three types of sediment loads. Bedload is when sediment goes down the riverbed's rock bottom by rolling, sliding, or bouncing when the power of the water flow force overcomes the load and cohesiveness of the sediment. Other than that, suspended sediment is particles contained in the column of water. It is either a flow of water or it is not. Moving water is required for suspended loads because it causes turbulence, which creates tiny upward currents that carry the particles above the bed. The finest suspended sediment, on the other hand, is the wash. These particles remain suspended indefinitely because they are small enough to bounce off water molecules and maintain a floating load, and they will not sink to the bottom of a channel during periods of little to no flow. Based on Figure 1, the sediment transport classes are illustrated.

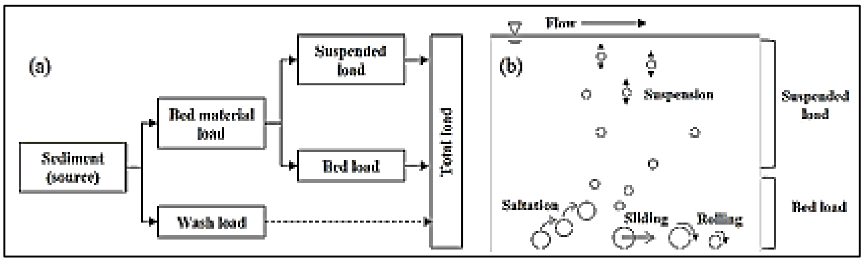

Figure 1: Classification of Sediment Transport [3]

According to Roozitalab et al [4], highland regions operate and function as the primary source of lowland hydropower as well as deliver water downstream for agricultural, industrial, and residential uses. Any forest area that is 1000 meters above sea level is categorized by Malaysia Islands and Highlands Development Guideline as limited forest or catchment forest land. Cameron Highlands is Pahang's smallest district, bordered to the north by Kelantan, to the west by Perak, and the south by the Kuala Lipis district illustrated in Figure 2. Hulu Telom (63, 990 ha), Ringlet (5, 165 ha), and Tanah Rata (2070 ha) are the three primary sub-districts of Cameron Highlands, which cover a total area of 71, 225 hectares [5]. In the centre high altitude of the Titiwangsa Range, Cameron Highlands where Gunung Brinchang is the highest point totaling is one of Malaysia's most popular getaway spots. The Cameron Highlands catchment, which covers 183 km², provides water to the Ringlet Reservoir and is divided into many sub-catchments. Cameron Highlands basin's largest rivers, Sg. Bertam and Sg. Telom flows east into the Sg. Pahang and into the South China Sea on the Malaysian Peninsula's eastern coast [5].

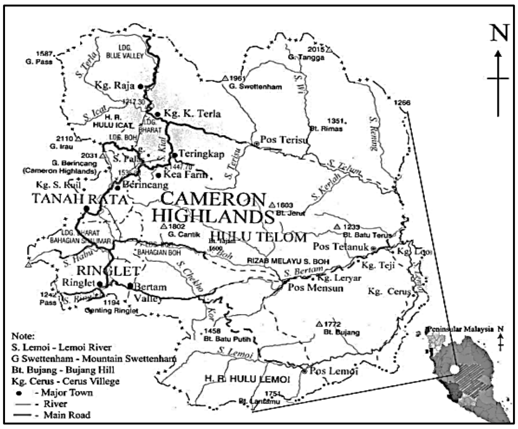

Figure 2: Map of Cameron Highlands, Pahang [6]

Sediment transport concerns are also connected to rivers in the Cameron Highlands as there is much sedimentation that is caused by the transport of sediments. Rapid land development and human activities in the Cameron Highlands have led to extreme soil degradation for years, causing the runoff to move at a fast rate. The high runoff moves together along with the sediment load that comes from the upland activities. The more the land area used, the higher the rate of runoff, so the higher the number of sediments will be transported to the catchment area. This will cause sediment loads from several rivers to increase rapidly. And therefore, this is the reason of this study was to simulate the sediment transport concentration in Cameron Highlands river by using HEC-RAS. This study also was to determine the flow characteristics of Cameron Highlands river. Excess water in the Lake Ringlet reaches the level of danger faster than expected, especially in the event of downpours. This issue of sedimentation will result in flooding and indeed cause extensive damage and inconvenience to the Cameron Highlands community.

This research attempts to find out how much sediment flows into the Cameron Highlands and what it is composed of. To choose the best model, it is important to choose one that has less comprehensive input data and has sufficiently precise performance. The HEC-RAS program is an excellent choice for one-dimensional (1D) quasi unsteady flow since it fits all the requirements and has been widely utilized in numerous hydrological investigations. HEC-RAS is a single-dimensional tool commonly used to analyze stream reaches [7]. HEC-RAS is commonly utilized in a variety of water management groups to evaluate dam failure evaluations in controlled catchments around the country. HEC-RAS is used in various studies on river simulation, including steady, unsteady, and mixed flow patterns [8]. According to Halgren [9], HEC-RAS also allows river forecasters to recreate river reaches for daily flow predictions by utilizing the recorded data. Even if we assume that the software has been used to evaluate dam collapses, map floods, do flood frequency studies, and simulate day-to-day outflows, the software is highly applicable in a wide variety of disciplines. Thus, HEC-RAS model is widely used and tested for years, thus, the model's validity and limits are well known.

2. Methodology

To explore Cameron Highlands' sediment transport and sediment characteristics in the catchment region, a research project was done to select the most suitable method to simulate sediment transport and evaluate the features of sediment that is transported within the catchment area. The simulation was conducted using the HEC-RAS mapping programs created by the United States Army Corps of Engineers (USACE). Figure 3 shows the flow chart of the research methodology.

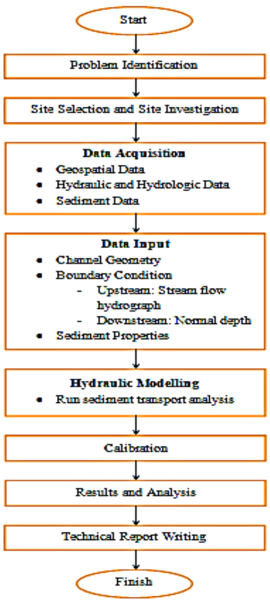

Figure 3: Flowchart of Methodology Research

2.1 Study Area

The study area for this project was located in the district of Pahang, in Sg. Bertam, Cameron Highlands. The length of the stream is about 20 km. The estimated terrain elevation above sea level is approximately 1829 m. The shape of the stream is irregular along the river. The entire area for the river basin of Sg. Bertam is 71,218 ha [10]. Sg. Bertam is divided here into two upstream parts (STN 1041) reach and downstream (STN 39) reach. Figure 4 below shows the river basin of Sg. Bertam, Cameron Highlands, Pahang.

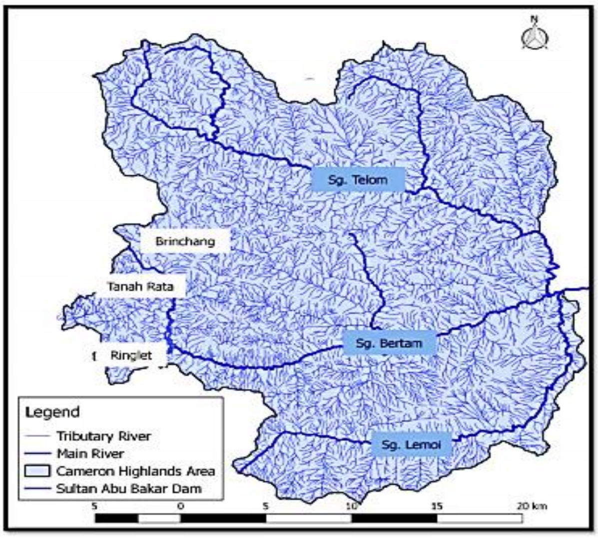

Figure 4: River Basin of Sg. Bertam, Cameron Highlands [11]

Due to its cool weather and spectacular scenery, the area is a popular tourist attraction and an active highland agricultural area. Cameron Highlands has an average annual precipitation of around 2,800 mm and average monthly precipitation of 150 to 250 mm [12].

2.2 Data Acquisition

In this study, the data from year 2014 is collected through secondary data. Secondary data is the data that has already been collected from other trusted organizations which helps to gather information for the proposed thesis. It is a type of data that has already been collected in the past. A few secondary data are required to model the sediment transport by using HEC-RAS which are geospatial data, hydraulic and hydrologic data and sediment data. The United States Geological Survey (USGS) and the Department of Irrigation and Drainage (DID) provide all of the data. To replicate the sediment transport, the starting condition and transport parameters must be identified.

2.3 Development of HEC-RAS mapping software

HEC-RAS is applied in this study to operate the hydraulics calculations of the one-dimensional Cameron Highlands sediment transport model. To efficiently replicate the examination of sediment data for a specified river stretch, the model requires precise input data and it is capable of calculating water surface profiles using geometric data for 1D flow consideration. A high-precision hydraulic model, HEC-RAS is then used to simulate the current discharge and sediment transport analysis of sediment supply. The geometry data, flow data, and sediment data are the key parameters for the HEC-RAS hydraulic model, as illustrated in Figure 5.

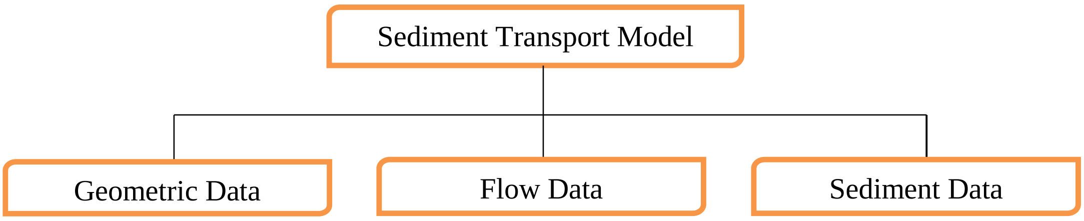

Figure 5: Flowchart of data required for sediment modeling in HEC-RAS

Geometry data is a basic input. The topography of this geometric data are illustrated in Figure 7, defined by using the Digital Elevation Model (DEM) in Arc-GIS 10.8 with the help of Geo-RAS; an extension of Arc-GIS developed with the Hydrologic Engineering Center (HEC) and used to obtain the river alignment, banks location, flow path and cross-section in the GIS environment. The United States Geological Survey (USGS) National Map Viewer is used to download a DEM of 1/3 arc-second resolution, which defines the elevation of every particular point in a region at a certain resolution.

DEM is useful to develop geometric data including cross-sections, reach lengths and bank locations that are imported from Arc-GIS to HEC-RAS. This shape file as shown in Figure 6 is in the form of a TIFF file which is then converted into a GIS file in order to be read and utilized by the HEC-RAS. The geometric data in this study consists of cross-sections between the river downstream (STN 39) and the upstream of Sg. Bertam (STN 1041). Cross sections to be ordered within a reach from the highest river station upstream to the lowest river station downstream.

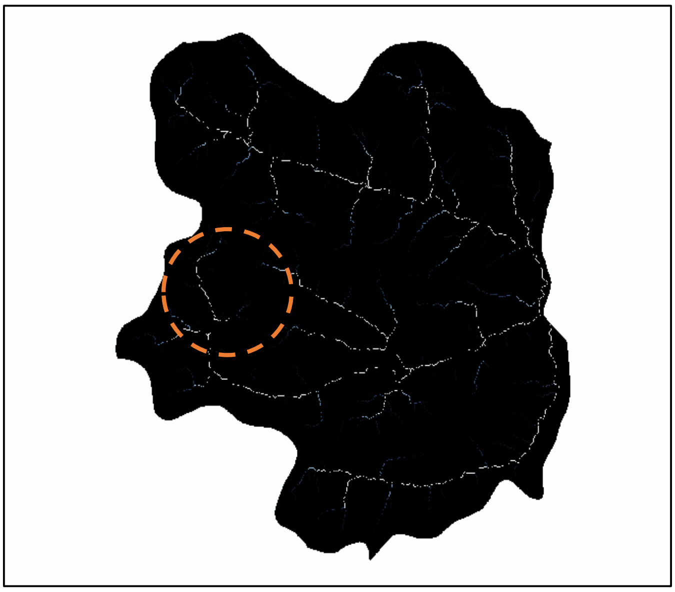

Figure 6: DEM of Cameron Highlands in Raster format

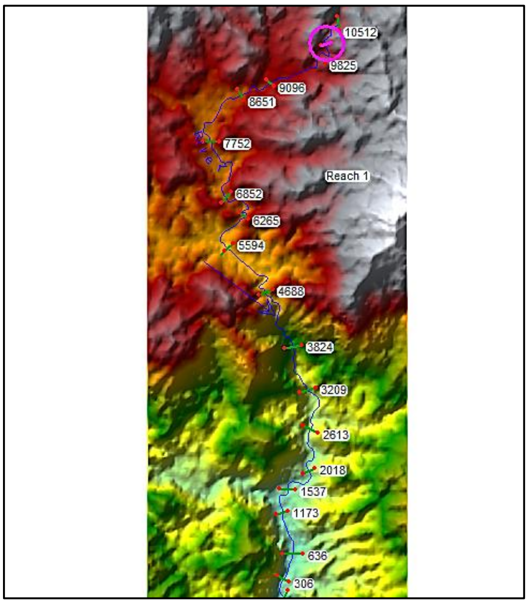

Figure 7: Plan view of Sg. Bertam in GIS Format

Manning's value should be introduced for each cross-section of the river and banks separately. So in this study, Manning's n value is considered 0.035 for the river as per the guidance modeling of the Urban Stormwater Management Manual for Malaysia (MSMA).

A time series of flow data is required to simulate the sediment model for quasi-unsteady flow. The long term flow data available from the previous study was used. The flow data is upstream and downstream boundary conditions. In this study, a normal depth was selected for downstream boundary condition. The input flow hydrograph is from January 2014 to December 2014; that is the model simulation period used was from 1 January 2014 to 31 December 2014. STN 10411 is the upstream boundary and STN 39 is the downstream boundary of Sg. Bertam. The flow data is given as below in Figure 9 while Figure 10 shows the inflow hydrograph used for the sediment transport modeling of Sg. Bertam. The peak discharge took place in November with a value of 71.58 cum/sec.

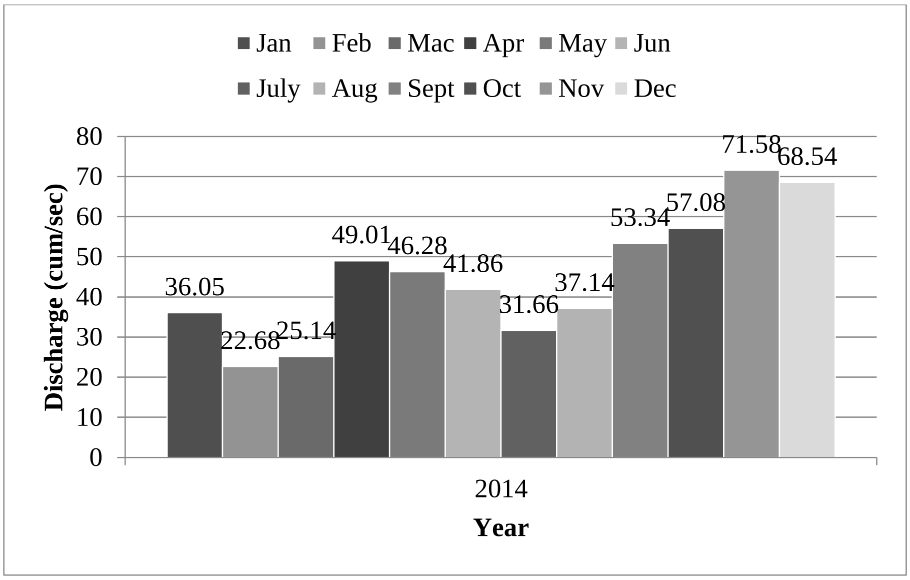

Figure 9: Flow Data for Sg. Bertam throughout the Year 2014

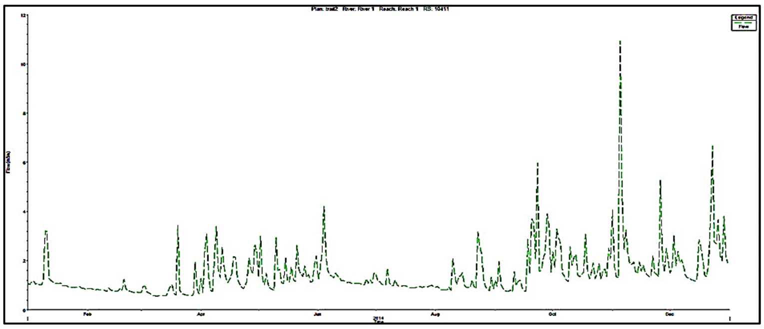

Figure 10: Inflow Hydrograph Used for the Sediment Transport Modelling of Sg. Bertam

Sediment data consist of river bed gradation transport function and sediment boundary condition. The sizes of sediment particles are critical in the processes of erosion and sedimentation. In a separate bed, each cross-section should have a gradation curve. The default sediment features for sand, silt, and gravel are determined in this study. The cross-sections having statistical data of gradation for river reach from upstream to downstream have been used and the interpolation has been used to generate data for cross-sections that do not have data. For sediment modeling, the equilibrium sediment boundary condition was used. Figure 11 and Table 1 show the bed gradation data that was used in this study. The Laursen-Copeland equation was employed in the study to simulate the sediment transport mechanism. After all of the required computational limits and inputs were set, the HEC-RAS model simulations were conducted using a sediment analysis module.

Table 1: Bed Gradation Data

No.	Class	Diameter (mm)	Percentage of Finer (%)
1	Clay	0.004	0
2	VFM	0.008	0.01
3	FM	0.016	0.02
4	MM	0.032	0.03
5	CM	0.0625	0.07
6	VFS	0.125	0.15
7	FS	0.25	0.81
8	MS	0.5	4.68
9	CS	1	56.12
10	VCS	2	92.69
11	VFG	4	99
12	FG	8	99.5
13	MG	16	100

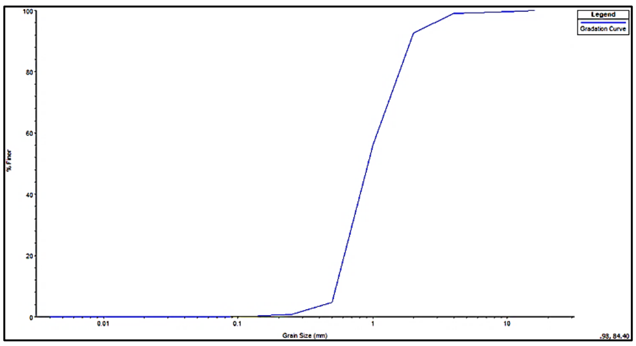

Figure 11: Bed Gradations of Sg. Bertam

3. Results and Discussion

There are many advantages in using DEM data to generate river geometry. One of them is the time saved in preparing river geometry data, and the fact that the coordinates of the river cross section can be more accurate based on the river condition. However, the quality of river cross-section shapes is very dependent on the resolution of the DEM data used.

The quasi-unsteady flow has been carried for given geometric data and flow data of the river for sedimentation study in the HEC-RAS model. In this study, a sample area of 11 km from Sg. Bertam was studied. To do so, the geometric data, sedimentation and flow data in year 2014 were studied. Accordingly, the geometric data related to 31 river stations were gathered and introduced to the model. The study reach starts at upstream side (STN 1041) to (STN 39) which represents the downstream of the river reach. To calibrate the model, the flow discharge data and Manning's roughness coefficient, 0.035 were provided.

In this software, a well-known equation is used to determine the total sedimentation concentration. To calibrate the sedimentation model, sediment transport and fall velocity equations were analyzed in the software. The results showed the among sediment transport and fall velocity equations, Laursen-Copeland equation was most consistent with the conditions of the area. It was selected to model this reach because of the dominance of very fine sand and coarse silt as well as the occurrence of gravel.

After calibration of flow and sediment, the model was used to simulate the flow sedimentation. Predicted change in bed level, the maximum change in elevation and other effects are observed which are mentioned in graphical form. The HEC-RAS model for sedimentation gives a piece of detailed information on erosion or deposition of each cross-section, river invert and water surface elevation, flow, velocity, shear stresses and mass changes.

The invert of a river is a vital criterion in geometry of the river cross-section for determining the possibility of erosion or deposition. It undergoes changes throughout the time affected from river phenomena. The HEC-RAS model has the capability of drawing the spatial plot for many hydraulic characteristics like velocity, water surface elevation and shear stress for all cross-sections. If the invert change is lesser than the initial bed level, then deposition takes place in that particular cross section and vice versa. Figure 12 shows the longitudinal invert of the reach at the start and the end of the period from 1 January 2014 to 31 December 2014 relative to the average yearly flow rate as shown in Figure 9. The invert change in the model was produced using Laursen-Copeland sediment transport function, the difference between invert change in each cross-section and initial bed level will determine the sedimentation. Channel profiles (elevation vs. distance plots) depict slope trends on a river system. Results shows significant changes in the longitudinal profile of the Sg. Bertam where the upstream (STN 4000 m-10000 m) reach half of the river has more slope than the downstream half-length (STN 0 m-4000 m) reach. For this reason may cause serious erosions in the upstream half-length and sedimentation in the downstream length of the river.

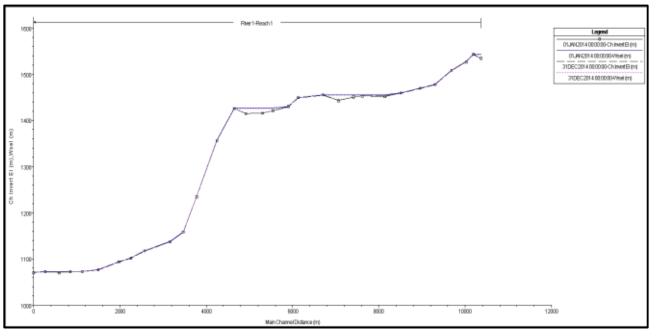

Figure 12: Longitudinal Surface Water Profiles along Sg. Bertam

Figure 13 illustrates the variation of velocity along the length of Sg. Bertam. The velocity distributions show the flow characteristic along Sg. Bertam. There is a large fluctuation in velocity along the considered reach of the channel. The minimum velocity is very small in some sections where the water depth is more and has a wide surface area. The maximum velocity observed is 1.7199 m/sec where it may contribute to major impacts on the Sg. Bertam due to possible changes to the slope of the channel, increase in the power of flows and mobilization of sediment. The increased amount of flow velocity being conveyed by Sg. Bertam may cause further erosion of the banks or bed, resulting sedimentation in the downstream.

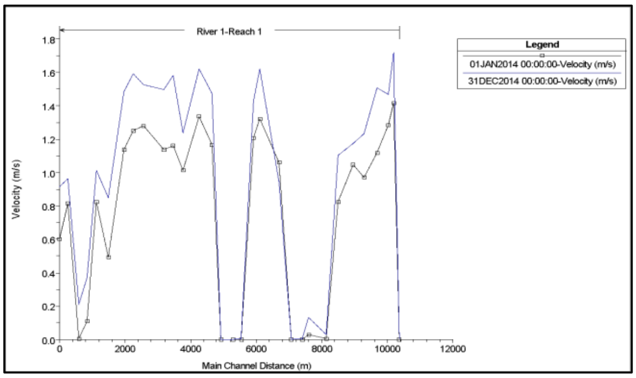

Figure 13: Flow Characteristic along Sg. Bertam

Shear stresses are the frictional force that acts against gravity action and they are directly proportional to a specific weight of water, hydraulic radius and slope of the channel. Variation of shear stress given in Figure 14 along the river stream indicates that there are almost shear stresses in both downstream and upstream. However, in upstream reach, shear stresses are more and fluctuating. Variation of shear stress along Sg. Bertam may be due to variation of bed slope. The maximum shear stress is 5.219 Pa while the minimum stress is 0.110 Pa. As the illustration in Figure 14, the maximum shear stress in upstream reach gives the idea that Sg. Bertam upstream flow through a rocky, steep-sided and narrow valley. The strength of bank materials is probably too low to resist gravity forces, or they may be unstable and cause high friction losses, which leads to severe erosion problems.

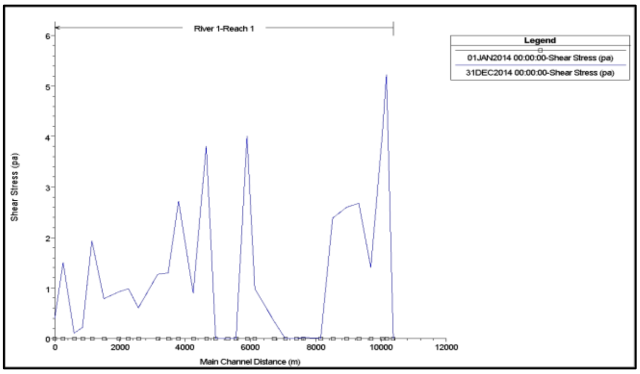

Figure 14: Shear Stress Variations along Sg. Bertam

Mass bed change cumulative is cumulative mass of the change in the bed elevation over time. The variation in mass changes in both positive and negative (sedimentation and erosion) direction along Sg. Bertam in Figure 15 exhibits irregular happenings of both erosion and deposition processes. In the middle, there is no erosion or deposition between the STN 4400 m to STN 5200 m reach and also between the STN 6800 m to STN 7600 m reach. The highest erosion and deposition are observed around STN 400 m to STN 1600 m reach. Although bank erosion happens naturally over time, human activities can accelerate this process due to changes in land use such as urbanization, logging or agricultural purposes. These activities usually lead to an increase in runoff and sediment formation in a natural condition. Removal of trees or bushes from stream banks and adjacent areas often triggers or accelerates the river bank erosion.

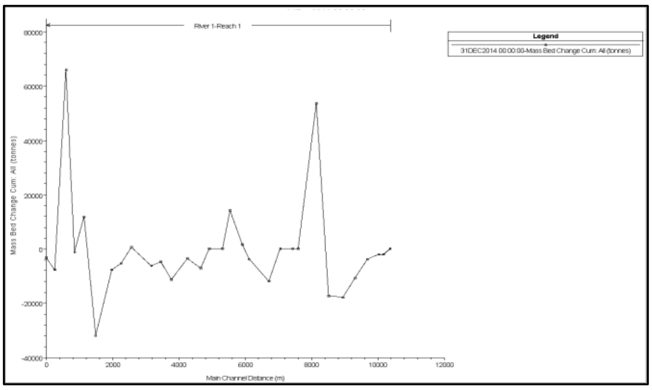

Figure 15: Mass Changes along Sg. Bertam

The magnitude of bed level changes in Sg. Bertam is illustrated in Figure 16 which is in the form of positive and negative values, where the positive numbers show the sediments deposition and the negative numbers display the transported or eroded sediments. The intermediate occurrences of erosion and sedimentation are observed in all parts of the river. The maximum depth of erosion in these reaches is about -0.773 m which happens in STN 1537 m and the maximum deposition is about 0.794 m in downstream STN 636 m reach of the river having a wide cross-section. It is seen that Sg. Bertam experiences sequentially both erosion and deposition. The deposited sediments show variable textures that are dependent upon location, though sands and gravels are found along the Sg. Bertam. It shows that these sediments are in continuous, downstream transport and have led to shallowing of the channel.

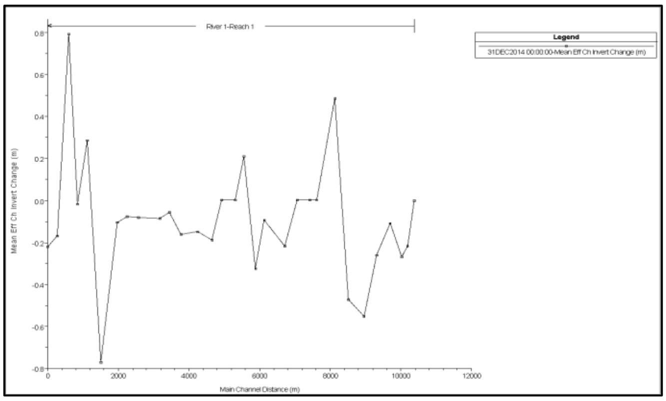

Figure 16: Bed Level Changes along the Modeled Length of Sg. Bertam

Figure 17 presents the trend of the cumulative bed volume change over the simulation period. The pattern of cumulative volume change of individual particle size distribution along Sg. Bertam is illustrated by the dense curves at the bottom of the plot. The model shows the dominance of particle sizes ranging from very fine silt (VFM-0.008 mm) to medium gravel (MG-16 mm) along the stretch of STN 0 m to STN 10000 m. The result shows there are occurrence of deposition and erosion. The bed degradation that leads to over steepening the banks and subsequent erosion to be happened is high. The type and percentage of soil which are sand and gravel may cause the erosion.

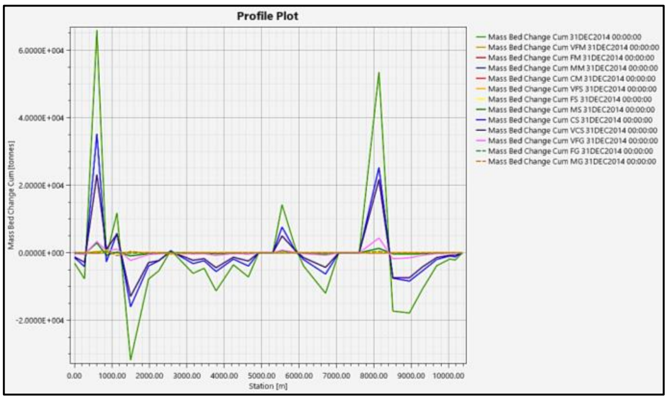

Figure 17: Individual Particle Size Gradation's Cumulative Bed Volume Change Distribution along Sg. Bertam

Sediment concentration is the total sediment concentration in mg/L leaving of the sediment control volume at the end of the computational time step. This parameter is computed from the Mass Out and Flow results. The river transported sediments in the form of dissolved suspended load, saltation, wash and bed load. Suspended sediments are part of the clastic load that flows via channels in the water column. The channel bed's upward turbulent flow, in particular, keeps silt and sand suspended. The maximum concentration of sediment along Sg. Bertam is obtained to be 54008.60 mg/L. The variation suspended load concentration along Sg. Bertam is given in Figure 18. The concentration of sediment determines its transportability via surface runoff.

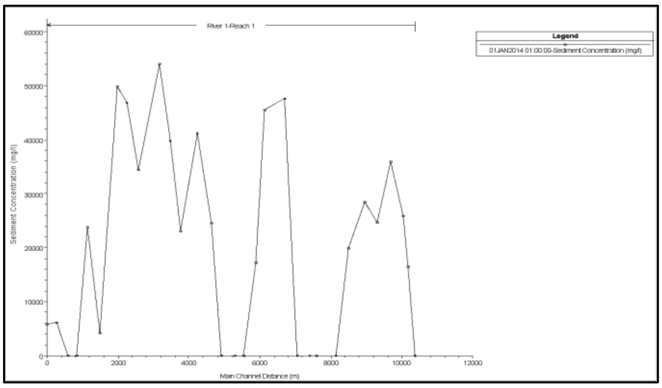

Figure 18: Sediment Concentrations along Sg. Bertam

4. Conclusion

Cameron Highlands has a peak elevation of almost 2000 m and is surrounded by busy agricultural and tourism activity. During the catchment area's strong semi-annual rainy season, the average yearly rainfall is 2800 mm. The amount of soil erosion in the region has increased and is becoming a serious issue, resulting in Ringlet Reservoir's excess sedimentation, which impacts the reservoir's storage and longevity. The approach was the use of ArcGIS together with HEC-GeoRAS to draw the river and extract cross-sections from a DEM of the river. HEC-RAS was then used to simulate the river quasi-unsteady flow modelling and sediment transport mobile bed computations. From 1 January 2014 to 31 January 2014, the sediment simulation model for Sg Bertam was created. One of the limitations is upstream of Sg. Bertam cannot be defined well when drawing river geometry in ArcGIS. The major findings of this study are:

- Results showed that Sg. Bertam experiences erosion in upstream half-length (STN 4000 m-10000 m) and the sedimentation happens in downstream half-length (STN 0-4000 m) reach.

- The velocity distributions show the flow characteristic where there is a large fluctuation in velocity along the considered reach of the channel. The maximum velocity observed is 1.7199 m/sec and the minimum velocity is very small in some sections where the water depth is more and has a wide surface area.
- Through the reach, the sediment distribution is non-uniform and the maximum sediment concentration along Sg. Bertam is obtained to be 54008.60 mg/L.
- HEC-RAS results indicate that the Sg. Bertam has majorly experienced sedimentation and the bed level increase has been widely observed during the simulation period.

Acknowledgement

The additional information and data on the study area are provided by trusted organizations including Department of Irrigation and Drainage (DID). We would also to offer our sincere thanks to Universiti Tun Hussein Onn Malaysia (UTHM) and everyone who have helped in order to complete this project.

References

[1] Towens, “The Facts of Sediment,” Water Pollution Control, Apr. 2018.

[2] A. Card, K. Fitch, D. Kelly, C. Kemker, and K. Rose, “Sediment Transport and Deposition,” Fundamentals of Environmental Measurements, Dec. 2014.

[3] J.-H. Choi, K.-W. Jun, and C.-D. Jang, “Bed-Load Collision Sound Filtering through Separation Of Pipe Hydrophone Frequency Bands,” Water, vol. 12, no. 7, p. 1875, 2020.

[4] M. H. Roozitalab, H. Serghini, A. Keshavarz, V. Eser, and E. de-Pauw, “Sustainable Agricultural Development of Highlands in Central, West Asia and North Africa,” International Center for Agriculture Research in the Dry Areas (ICARDA), 2013.

[5] A. Razali, S. N. Syed Ismail, S. Awang, S. M. Praveena, and E. Zainal Abidin, “Land use change in highland area and its impact on river water quality: a review of case studies in Malaysia,” Ecological Processes, vol. 7, no. 1, 2018.

[6] (DSM), “Map of Cameron Highlands 1:30,000,” Malaysia.for Agricultural Research in the Dry Areas (ICADAR), pp. 1–52, 2008.

[7] A. ShahiriParsa, M. Noori, M. Heydari, and M. Rashidi, “Floodplain Zoning Simulation by Using HEC-RAS and CCHE2D Models in the Sungai Maka River,” Air, Soil and Water Research, vol. 9, 2016.

[8] R. Agrawal and D. G. Regulwar, “Unsteady Flow Analysis of Lower Dudhana River using HEC-RAS,” Sustainable Water Resources Development and Management , vol. 3, Jul. 2016.

[9] J. Halgren, “Coastal Hydraulics and Downstream Boundary Conditions,” COMET Advanced Hydrologic Sciences Virtual Course, vol. Part 2, 2011.

[10] M. B. Gasim, I. Sahid, E. Toriman, J. J. Pereira, M. Mokhtar, and M. P. Abdullah, “Integrated Water Resource Management and Pollution Sources in Cameron Highlands, Pahang, Malaysia,” American-Eurasian Journal of Agricultural and Environmental Science, 2009.

[11] “Department of Irrigation and Drainage.” [Online]. Available: https://water.gov.my/. [Accessed: 21-Jul-2021].

[12] R. Fortuin, “Soil Erosion in Cameron Highlands; an Erosion Rate Study of a Highland Area,” Saxion University Deventer, Netherlands, 2006.