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RESEARCH ARTICLE

Estimating Sediment Yield at Sungai Pusu Watershed using Soil and Water Assessment Tool (SWAT) Model

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ABSTRACT - Sediment yield is the net result of soil erosion and sediment deposition processes. In the watershed, sediment yields are dominantly determined by stream flow, drainage area, and channel size. Land-use activity conducted by human is one of the major contributions to the sediment yield in the watershed. The study area covered in this study is the Sungai Pusu which flows through International Islamic University Malaysia (IIUM). Significant amount of sediments is deposited in Sungai Pusu due to the improper land clearing activities that are taking place along the river's main tributaries. As a result, the water quality of Sungai Pusu is rapidly deteriorating. Sediment yield estimation is crucial in order to design suitable measure to rehabilitate the river. The aim of this study is to estimate sediment yield at Sungai Pusu watershed using SWAT model. Remote sensing and Geographic Information System (GIS) were used to evaluate sedimentation over time in the Sungai Pusu watershed. The SWAT model was performed to simulate water balance, stream flow, and sediment yield. The annual sediment yield obtained by the model is 427-ton ha^{-1} $year^{-1}$.

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Watershed,
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1.0 INTRODUCTION

Many recent studies focus on the catchment's erosion, stream flow, and sediment yield. Duru [1] claims that degradation due to erosion involves approximately 40% of the world's rich land. The sediment yield refers to the amount of the material eroded from the agricultural land, field, channel, or basin [2]. At the same time, Duru [1] emphasizes that sediment yield is a substance that eroded within a specified duration when it reaches a watershed point. According to Julien [3], sediment was not a significant pollutant alone. It is also the transporter, enhancer, and agent to other pollutant units. Julien [3] also adds that it affects other facilities such as hydroelectric facilities, recreational facilities and aquatic life. Sediment yield is accumulated because of the basin characteristics, land use and cover, drainage properties, and climate. In the basin, sediment yields are majorly determined by channel length, network drainage, and streamflow, according to multiple regression analyses. No other variables on sediment yield in the area can be considered prime control factors [1]. Thus, only through careful examination of scientific innovations and practical engineering technology can state of the art in erosion and sedimentation be assessed.

2.0 FACTORS CAUSING EROSION AND SEDIMENT YIELD

The major hydrological challenges faced in tropical regions include soil erosion, sedimentation and riverbed filling [4]. Land-use activity conducted by human is one of the major contributions to the sedimentation [3][4][5]. Excessive erosion can happen through street and parkway development if protective vegetation is removed and steep inclining cut and fill are left unprotected, causing neighbourhood scouring issues alongside massive downstream sedimentation [3]. The author also added that due to cultivation and tillage, the disturbance to the soil quality causes the ability of organic materials to erode increases. According to the Department of Statistics of Malaysia, the percentage of construction developed for the third quarter of 2019 in Malaysia was 0.6% which cost RM 36.1 billion. Construction work often leads to soil erosion which eventually increase the amount of sediments in the waterbody. The urbanization process has a significant impact to the hydrological cycle and river water quality [6]. Weng [7] stated that effects of urbanization could be viewed at different periods of urban advancement. In any case of urban development, the removal of trees and vegetation may reduce evapotranspiration and worsen stream sedimentation.

Anthropogenic activities such as sand mining has a physical impact on water quality and the stability of stream beds and banks [8]. Mine dumps and spoils banks also slowly erode for several years following the end of mining operations due to natural rainfall [3].

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3.0 SOIL AND WATER ASSESMENT TOOL (SWAT)

SWAT is a watershed or river basin scale hydrologic model that's frequently used to simulate hydrological processes, as well as the corresponding sediment and agricultural chemical yields [14]. The U.S. Department of Agriculture – Agriculture Research Service (USDA-ARS) is the generator of the SWAT model at the Grassland, Soil, and Water Research Laboratory in Temple, Texas [1]. The objective of creating SWAT simulations that execute worldwide was to Bieger [15] for land use assessment, and the executives rehearse hydrology and water quality in enormous, complex catchments. Moreover, SWAT acknowledges the diversification of the catchment by dividing it into a smaller scale sub-basin and further varies into a smaller area with a diversity of land management practices, land use, and soil type called hydrological response units (H.R.U.) [15, 16]. SWAT is assumed to be a hydrological transport model that can operate daily, monthly, and yearly. The data consisted in the SWAT model were from plant development, climate, hydrology, agricultural management criteria, erosion and sedimentation, and avenue [1]. In a watershed scale, sediment yield can be predicted by the SWAT model for proposal and administration of water resources. The major factor controlling the sediment yield is the transport capacity of drainage [1]. In each H.R.U., Modified Universal Soil Loss Equation (MUSLE) is used to obtain the sediment yield, which is a modified version of Universal Soil Loss Equation (USLE) [15, 16]. The equation is listed below:

$$sed = 11.8\ (Q_{surf}.\,q_{peak}.\,area_{HRU})^{0.56}.\,K_{USLE}.\,C_{USLE}.\,P_{USLE}.\,LS_{USLE}.\,CFRG \tag{1}$$

where;

sed	=	sediment yield (metric tons)
Q_{surf}	=	surface runoff volume (mmH_2O.H./ha)
q_{peak}	=	peak runoff rate (m^3/s)
$area_{HRU}$	=	area of H.R.U. (ha)
K_{USLE}	=	USLE soil erodibility factor
C_{USLE}	=	USLE cover and management factor
P_{USLE}	=	USLE support practice factor
LS_{USLE}	=	USLE topographic factor
$CFRG$	=	coarse fragment factor

4.0 STUDY AREA

The study area is Sungai Pusu which flows through International Islamic University Malaysia (IIUM). A large amount of sediment accumulation was spotted along the Sungai Pusu in IIUM campus. The catchment area of the river is 12.4km^2.

It is discovered that the sediment load and runoff peak flow increased tremendously due to improper activities in the upstream area of the Sungai Pusu [17][18]. The sand mining activities causes silts to be released in the river resulting in the river having high suspended solids concentration and turbidity [17]. The lake and retention pond created were covered with silt and lost their ability to flow properly and cannot handle the pressure; thus, it causes flash floods in the nearby area. Sungai Pusu which is facing severe sedimentation problem was chosen as the study area in order to estimate the sediment yield so as to design a proper measure to counter the problem.

Fig. 1 shows the overall view of the study area. Pond 1 can be located via a geological coordinate of 3º15'42.97" N, 101º44'23.34" E. While Pond 2 is situated at 3º15'34.44" N, 101º44'17.76" E. There was some significant evidence of sedimentation along the river network. Pond 1 and Pond 2 are located upstream of Sungai Pusu and International Islamic University Malaysia (IIUM), as shown in Figure 1.

Figure 1. Overall view of study area

5.0 METHODOLOGY AND DATA COLLECTION

The data used in this study includes hydrological, meteorological, land-use or cover map data, Food and Agriculture Organization (F.A.O.) soil map data and digital elevation map (D.E.M.).

Hydrological data is collected from the nearest runoff gauging station, which consists of streamflow, sediment load, and stream discharge data for the various historical duration, i.e., day, month, and years. The surface runoff can be determined from rainfall intensity, duration, geology, and surface cover distribution. The LOADEST software can be used to estimate the constituent loads in the stream and rivers every month. Hydrological data input is obtained from Water Resources Management and Hydrology Division, Department of Irrigation and Drainage (D.I.D.) through a link (http://h2o.water.gov.my).

Meteorological input consists of maximum and minimum temperature, precipitation, solar radiation, wind speed, and relative humidity. The meteorological data, including land use data, is collected from the SWAT website, which is in the grid form of one of the nearest stations in the study area.

D.E.M. is the representative of topographical data obtained from the USGS website EarthExplorer. D.E.M. data have been used to delineate the watershed and evaluate the land surface drainage pattern. The soil map is obtained from the F.A.O. soil map, which is projected to the geographic coordinate system W.G.S. 1984.

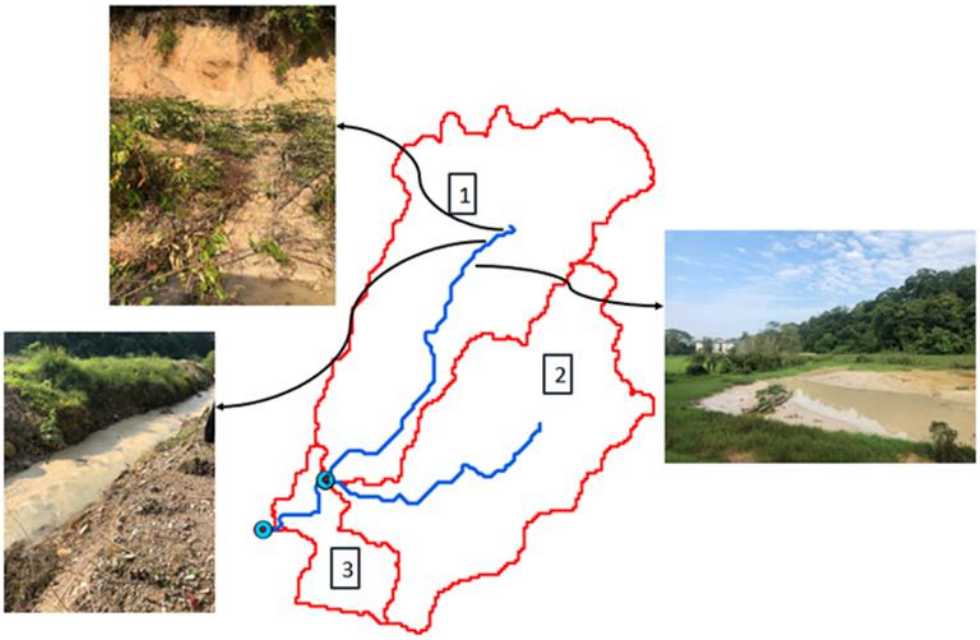

Figure 2. Sub-basin of the watershed from SWAT model

The Hydrologic Response Units (H.R.U.) definition comprises of slope delineation, land use, and soil types. In defining the HRU, land use data, soil data and slope delineation were loaded into the interface. The slope data is defined based on the DEM which was based on various threshold. The land use dataset was reclassified into three major types which is listed in Table 1. Figure 3 shows the land use for map of Sungai Pusu. The SWAT calculated the percentage area of the land cover by the watershed. As for the global soil dataset from FAO, it was clipped and identified with the existing delineated watershed. Next, multiple HRU were used to define the watershed.

Table 1. Land use characteristics

Land use	Description	Area (%)
RNGE	Range-Grasses	67.439
FRSE	Forest-Evergreen	31.800
RNGB	Range-Brush	0.761

Figure 3. Land use map of Sungai Pusu

The meteorological data such as wind speed, temperature, solar radiation, evaporation, relative humidity, and precipitation are also required for the model set-up. The SWAT software is executed based on the mentioned parameters to obtain the desired result which is the estimated sediment yield. Figure 4 shows the methodological flowchart of SWAT model.

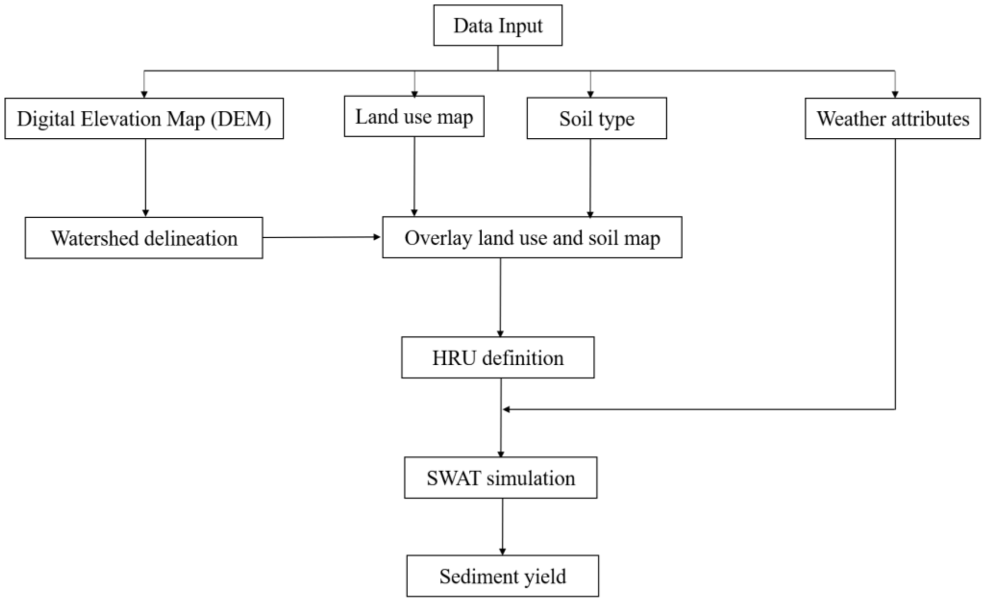

Figure 4. Flowchart of the SWAT model

6.0 RESULTS AND DISCUSSION

The SWAT simulation is carried out for two (2) years, from 01/01/2014 to 12/31/2015. Table 2 shows the detail of each of the H.R.U. in the Sungai Pusu watershed. The specification in the table indicates the "type of landuse and land cover → SWAT code for land use/soil type code/and the slope of H.R.U."

Table 2. Specification of each H.R.U. in the Sungai Pusu watershed

HRU	Sub-basin	Specification	Area (ha)
1	1	Range-Grasses→ RNGE/Ao108-2ab-4464/0-9999	226.5964
2	1	Range-Grasses→ RNGE/Ao90-2-3c-4284/0-9999	320.5511
3	1	Forest-Evergreen → FRSE/Ao108-2ab-4464/0-9999	146.8398
4	2	Range-Grasses→ RNGE/Ao108-2ab-4464/0-9999	313.0816
5	2	Forest-Evergreen → FRSE/Ao108-2ab-4464/0-9999	275.1353
6	3	Range-Grasses→ RNGE/Ao108-2ab-4464/0-9999	91.0007
7	3	Forest-Evergreen → FRSE/Ao108-2ab-4464/0-9999	28.8725

The sediment yield for H.R.U.1, 2, 4, and 6 produced the same pattern. This phenomenon is due to (from Table 2) the specification of the H.R.U. for the respective H.R.U.s was the same, which are range- grasses for land use land cover and the slope from 0 – 9999. The only difference produced from the H.R.U. 2 is the soil type Ao90-2-3c-4284. From the graph of H.R.U. 1, 2, 4, and 6 in April, the sediment yield produced is higher than the surface runoff recorded. The reason is the landuse cover for the H.R.U. 1, 2, 4, and 6 is covered with the range grasses where the strength of the root is quite low. Thus, the sediment produced is relatively high compared to the H.R.U. 3, 5, and 7. Despite the monsoon season in November 2015, the surface runoff is the highest in two years, but the sediment yield produced is only 100 ton/ha and below.

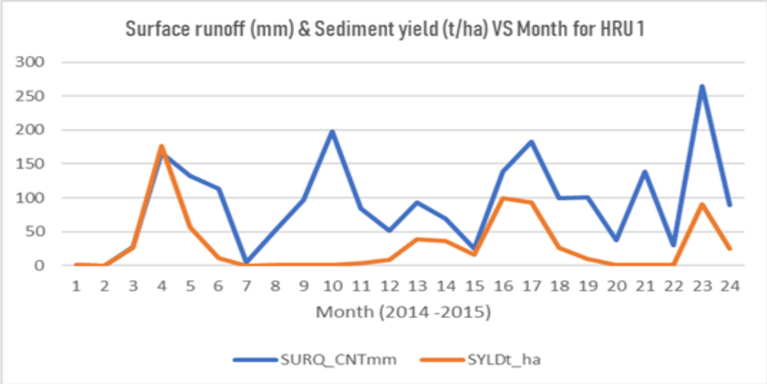

Figure 5. Surface runoff and Sediment yield VS month for H.R.U. 1

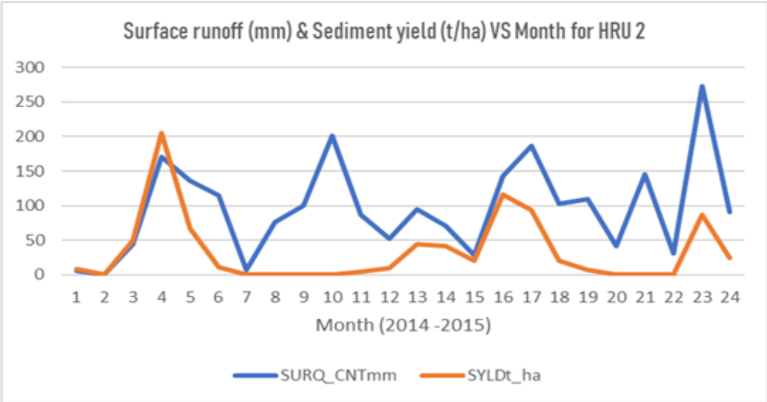

Figure 6. Surface runoff and Sediment yield VS month for H.R.U. 2

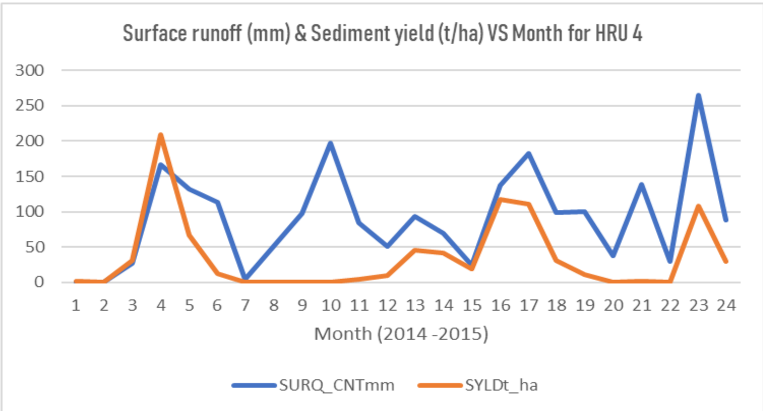

Figure 7. Surface runoff and Sediment yield VS month for H.R.U. 4

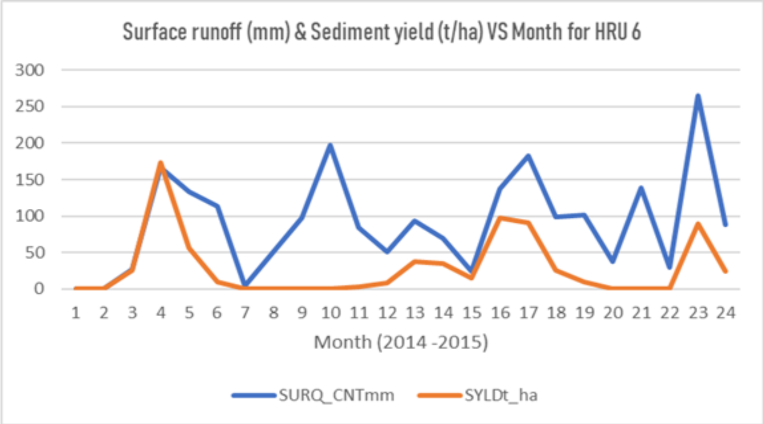

Figure 8. Surface runoff and Sediment yield VS month for H.R.U. 6

However, the H.R.U. 3, 5, and 7 produced the same pattern for the sediment yield. The graph shows that the sediment yields only in March, April, and May. The most contributed sediment yield is from the H.R.U.-5, located in sub-basin 2 in April, with 140 ton/ha.

Even though the H.R.U. 6 and 7 are located in the downstream area (sub-basin 3), the amount accumulated for sediment yield in their respective H.R.U. are low compared to the other H.R.U.s. This reason is due to the area covered for sub-basin 3 being 1.2 km^2 which is the smallest area compared to the sub-basin 1 and 2.

The land use land cover, soil type and the slope play a major part in contribution of sediment yield. This is because different HRUs produce different amount of sediment yield. The sediment yield reflects the influence of drainage properties (stream network foam and density), land use/cover, climate (precipitation) and catchment properties (soil type, topography) [14].

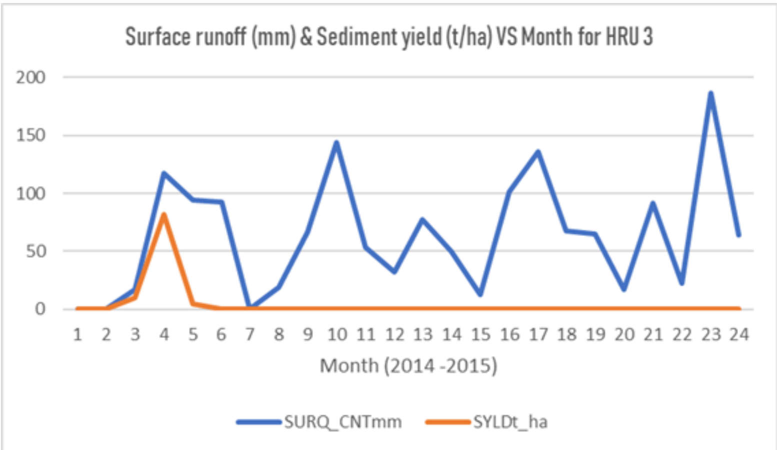

Figure 9. Surface runoff and Sediment yield VS month for H.R.U. 3

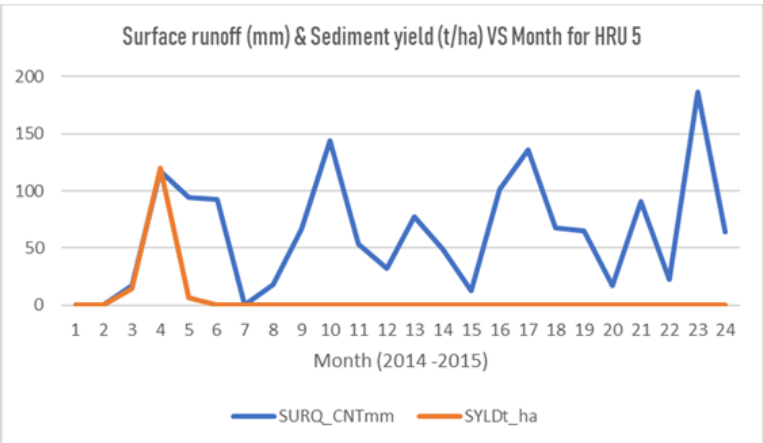

Figure 10. Surface runoff and Sediment yield VS month for H.R.U. 5

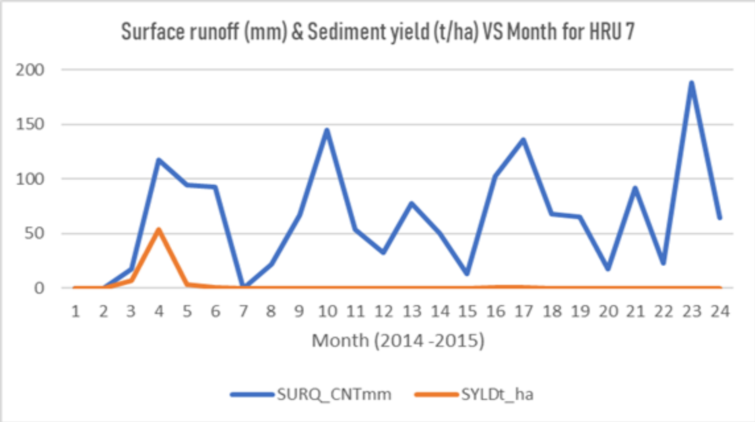

Figure 11. Surface runoff and Sediment yield VS month for H.R.U. 7

The average sediment yield values at the outlet is 427-ton ha^{-1} year^{-1}. Table 3 shows the comparison of estimated annual sediment yield for rivers in Malaysia based on the studies conducted by previous researchers. The annual sediment yield values estimated in this study are within the range obtained in different catchments in Malaysia.

Table 3. Estimated annual sediment yield for catchments in Malaysia

Study area	Sediment yield (ton ha^{-1} year^{-1})	Reference
Sungai Pusu Watershed	427	
Langat Watershed	9	[18]
Kelantan Watershed	1630	[19]
Johor River Basin	19 - 2179	[20]

7.0 CONCLUSION

In conclusion, land use, land cover, soil type, and the slope play a significant part in the contribution of sediment yield. Different H.R.U.s produce different amounts of sediment yield. The sediment yield reflects the influence of drainage properties (stream network foam and density), land use/cover, climate (precipitation), and catchment properties (soil type, topography) [15]. Human activities significantly contributed to the severity of the sediment deposition in the watershed. The estimated sediment yield extract from the simulation of the SWAT model is 427-ton ha^{-1} year^{-1} is considered as an enormous value of sediment yield.

General recommendations that might need to be done in order to obtain more satisfying results for the sediment yield in the Sungai Pusu catchment are that the accuracy of the input data in the SWAT model need to be improved. Map with higher resolution and most recent data were needed for the DEM, land use, meteorological data and soil type.

The land use data was retrieved from The Global Land Cover Characterization (GLCC) dataset which is a collection of land cover classification schemes based on AVHRR data from April 1992 through March 1993. In order to improve the result, the land use data need to be reclassified again since the study area has experienced some additional development. Moreover, the soil type chosen from FAO was broad and general as there are only two types of soil that were distinguished from the map. A better acquisition and sources of soil type data should be obtained. Moreover, further analysis should be done with calibration and validation so that the model performance can be evaluated using coefficient of efficiency (NSE) and relative error (RE).

8.0 AUTHOR CONTRIBUTIONS

Najihah Hakimah Abdullah: Software, Writing- Original draft preparation

Saerahany Legori Ibrahim: Supervision, Reviewing and Editing

Nur Aqilah Mohd Rosli: Writing- Reviewing and Editing

Rabitah Handan: Writing- Reviewing and Editing

Zamri Mohd: Writing- Reviewing and Editing

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11.0 CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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