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Research paper



Pollutant Loading Analysis of Suspended Solid, Nitrogen and Phosphorus at Bertam Catchment, Cameron Highlands using MUSIC

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Abstract

This paper aimed to analyze the pollutant loading composition of suspended solids, nitrogen and phosphorus in urban stormwater at Cameron Highlands which known as popular tourism, agriculture and function as reservoir water to generate electricity. Researchers found the urban stormwater quantity modeling has achieved sufficient accuracy benchmark. However, modeling stormwater runoff quality is relatively difficult and largely depends on catchment characteristics/land-uses. Model of Urban Stormwater Improvement Conceptualization (MUSIC) estimates pollutant transport from catchments and stormwater treatment through different application of Best Management Practices (BMPs). Result obtained from the observed and calculated data was compared with MUSIC's estimations under a similar scenario where no applications of BMPs. As a second scenario, series of treatment train is propose for each sub-catchments based on the suitability and verification on site that consists of constructed stormwater treatment BMPs (wetlands, bio-retention, on-site detention, sediment basin and gross pollutant traps). Implementation of BMPs reduce nearly 100% of gross pollutant, 65% - 83% TSS, 40% - 66% TP and 52% - 78% due to effectiveness of BMPs in treating the pollutant within different landuse. As a summary, MUSIC can conceptually determine the effectiveness of BMPs without giving a detailed design.

Keywords: *Pollutant loading; water quality modeling; stormwater; urban; Best Management Practices (BMPs)*

1. Introduction

Massive and uncontrolled urbanization generally leads to adverse impact to environment where it cause degradation of water quality and disturbance to hydrological cyle. High concentration of pollutant especially from non-point sources pollution will start to generate with the increased of impervious surface as more runoff are unable to infiltrate into the concrete surface [1-5]. In the past, urban waterways have been confined to narrow river corridors with the channels canalized and concrete and other synthetic materials forming the bed and banks of the river [6]. On top of that, flooding problems also tend to happened with the increase of gross pollutant such as debris, litter and sedimentation in the drainage system that eventually slowdown or block the flow of water in the channels [7-8]. The degradation of water quality and flooding problems could be mitigate by introduce a promising solution with the application of suitable stormwater Best Management Practices (BMPs) at the catchment [9]. This judgment of using Stormwater facilities/BMPs depends on not only relevant theoretical considerations but also a significant amount of practical experience and the availability of relevant data, as well [10].

Determining the nature and magnitude of a problem is a prerequisite to planning and development of cost-effective solutions [11]. Nonpoint source water pollution from agriculture is inherently difficult to determine [11]. Sampling sites for diffuse agricultural sources are not self-evident [12]. Pollutant movement can be by surface and subsurface pathways, and runoff is highly dependent of weather, antecedent conditions (e.g. soil moisture, fertilizer incorporation), slope, distance from the source to receiving water, and soil characteristics [13-14]. In contrast to many point sources, the contribution from diffuse agricultural sources may occur mainly during short time periods or events [12]. It follows those monitoring specific source areas or the accumulative input of larger agricultural use areas must take into account particular events such as storm events or low flow periods. Future individual studies should be undertaken in priority problem areas of Cameron Highlands to determine the relative magnitudes of runoff contribution from agricultural sources [12].

Computer simulations are essential tools in stormwater planning and management. However, the most stormwater modeling software has been designed to simulate the behaviors of engineered stormwater management systems (e.g., open channels, pipes, and pump stations), which is expensive, and is complicated to run. Increasingly, the government is trying to incorporate 'green', non-engineered technologies into their stormwater management plans and seek stakeholder input for the decision-making process [15-16]. (MUSICis categorized as one of the stormwater modeling that can simulate to calculate pollutant loading that transported from a particular catchment within two or more scenarios. The scenarios are develop with or without the application of stormwater treatment systems or Best Management Practices (BMPs). MUSIC capable to prefigure the effectiveness of the BMPs such as bio-retention, wetland, detention pond, gross pollutant trap, sediment

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basin etc. [17] and able to estimate the life-cycle cost of BMPs which applied in the model. Ideally, MUSIC ease water resources managers and other decision makers to come out with a conceptual design at the planning and design stage to ascertain ecologically sustainable development.

The aims of this study is to analyse the simulation result generated for each parameter which is Total Suspended Solid (TSS), Total Nitrogen (TN), Total Phosphorus (TP) and gross pollutant for existing landuse in Bertam catchment, Cameron Highlands. In addition, to discuss the effectiveness of conceptual BMPs applied in the model.

2. Study Area

The Study area falls within Cameron Highlands Districts situated at Pahang Darul Makmur, which the area estimated to be 712km^2. It is one of the frequent places visits by the tourist where its temperature falls not more than 25 C° and widely known as a hilly area with agricultural practices [18]. Cameron Highlands is made up of three major catchments of Bertam, Telom and Lemoi where due to its location situated at Highland, it received in average 2,800mm of rainfall annually [19].

One of three major rivers in Cameron Highlands is Bertam that covered around 73km^2 of an area and is among the river that plays an important role for irrigation at most of the local agricultural activities, drinking water supply for surrounding population and also function to generate hydroelectricity from the dam [20]. Bertam catchment mainly consists of five sub-catchments of Brinchang, Tanah Rata, Habu, Ringlet and Lembah Bertam. Fig. 1 shows overall catchments of Bertam which focus in this study.

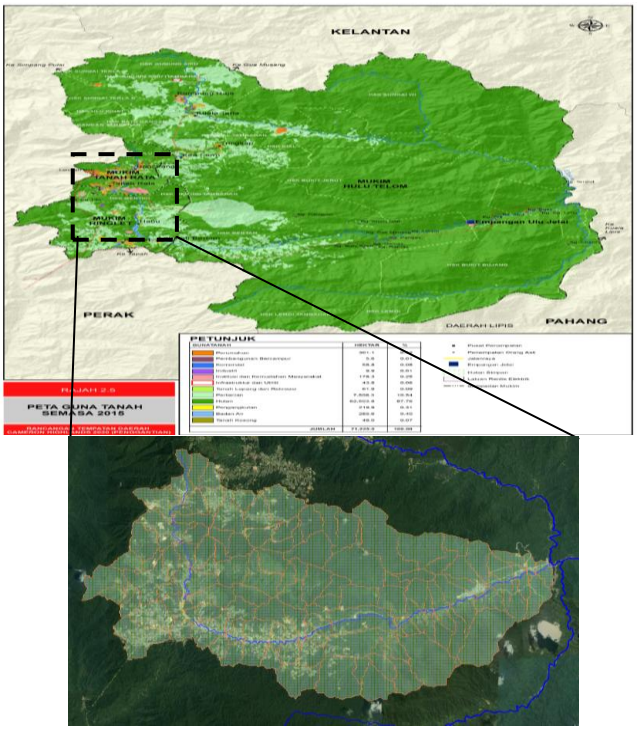


Fig. 1: Overall catchments of Bertam

3. Methodology

The Cooperative Research Centre for Catchment Hydrology (CRCCH) researchers and practitioners developed an idea named MUSIC, which generally provides function as decision support system (DSS). However, MUSIC is not a detailed design tool but it helps users to plan the conceptual design of any stormwater management systems for desired catchments. This permit to achieve pre-specified water quality objectives and to attain the designated sizes of each selected stormwater treatment facilities. Accordingly, MUSIC is an advance decision support tools that could predict the potential impact on water due to high-risk development.

In order to run MUSIC model network, respective steps need to be consider. Fig. 2 summarise the steps included in the model.

- Nearest rainfall rain gauge and evaporation DID stations are selected to develop meteorological template;
- Source nodes or the catchment areas are selected in order to incorporated into the model;
- Consideration for input of soil properties (rainfall-runoff properties); and
- The input of pollutant generation characteristics for selected source nodes.

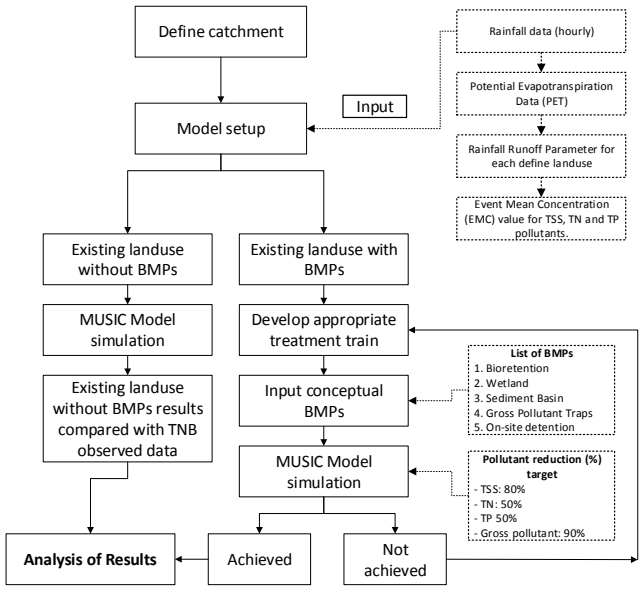


Fig. 2: Schematic of MUSIC modeling process

3.1. Music Input Data - Rainfall and Evaporation Data

Stormwater runoff (represented as surface runoff and base flow) is generated in MUSIC through the interaction of rainfall; evapotranspiration and the MUSIC Rainfall-Runoff Model. Rainfall time series data is based on the Department of Irrigation and Drainage (DID), Malaysia rainfall station named as Gunong Brinchang station with number 4513033.

One of the inputs required by MUSIC is the potential evapotranspiration (PET) on a monthly average basis. The monthly average evaporation for grass was assumed to be equivalent to PET and was adopted in MUSIC. The average monthly PET is summarised in Table 1 which also adopted from DID evaporation station named as Station JPS Raub with number 818354. Rainfall and evaporation station is selected based on the nearest station to the study area and have a series of consistent data for more than 20 years.

Table 1: Average Monthly PET for 10 years (unit:mm)

Month	Average Evaporation	
January		124
February		135
March		145
April		143
May		130
June		132
July		134
August		121
September		121
October		122
November		117
December		114

3.2. Source Nodes

Once the meteorological data has been input into the model the user must then define the source nodes to reflect the details (i.e. area, landuse) of the contributing catchments.

- Forest;
- Agricultural;
- Urban;
- User Defined; Commercial

Source Nodes for the five sub-catchments of Bertam for Brinchang, Tanah Rata, Habu, Ringlet, Lembah Bertam are defined below:

- Urban Source Node used to address low to high-density residential and commercial areas. These areas comprise private allotments together with all related facilities, such as parks, schools, roads etc.
- Agricultural Source Node refers to areas of large-scale farming activities with low density of rural area.
- Forested Source Node used to describe natural forested area. This node is to be utilized in areas where canopy densities are greater than 50%.
- The Imported Data Source Nodes are required when modeling previous areas, in order to separate surface and baseflows.

3.3. Runoff Parameter

The MUSIC model for the study area catchment was assembled with the following data; listed landuse areas for existing and future conditions, hourly rainfall time series for one year , the average monthly PET that obtained from DID and the listed adopted values for runoff generation parameters as shown below (Table 2):

Table 2: Adopted Values for MUSIC Runoff Generation Parameters (CRRCH, 2007)

Parameters	Urban Residential	Commercial	Industrial	Rural Residential	Forested
Field Capacity (mm)	200	80	80	80	80 (250)
Field Capacity (mm)	200	80	80	80	80 (250)
Infiltration Capacity Coefficient a	50	200	200	200	200 (200)
Infiltration Capacity Exponent b	1	1	1	1	1 (1)
Rainfall Thereshold (mm)	1	1	1	1	1 (1)
Soil capacity (mm)	400	120	120	120	120 (300)
Initial Storage (%)	10	25	25	25	25 (30)
Daily Recharge Rate (%)	25	25	25	25	25 (25)
Daily Baseflow/Drainage Rate (%)	5	5	5	5	5 (5)
Initial depth (mm)	50	50	50	50	50 (10)
Deep Seepage (%)	0	0	0	0	0

Note: Darwin MUSIC parameters

3.4. Pollutant Parameter

MUSIC models pollutants using stochastically generated event mean concentrations (EMCs) and mean EMC from a study in Malaysia. The EMCs are log-normally distributed; therefore it is necessary to specify a mean and standard deviation for each pollutant. MUSIC is set up with default parameters for total suspended solids (TSS), total phosphorus (TP) and total nitrogen (TN). The default parameters are derived from a comprehensive review of stormwater quality monitored in urban catchments. Water quality parameters of MUSIC refer to the dry weather pollutant concentrations (baseflow concentrations) and the wet weather pollutant concentrations (storm flow event mean concentrations or EMC).

Consequently, since there is no local information regarding the dry and wet weather pollutant concentrations, the average EMC from MSMA 2nd Edition was adopted. These EMC values are summarised in Table 3. In the MUSIC model, these values are entered as logarithms. To account for variability, the default values of standard deviations of each parameter are retained. The adopted quality parameters (stormwater and baseflow) were later used for the assessment of treatment effects for a number of proposed BMPs structures.

Table 3: Adopted EMC Values in MUSIC

Parameter	Event Mean Concentration (EMC), mg/l					
	Residential	Commercial	Industrial	Highway	Forest / Open space	Agricultural
TSS	128	122	166	80	68.33	220.89
TP	0.34	0.32	0.49	0.16	11.54	0.895
TN	4.21	4.84	5.00	2.25	2.65	5.15

(Manual Saliran Mesra Alam, Jabatan Pengairan dan Saliran, 2012)

3.5. Selection of BMPs Site

The selection of the most suitable sites for locating stormwater quality control structures involves characterizing and analyzing the sites based on the topography, aerial photographs, site visit and subsequent load analysis. Generally, the following factors are considered in the selection process:

- Open Space (undeveloped land availability primarily owned by the Government)
- Landuse activity
- Easy access for construction and maintenance
- Type of stormwater quality control structures/systems

4. Results and Discussions

4.1. MUSIC Modeling Results without BMPs Compared with Calculated Annual Pollutant Loading

Total of five sub-catchment pollutant loading was simulated using MUSIC and has been compared with annual pollutant loading calculation that adopted from Manual Saliran Mesra Alam (MSMA) 2nd Edition, 2012 [21]. As can be noted from the Table 4, there is no significant reduction in pollutant concentrations at receiving node of all sub-catchment. This is due to the fact that there are no BMPs proposed in the MUSIC.

In order to calculate the annual pollutant loading using formula in MSMA 2nd Edition (2012), the input data will be mean annual rainfall, area for each type of landuse for particular sub-catchment, runoff coefficient (C) and also mean EMC values for Total Suspended Solids (TSS), Total Phosphorus (TP) and Total Nitrogen (TN) for selected landuses that adopted from MSMA. The value of runoff coefficient, C depends mainly on landuse of the sub-catchments and is very close to its imperviousness. The value of C also varies with soil type, soil moisture condition, rainfall intensity and etc. [21]. The sub-catchment area is grouped into general landuse types either residential, commercial, industrial, open spaces, roads and highway and agriculture to calculate annual pollutant loads. It is important that the approach used to model the pre-condition is also used to model the post-condition.

Both results simulated and calculated give different values as the Annual Pollutant Loading calculation only consider general im-

perviousness of the landuse while MUSIC allows specific imperviousness for each landuse type. The pollutant loading obtained for each sub-catchments is individually different depends on the size of each landuse [22]. However, no gross pollutant loading for calculated because EMC value for a gross pollutant is unavailable.

Table 4: Simulated result from MUSIC modeling without implementation of BMPs compared with Annual Pollutant Loading calculation that based on MSMA 2nd Edition.

Pollutant (kg/yr)	Simulated	Calculated
Brinchang Town		
Total Suspended Solids	1.38E+06	1.57E+06
Total Phosphorus	22.9E+03	22.7E+03
Total Nitrogen	47.6E+03	55.0E+03
Gross Pollutants	318E+03	-
Tanah Rata Town		
Total Suspended Solids	2.52E+6	2.8E+06
Total Phosphorus	27.3E+03	42.6E+03
Total Nitrogen	88.3E+03	100E+03
Gross Pollutants	543E+03	-
Habu Town		
Total Suspended Solids	2.60E+06	3.11E+06
Total Phosphorus	49.8E+03	56.9E+03
Total Nitrogen	75.2E+03	95.2E+03
Gross Pollutants	454E+03	-
Ringlet Town		
Total Suspended Solids	1.45E+06	2.01E+06
Total Phosphorus	12.3E+03	16.2E+03
Total Nitrogen	45.7E+03	66.4E+03
Gross Pollutants	257E+03	-
Lembah Bertam Town		
Total Suspended Solids	2.64E+06	2.98E+06
Total Phosphorus	37.0E+03	41.5E+03
Total Nitrogen	77.5E+03	84.8E+03
Gross Pollutants	498E+03	-

As shown in Fig. 3, Fig. 4 and Fig. 5, which respectively for Total Suspended Solids (TSS), Total Phosphorus (TP) and Total Nitrogen (TN) indicate, that Lembah Bertam concludes as the highest loading for each pollutant compared to other sub-catchments. Meanwhile, TSS is noted to have the highest loading followed by TN and TP for all sub-catchments. According to the previous study stated that the downstream part after Brinchang was reported to have an excessive loading of TSS especially during wet weather flow that causes more soil erosion and brings all the sediments and nutrients due to agricultural activities and residential areas [23]. Annual pollutant loads are a good indicator of the potential for impairments but consideration should be made as they do not necessarily give a complete picture of the vulnerability of a watershed to impairments caused by a particular pollutant [24].

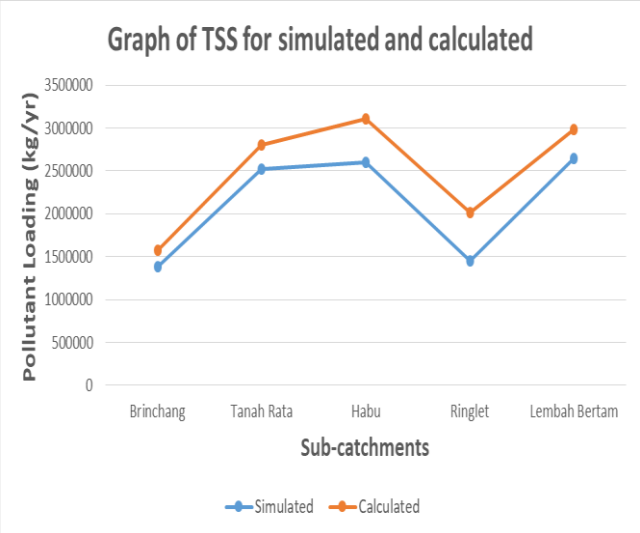


Fig. 3: Graph of TSS for simulated and calculated

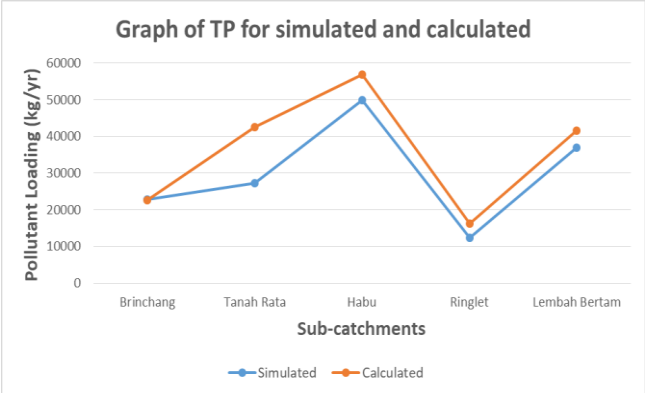


Fig. 4: Graph of TP for simulated and calculated

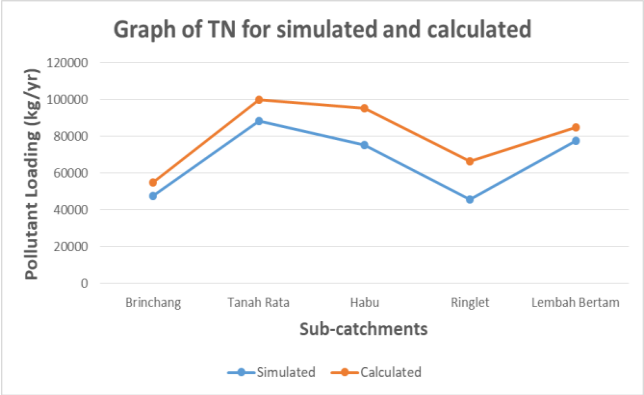


Fig. 5: Graph of TN for simulated and calculated

4.2. MUSIC Modeling Results with the Implementation of BMPS

The five functional categories of treatment systems generally proposed for the Brinchang, Tanah Rata, Habu, Ringlet and Lembah Bertam are wetlands, bio-retention, detention pond or on-site detention (OSD), sediment basin and gross pollutant traps. MUSIC modeling is used to demonstrate that the proposed plan can achieve a sustainable neutral or beneficial effect on water quality including wet weather as required by the DID. The pollution reduction target proposed by DID is 90%, 80%, 50% and 50% for the gross pollutant, TSS, TN and TP respectively.

In this scenario, the same source nodes or landuse as are used for each catchments. The source nodes are integrate with the series of treatment train which is the BMPs to achieve the reduction of pollutant at the catchment receiving nodes. In order to achieve the load reduction target for TSS, TN, TP and a gross pollutant of BMPs components have been selected for the catchment to be modeled in MUSIC are as presented in Table 5.

Table 5: Summary of Proposed Water Quality BMPs

Sub-catchment	Water Quality Best Management Practices (BMPs)				
	On-site Detention (OSD)	Gross Pollutant Trap (GPT)	Bioretention	Wetland	Sedimentation Basin
Brinchang	-	3	3	1	3
Tanah Rata	1	3	3	-	3
Habu	-	4	1	-	2
Ringlet	-	4	3	-	3
Lembah Bertam	-	4	4	-	2
Total	1	18	14	1	13

Table 6 shows the results obtained from MUSIC simulation modeling with the application of BMPs at Brinchang, Tanah Rata, Habu, Ringlet and Lembah Bertam. Selected BMPs component were incorporated into MUSIC modeling to study the water qual-

ity performances at the study area with the application bio-retention, sedimentation basin, wetland, on-site detention and GPT. There is a significant reduction in pollutant concentrations at receiving node of all catchments. This is due to the fact that there are BMPs proposed in the MUSIC modeling.

Table 6: Mean Annual Loads and Treatment Train Effectiveness at Receiving Node with the application of BMPs.

Pollutant (kg/yr)	Without BMPs	With BMPs	% Reduction
Brinchang Town			
Total Suspended Solids	1.38E+06	302E+03	78.1
Total Phosphorus	22.9E+03	7.36E+03	67.8
Total Nitrogen	47.6E+03	23.0E+03	51.6
Gross Pollutants	318E+03	0.00	100.0
Tanah Rata Town			
Total Suspended Solids	2.52E+6	563E+03	77.7
Total Phosphorus	27.3E+03	12.3E+03	55.5
Total Nitrogen	88.3E+03	43.3E+03	50.9
Gross Pollutants	543E+03	504	99.9
Habu Town			
Total Suspended Solids	2.60E+06	462E+03	82.2
Total Phosphorus	49.8E+03	11.4E+03	77.1
Total Nitrogen	75.2E+03	25.8E+03	65.6
Gross Pollutants	454E+03	2.51E+03	99.4
Ringlet Town			
Total Suspended Solids	1.45E+06	429E+03	70.4
Total Phosphorus	12.3E+03	4.80E+03	61.1
Total Nitrogen	45.7E+03	26.7E+03	41.6
Gross Pollutants	257E+03	0.00	100.0
Lembah Bertam Town			
Total Suspended Solids	2.64E+06	912E+03	65.5
Total Phosphorus	37.0E+03	17.7E+03	52.1
Total Nitrogen	77.5E+03	46.3E+03	40.3
Gross Pollutants	498E+03	706	99.9

As summarised in the graph shown in Fig. 6, there are significant reductions of residual loads for TSS, TP, TN and Gross Pollutant for Brinchang, Tanah Rata, Habu, Ringlet and Lembah Bertam. Total Suspended Solids (TSS), Total Phosphorus (TP) and Total Nitrogen (TN) are regarded as the most visible and significant water pollution problem in the study area. These pollutants can inhibit the growth of aquatic vegetation, harm aquatic organisms, transport pollutants and reduce the aesthetic value of the river (high turbidity).

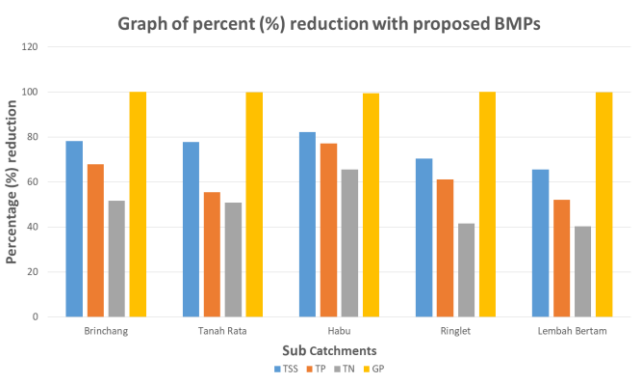


Fig. 6: Percentage (%) reduction after with proposed BMPs

Gross pollutant (GP) was greatly reduced after proposing Gross Pollutant Traps (GPTs) for each sub-catchments where it is designed to treat stormwater by traps GP once the water flows into it. It also is proven by the previous study that it has the ability to purifies BOD, COD, AN and TSS and in overall improve the water quality index of the water bodies [25]. TSS is the visible pollutant in the water body where this pollutant is due to the land erosion, runoff and discharge which causes a high amount of suspended solids and siltation in the river [25]. These also come from agriculture, which most on the extremely steep slope [18]. The percentage reduction of TSS mostly contributes to the application of a sediment basin, which function to trap discharge and runoff and allow the particles to settle down before it flows back to the river. Since Lembah Bertam has the highest load of TSS, thus it has the lowest reduction after the application of BMPs.

For TP and TN, both consistently reduce after application of qualitative BMPs that are bio retentions and wetlands. Agricultural activities mainly contribute to increasing amount of this pollutant. The high level of nutrients indicates excessive use of pesticides and fertilizers for farmers' agriculture plot. Bio-retention systems are selected because it is an infiltration based that capable to treat water by removing various range of pollutants including TSS, TN and TP throughout its filter media [26].Wetlands also will give an improvement in reducing nutrients in water by having its different types of plants that capable to absorbs pollutant through their roots [27].

4.3. Comparison Total Suspended Solids with the Previous Study

The data in Table 7 from the previous study was review and compared with the current study [28]. This data shows the estimation of annual sediment inflow for Ringlet outlet. Current study estimated 1,450,000 kg/year for 2016 and 1,280,000 kg/year for 2017 of total suspended solids compare to previous study, which is 841,722.15 kg/year for 2016 and 1,151,149.4 kg/year for 2017 of annual sediments inflow. The current study shows a higher result compared to the previous study which is 608,277.85 kg/year; 2016 and 128,850.6 kg/year; 2017. It shows that in the year 2016 and 2017 there are only small differences. Even though the comparison cannot be made directly, which is sediment and suspended solids, but it still can be used to pictures the actual conditions. From this result, it shows that the simulation on this model can be used and continue for the further analysis.

Table 7: 2016 and 2017 data comparison with TNB Data

Year	**2016**	**2017**
Current study (simulated)	**1,450,000 kg/year**	**1,280,000 kg/year**
TNB (observed)	317,631 m^3/year = **841,722.15 kg/year**	434,396 m^3/year = **1,151,149.4 kg/year**

**with density 2.65 kg/m3*
**simulation using hourly data*

5. Conclusion

The performance of each BMPs in removing pollutants can be described by looking at the percentage reduction simulated in the MUSIC. These give a clear picture that these BMPs have capabilities in improving water quality in terms of TSS, TN, TP and GP. Bio-retention systems are analyzed to be most suitable and effective in removing TN, TP as well as TSS. However, some reduction is unable to meet the target as set by DID due to space constraints at the study area since Cameron Highland is a hilly area which we need to also consider on the geographical challenge. As to meet the target, more BMPs with larger size are required to be proposed in the study area.

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