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# Morphometric Analysis of Upstream Sungai Batu Catchment in Selangor, Malaysia Using Geographical Information System (GIS)

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## Abstract

The evaluation of morphometric analysis was conducted in upstream Sungai Batu catchment with the total area 24.40 km$^2$. The GIS application used as a tool to generate drainage network from ASTER Global Digital Elevation Model (30m) and obtains reliable information of linear, areal and relief morphometric parameters towards the hydrological responses. Results show that the study area is 4$^{th}$ order catchment having 99 total streams, indicate the lower stream order. The study area is having elongated shape with high permeability surface, high infiltration rates and moderate surface runoff. The moderate runoff condition is highly associated with lower erosion and sediment transport capacities and tend to form a floods diminution due to the flow from tributaries into the main stream which require greatest basin lag time to peak discharge. The GIS application in morphometric study is very efficient tool for better understanding in terms of the several morphometric parameters and terrain parameters such a surface runoff, capacity of infiltration and lithology which are valuable and act as a guidance for decision makers to make sustainable development in watershed planning, management and mitigation measure control.

***Keywords:*** Digital elevation model; GIS; Morphometric analysis; Watershed management

## 1. Introduction

River catchment is very crucial geographical unit for water resource management. The hydrological response of a catchment can be described through runoff generation from a given rainfall and characterized with land use types, soil characteristic and morphometrical parameters. Chandniha and Kansal (2017) have stated that runoff generation is depends upon morphology of the catchment, lithology, bed rock and geological structures.

The definition of morphometric is the quantitative analysis which involve the measurement and mathematical analysis of the Earth's surface configuration and landform shapes and its dimensions (Pandi *et al.*, 2017). The morphometric analysis provides the

better understanding on the characteristic of hydrogeological drainage basin and expresses the current climate, geology, geomorphology and structure (Hajam *et al*., 2013; Rao *et al*., 2015; Chandniha & Kansal, 2017).

In the present study, morphometric analysis of upstream Sungai Batu catchment in Selangor with the total area 24.40 km$^2$ has been carried out as this study area has confronted with the flash flood events on November 2012 with maximum annual rainfall (512.50 mm) that cause a severe damage of properties (Source: http://www.themalaysiantimes.com.my/flash-floods-in-selayang/ ,accessed on 29$^{th}$ December 2018). The high number of development area indirectly affects the runoff characteristics in hydrological regime. During the high rainfall intensity in monsoon seasons on November 2012, the Batu Dam which is located at the upstream Sungai Batu was unable to accommodate the water volume in the dam. Subsequently, the water need to be released into Sungai Batu and indirectly cause a flood and affect the residential areas as the water is exceed beyond capacity of the river. The Sungai Batu also has a retention pond known as Kolam Takungan Batu used for flood mitigation measures in River of Life (RoL) project. Thus, morphometric analysis of upstream Sungai Batu catchment in Selangor specifically on the affected residential area have been carried out by using GIS technique to derive the catchment characteristics of linear, areal and relief aspects. The Digital Elevation Model (DEM) also used in this study as it is the major dataset for various applications in hydrology and morphometric study (Bastawesy *et al*., 2013).

Most of the previous studies conducted by Hajam *et al*. (2013), Das (2014), Kusre (2016) used the GIS as it is the most efficient tool to assess the basic parameters such as area, perimeter, stream order, stream length, number of stream and elevation for the catchment. Moreover, the GIS application in morphometric analysis provides the flexible environment, interpretation and analysis of spatial information related to the river catchment (Pande and Moharir, 2017). Therefore, in such situation, the main objective of this study is to analyze the morphometric parameters of linear, areal and relief aspect for upstream Sungai Batu catchment in Selangor by using the GIS application as it is very crucial and significant to understand more on the capabilities of runoff generation. The morphometric parameters will provide the reliable information on the Sungai Batu catchment characteristics towards the hydrological response, quantitative description of drainage system (Strahler, 1964) and catchment characteristics (Chandniha and Kansal, 2017). When a morphometrical analysis is carried out, it also helps to predict the flow direction and the total discharge which are useful for in designing hydraulic structures (Salami *et al*., 2016) and act as guidance for decision makers to make sustainable development in watershed planning, management and mitigation measure control.

## 2. Materials and Methods

*2.1 Study area*

Selangor state is located at the 3.0738° N latitudes and 101.5183° longitude in the west coast of Peninsular Malaysia. The investigated area of upstream Sungai Batu catchment lies at the Gombak district which covering a total area of 24.40 km$^2$ (Figure 1). The elevation varies from 44 to 369 m from mean sea level (MSL). The humid topical climate occurs within the study area with two monsoonal seasons where; the southwest monsoon from April to June and the northeast monsoon from October to February. The range of average annual rainfall throughout the study area is between 2294.24 mm to 2781.77 mm. The average annual rainfalls have been executed by using the Inverse Distance Weighting (IDW) interpolation method in GIS.

In terms of climate, the humidity in the study area is varies from 64 % to 90%. The temperature range throughout the study area ranges from 22°C to 37°C . The range of wind speed throughout the study area is about 3.6 km/h to 11.2 km/h. In terms of geologically, majority of the study area is covered by Devonian and Ordovician – Silurian type of sedimentary rocks. The lithological constituents

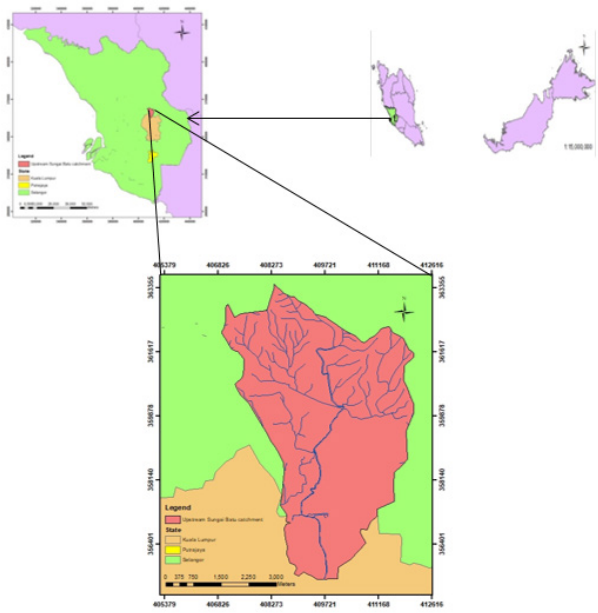


**Figure 1.** The location of upstream Sungai Batu Catchment in Selangor, Malaysia

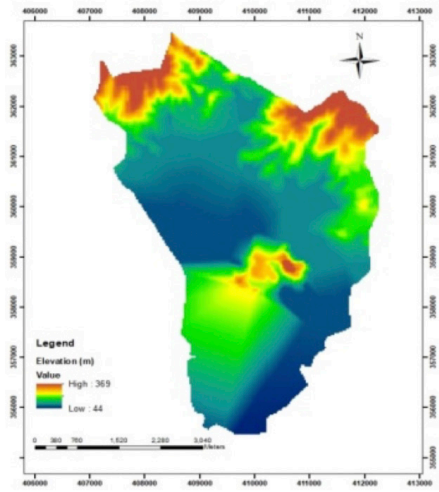


**Figure 2.** The Digital Elevation Model (DEM) of upstream Sungai Batu Catchment in Selangor

of the group are phyllite, schist, slate, limestone, sandstone and conglomerate. Only a small part is covered by Permian – Jurassic type in the study area (Source: https://www.jmg.gov.my/add_on/mt/smnjg/tiles/, accessed on 24th December 2018).

*2.2 Data collection and analysis*

The main data used in this study was the 30m*30m resolution grid of ASTER Global Digital Elevation Model (ASTGTM) (Figure 2) which downloaded from the https://earthexplorer.usgs.gov/. The downloaded data was undergoes further process by using ArcGIS tools for watershed delineation and compute the area, perimeters and others important morphological parameters of the catchment.

The quantitative morphometric analysis of upstream Sungai Batu catchment has been carried out by using the standard formula for

**Table 1.** The standard formula for morphometric parameters

| Aspect | Parameters | Formula | References |
|---|---|---|---|
| **Linear** | Stream order (U) | Hierarchical ranking | Strahler (1957) |
| | Stream length ($L_u$) | Length of stream | Horton (1945) |
| | Bifurcation ratio ($R_b$) | $R_b = N_u/( N_{u+1})$ | Horton (1945) |
| | Mean bifurcation ratio ($R_{bm}$) | The average of bifurcation ratio of all orders. | Strahler (1964) |
| **Areal** | Drainage density ($D_d$) | $D_d = L_u / A$ | Horton (1945) |
| | Stream frequency ($F_s$) | $F_s = N_u / A$ | Horton (1945) |
| | Drainage texture ($D_t$) | $D_t = N_u / P$ | Horton (1945) |
| | Elongation ratio ($R_e$) | $R_e = 2/ L_b * \sqrt{((A/\pi))}$ | Schumm (1956) |
| | Circularity ratio ($R_c$) | $Rc = 4\pi A / P^2$ | Miller (1953) |
| | Form factor ($F_f$) | $R_f = A / L_b^2$ | Horton (1945) |
| | Length of overland flow ($L_g$) | $L_g = 1/ 2D_d$ | Horton (1945) |
| | Constant channel maintenance ($C_c$) | $Cc = 1/ D_d$ | Schumm (1956) |
| **Relief** | Basin relief (R) | $R = H – h$ | Schumm (1956) |
| | Relief ratio ($R_r$) | $Rr = R/ L_b$ | Schumm (1956) |
| | Ruggedness number ($R_n$) | $Rn = R \times D_d$ | Strahler (1964) |

**Note**: *A is the area for catchment ($km^2$); P is the perimeter for catchment (km); H is the maximum elevation (m); h is minimum elevation within the basin (m)

several morphometric parameters of linear, areal and relief aspects (Table 1). The linear aspect (stream order, stream number, stream length and bifurcation ratio); areal aspect (drainage density, stream frequency, drainage texture, length of overland flow, constant of channel maintenance, form factor, circularity ratio, and elongation ratio); and relief aspect (basin relief, relief ratio and ruggedness number) are three major aspects that have been described in this analysis.

## 3. Results and Discussion

*3.1 Linear morphometric parameters*

The linear morphometric parameters of upstream Sungai Batu catchment were calculated by using standard formula as given in Table 1. The properties of stream network are very crucial in order to study the characteristics of basin as it is the primary step of morphometric analysis. The Strahler method has been used in this study due to its simplicity where the 1st order is normally known as the unbranched fingertip streams; the segments of 2nd order is the confluence of 1st order channels as a result; subsequently the 3rd order is designated from the combination of two 2nd order streams (Strahler, 1964). Based on Figure 3, the result shows that the stream numbers decrease as the stream order increase with $R^2 = 0.9509$. This result is supported by Horton (1932) "law of stream numbers" where stream number decrease as the stream order increase in this catchment. The previous study conducted by Meraj *et al.* (2015) in Jhelum basin, Kashmir Himalaya have stated that the higher stream order is associated with higher discharge and velocity which lead to high sediment load. However, the upstream Sungai Batu is 4th order catchment having 99 total streams, indicate the lower stream order. In this study area, it clearly contributes to low discharge and velocity that contribute to less erosion rate and subsequently sediment load.

The stream length ($L_u$) describes the

significant hydrological features of catchment in terms of surface runoff characteristics. The results show that the total stream length ($L_u$) is higher at the 1st stream order and decreases as the stream order increases (Table 2). The result for $L_u$ is supported by Horton (1945) second "law of stream length" where length of stream segment decreased as the stream order increases. The regression line plotted in Figure 4 validates the Horton's law of stream length with the $R^2 = 0.8823$. According to Thomas *et al.* (2010), the variation type may occur due to stream flow, types of rock, slope and topography. The smaller $L_u$ reveals area characteristics with large slopes and finer textures (Salami *et al.*, 2016). The longer $L_u$ indicates flatter gradients. The velocity is slower as the channel is wider due to the cumulative amount of water flowing into the main river increase from tributaries.

The bifurcation ratio ($R_b$) is the ratio of stream number of any given order to the stream number in the next higher order (Schumm, 1956). Verstappen (1983) indicate that the $R_b$ reflects to the basin shape where the elongated basin has a low $R_b$. The result shows that the mean bifurcation ratio ($R_{bm}$) is low with 3.47 (Table 2), which indicates the high infiltration rate in this catchment. Thus, the low $R_{bm}$ specifies a late hydrograph peak during the storm events for this area.

*3.2 Areal morphometric parameters*

The areal aspects of the drainage were calculated and the results were systematically presented in Table 3. The total area of the catchment is 24.40 km$^2$. The basin length of the catchment is 8.05 km. The perimeter is the outer boundary of the catchment that encloses its area as 24.10 km using ArcGIS software.

Drainage density ($D_d$) is one of the important drainage parameters in morphometric analysis. Horton (1945) defined the drainage density as the ratio of total stream length in a catchment over its contributing area. Langbein (1947) has suggested that the $D_d$ in humid region varies between 0.55 and 2.09 km/km$^2$ with average density of 1.03 km/km$^2$. The $D_d$ for upstream Sungai Batu catchment is more than the average with 1.93 km/km$^2$ (Table 3), which indicate the moderate category with

**Table 2.** Linear aspect for upstream Sungai Batu catchment

| Stream order | Linear aspect | | |
|---|---|---|---|
| | Stream number ($N_u$) | Stream length ($L_u$), km | Bifurcation ratio ($R_b$) |
| **1** | 58 | 29.66 | |
| **2** | 27 | 10.61 | 2.15 |
| **3** | 12 | 5.52 | 2.25 |
| **4** | 2 | 1.22 | 6.00 |
| **Mean** | 24.75 | 11.75 | 3.47 |

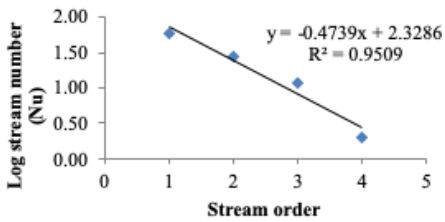


**Figure 3.** Stream number – stream order for upstream Sungai Batu catchment

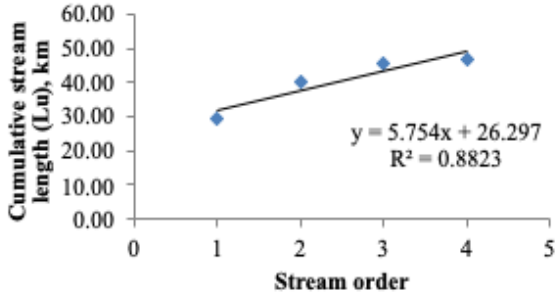


**Figure 4.** Cumulative stream length – stream order for upstream Sungai Batu catchment

gentle to steep slope terrain, moderate dense vegetation, and less permeable with medium precipitation (Soni, 2016). Low and moderate drainage density have a greatest basin lag time (Altaf *et al.*, 2013), subsequently reflects with moderate hydrological response to rainfall events.

Stream frequency ($F_s$) can be defined as the total number of streams in drainage basin over basin area (Horton, 1945). The $F_s$ measures the permeability of surface lithology, vegetation and relief. The $F_s$ for upstream Sungai Batu catchment is 4.06 (Table 3) which indicate the moderate runoff. In the previous studies, Soni (2016) has indicated that the 3.17 is a low $F_s$ and Meraj *et al.* (2015) have indicated that the 5.34 is a high $F_s$. The moderate runoff condition associated with the greatest lag time to peak discharge that could result in flooding especially during monsoon seasons with high rainfall intensity.

Drainage texture ($D_t$) is one of the important in geomorphology concept which shows the relative spacing of the drainage lines and it has been described as the total number of stream segments of all order per perimeter of that area (Horton, 1945). Drainage texture is influenced by infiltration capacity (Horton, 1945). The drainage texture has been classified into 5 classes (Smith, 1950); very coarse (< 2), coarse (2 – 4), moderate (4 – 6), fine (6 – 8), and very fine (> 8). In the present study, the $D_t$ for upstream Sungai Batu catchment is 4.11 (Table 3) which categorized under moderate drainage texture category. Hydrologically, this condition indicate that moderate $D_t$ have a moderate or large basin lag time period to peak discharge. The basin lag time to peak discharge is getting large as the $D_t$ is become very coarse. Esper Angillieri (2008) has stated that the very coarse texture has a large basin lag time period and vice versa.

The elongation ratio ($R_e$) can be defined as the ratio between the diameter of circle of the same area as the drainage basin and the maximum basin length (Schumm, 1956). Strahler (1964) has classified the elongation ratio into 5 main groups such as; circular (0.9 – 1.0), oval (0.8 – 0.9), less elongated (0.7 – 0.8), elongated (0.5 – 0.7) and more elongated (< 0.5). Based on Table 3, the $R_e$ for upstream Sungai Batu catchment is 0.69 (elongated). For the circularity ratio ($R_c$), it can be expressed as the basin area ratio to the area of circle having the same perimeter as the basin (Miller, 1953). Singh *et al.* (2014) have stated that the circularity ratio is significantly influenced by the stream length and frequency; geological structures; land use or land cover; climatic condition; relief and basin slope. The $R_c$ for upstream Sungai Batu catchment is 0.53 (Table 3) indicating that the area is elongated and has a permeable surface. Form factor ($F_f$) can be defined as the ratio of basin area to square of the length of basin (Horton, 1932). The $F_f$ for upstream Sungai Batu catchment is 0.38 (Table 3). In terms of hydrological stream response, the values of $R_e$, $R_c$, and $F_f$ indicate that the elongated basin shape with flatter peak of low flow for longer duration, lower erosion and sediment transport capacities and tend to form a floods diminution due to the flow from

**Table 3.** Areal aspect and relief aspect for upstream Sungai Batu catchment

| Aspect | Parameters | Value |
|---|---|---|
| Areal | Area, A ($km^2$) | 24.40 |
| | Perimeter, P (km) | 24.10 |
| | Basin length, $L_b$ (km) | 8.05 |
| | Drainage density, $D_d$ | 1.93 |
| | Stream frequency, $F_s$ | 4.06 |
| | Drainage texture, $D_t$ | 4.11 |
| | Elongation ratio, $R_e$ | 0.69 |
| | Circularity ratio, $R_c$ | 0.53 |
| | Form factor, $F_f$ | 0.38 |
| | Length of overland flow, $L_g$ | 0.26 |
| | Constant channel maintenance, C | 0.52 |
| Relief | Basin relief, R (km) | 0.33 |
| | Relief ratio ($R_r$) | 0.04 |
| | Ruggedness number ($R_n$) | 0.63 |

tributaries into the main stream which require a greater basin lag times and space (Altaf *et al.*, 2013; Soni, 2016).

Length of overland flow ($L_g$) is one of the most important parameters which significantly influenced the hydrologic and physiographic development of drainage basin. Horton (1945) expressed the length of overland flow as the equals half the reciprocal of the drainage density. Chandrashekar *et al.* (2015) has stated that the rapid of surface runoff is mainly influenced by the length of the overland flow. The $L_g$ for upstream Sungai Batu catchment is 0.26 (Table 3). The $L_g$ between 0.2 to 0.3 $km/km^2$ indicates the moderate ground slope, moderate infiltration which leads to moderate runoff (Chandrashekar *et al.*, 2015). The constant channel maintenance ($C_c$) is the inverse of the drainage density having the dimension of length as a property (Schumm, 1956). The $C_c$ for upstream Sungai Batu catchment is 0.52 (Table 3), indicate the higher value of $C_c$ reveals strong control of lithology with high permeability surface, high infiltration rates, moderate surface runoff (Soni, 2016).

### *3.3 Relief morphometric parameters*

Basin relief (R) is important factor in morphometric study to understand the geomorphic processes involved and land form characteristics (Sahu *et al.*, 2017) which are responsible for stream gradient that could influences flood pattern and amount of sediment volume that can be conveyed (Hadley and Schumm, 1961). To define relief DEM is shown in Figure 2. The R value of upstream Sungai Batu catchment is 0.33 km (Table 3). Relief ratio ($R_r$) indicate the overall steepness of drainage basin and the intensity of erosional process operating on the basin slope (Schumm, 1956). The value of $R_r$ in the present study is relatively low with 0.04 (Table 3), indicate the existence of basement rocks and moderate relief (Sahu *et al.*, 2017) and gentle slope (Soni, 2016). The upstream Sungai Batu catchment has a ruggedness number ($R_n$) of 0.63 which is relatively low and indicate the least susceptible to soil erosion (Altaf *et al.*, 2013; Sahu *et al.*, 2017).

## 4. Conclusion

The morphometric analysis was carried out for upstream Sungai Batu catchment by measuring the landform shape and its dimension through GIS as a main tools and mathematical analysis in the morphometric study. The morphometric study emphasize on

3 main aspects; linear, areal and relief. Based on 3 main aspects in this morphometric study, it can be safely concluded that most of the morphometric parameters value influenced the hydrological stream response for upstream Sungai Batu catchment with a moderate runoff condition. The moderate runoff condition is highly associated with the greatest basin lag time to peak discharge, lower erosion and sediment transport capacities and tend to form a floods diminution due to the flow from tributaries into the main stream which require a greater basin lag times and space. Although this study area has been concluded as a catchment with high permeability surface, high infiltration rates and moderate surface runoff, the study area has confronted with the flash flood events on November 2012 that cause a severe damage of properties. The high rainfall intensity cause the water from Batu Dam released into Sungai Batu and indirectly result in flooding and affect the residential areas as the water is exceed beyond capacity of the river. The time of concentration, lag time, peak discharge of various return periods parameters is suggested to be highlighted in the further research study for the better understanding and subsequently, it can benefit the decision makers to make sustainable development in watershed planning and management; land and water resources management; flood hazards and mitigation measure control; and erosion control.

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