DELINEATION OF THE ROMPIN RIVER BASIN AND NETWORK USING VARIOUS GIS APPLICATIONS

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ABSTRAK

Lembangan Sungai Rompin terutama di rantau hilir sangat sensitif terhadap banjir monsun atau banjir kilat. Kawasan-kawasan banjir sangat bergantung kepada ketinggian puncak di lembangan di mana tanah rendah lebih cenderung dipengaruhi. Oleh itu, ini sangat penting untuk mengekstrak ciri-ciri fizikal lembangan untuk disepadukan dalam analisis banjir. Objektif kajian ini adalah untuk menggambarkan rangkaian sungai dan tadahan untuk Lembangan Sungai Rompin menggunakan aplikasi GIS yang berbeza, dan menilai prestasi aplikasi GIS. Digital Elevation Model(DEM) dengan resolusi 30 m telah digunakan dalam kedua-dua alat aplikasi GIS (ArcGIS dan QGIS) untuk penambatan rangkaian sungai dan lembangan. Proses penggalian termasuk penyejukan rangkaian sungai, proses penyisihan menGISi, proses pengumpulan aliran, proses pengekstrakan rangkaian saliran dan proses pengekstrakan aliran sungai. Rangkaian sungai simulasi dari ArcGIS dan QGIS telah dinilai dan dibandingkan dengan rangkaian sungai digital dari peta Google untuk persembahan mereka. Ciri fizikal dari dua alat aplikasi GIS telah dibandingkan dan diteliti dalam kajian ini. Bagi kawasan lembah sungai, ArcGIS mempunyai 4185 km^2 kawasan dan QGIS mempunyai 4234 km^2 kawasan. Perimeter lembangan sungai untuk ArcGIS adalah 651 km, sementara QGIS mempunyai 718 km perimeter. Ketinggian minimum untuk ArcGIS dan QGIS adalah -16 dan 2 masing-masing, manakala untuk ketinggian maksimum untuk ArcGIS dan QGIS adalah 988 dan 804. Untuk ciri-ciri sungai, ArcGIS mempunyai 771 stream, manakala QGIS mempunyai 93 stream. Peratusan kesilapan purata bagi tiga ketinggian yang berbeza telah dinilai dan dibahagi kepada ketinggian yang tinggi, ketinggian pertengahan dan ketinggian yang rendah. Untuk ArcGIS, nilai yang diperolehi untuk ketinggian tinggi, pertengahan dan rendah adalah 188m, 240m dan 470m, manakala untuk QGIS, nilai yang diperolehi untuk ketinggian tinggi, pertengahan dan rendah adalah 217m, 446m dan 485m. Membandingkan keputusan yang diperoleh daripada ArcGIS dan QGIS dengan rangkaian sungai digital, didapati bahawa aplikasi ArcGIS dapat menggambarkan rangkaian sungai dengan lebih tepat pada ketinggian yang tinggi dan pertengahan, sementara QGIS hanya boleh melakukan lebih baik pada ketinggian yang tinggi. Walaupun QGIS boleh dimuat turun secara percuma dari laman web, namun ia hanya boleh berfungsi dengan baik pada ketinggian yang tinggi. Oleh kerana masalah banjir biasanya berlaku di ketinggian yang lebih rendah, QGIS mungkin tidak mencukupi untuk digunakan untuk menggambarkan rangkaian sungai pada tahap yang lebih rendah dalam kajian ini.

ABSTRACT

Rompin River Basin especially at the downstream region is highly prone to monsoon flood or flash flood. Flooding areas are closely depending on the topographical elevation in the basin where lower ground is more likely to be affected. Thus, it is essential to extract the physical characteristics of the basin to be integrated in flood analysis. The objectives of this study are to delineate river networks and catchment for the Rompin River Basin using different GIS applications, and evaluate the performance of the GIS applications. Digital Elevation Model (DEM) of 30 m resolution was applied in both GIS application tools (ArcGIS and QGIS) for the delineation of the river network and basin. The delineation processes include river network conditioning, fill sink process, flow accumulation process, drainage network extraction process and watershed basin extraction process. The simulated river network from ArcGIS and QGIS were evaluated and compared with the digitized river network from Google map for their performances. The physical characteristics from two GIS application tools were compared and tabulated in this research. For the area of the watershed basin, ArcGIS has an area of 4185 km^2 and QGIS has an area of 4234 km^2. The perimeter of the watershed basin for ArcGIS is 651 km, while QGIS has a perimeter of 718 km. The minimum elevation for ArcGIS and QGIS are -16 and 2 respectively, while for the maximum elevation for ArcGIS and QGIS are 988 and 804. For the river attributes, ArcGIS has around 771 attributes, while QGIS has around 93 attributes. The average error percentage for three different elevation has been evaluated which are high elevation, intermediate elevation and low elevation. For ArcGIS, the value obtained for high ,intermediate and low elevation are 188m, 240m and 470m, while for the QGIS, the value obtained for high ,intermediate and low elevation are 217m, 446m and 485m. Comparing the result obtained from ArcGIS and QGIS to the digitized river network, it is found that ArcGIS application can delineate the river network more accurately at the intermediate and high elevation, while QGIS can only perform better at high elevation. Although QGIS can be download for free on website, however it can only perform well on high elevation. Since the flood problem is normally occur in lower elevation, QGIS may not be sufficient to be used to delineate the river network at lower level in this study.

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LIST OF SYMBOLS

µ	Mean value
n	Population size

LIST OF ABBREVIATIONS

DID	Department Of Irrigation And Drainage
GIS	Geographic Information System
ASTER	Advanced Spaceborne Thermal Emission And Reflection Radiometer
DEM	Digital Elevation Model
DTM	Digital Terrain Model
DSM	Digital Surface Model
GRASS	Geographic Resources Analysis Support System
HMS	Hydrologic Modelling System
IFSAR	Interferometric Synthetic Aperture Radar
LIDAR	Light Detection And Ranging
NASA	National Aeronautics And Space Administration
RRB	Rompin River Basin
SRTM	Shuttle Radar Topography Mission
USGS	United States Geological Survey

CHAPTER 1

INTRODUCTION

1.1 Background

Natural disasters such as floods are happening more frequently due to climate change (Ghani, et al., 2012). Climate variability of a region is often difficult to predict and hence causing it impossible to completely mitigate flood problems. In Malaysia, two types of floods that hit this country in a yearly base are flash flood and monsoon flood. Flash flood is caused by high intensity rainfall in a short period and generally occurs in high imperviousness urban area. Meanwhile, monsoon flood is caused by the seasonal rainfall that takes place during October to March.

Floods in Malaysia occurred in many areas regardless of the topographical characteristic. Rompin District is one of the area that is frequently affected by flood particularly during the monsoon season. The most recent monsoon flood as reported by (DID, 2018) occurred in January 2018. Total area affected by the monsoon flood was about 12.5 km^2 with flood depth between 1 m to 4.5 m. Five river levels were observed to be at the warning level, namely the Sungai Kurnia at Kampung Kurnia (1.96m), Sungai Puteri at Kuala Rompin (2.03m), Sungai Rompin at Kampung Kerpal (2.18m), Sungai Aur at Kampung Aur (14.60m) and Sungai Keratong at Bukit Serok (21.82m). The flood was caused by heavy rainfall, river overflow and clogging of the drainage system. Besides monsoon flood, flash flood also occurred in the Rompin District in the early January of 2018 covering a total area of 1 km^2. The flood depth recorded was 0.4 m. The main causes of the flash flood event are heavy rainfall and clogging of the drainage system.

Since flood problems imposed serious damaged to the society, it is essential to establish a mapping system indicating the prone areas for future urban planner.

Mapping is very useful to identify and demarcate potential flood area based on physical and topographic characteristic. Traditionally, topographical map was used to study the characteristics of the area of interest (Kumar & Dhiman, 2014). The watershed area was drawn in reference to the contour map and the highest points of the contour were linked to generate the model boundary (Visharolia, et al., 2017). This process is time consuming and a good quality of topographical map is needed. With the fast development in the technology nowadays, researcher and water manager have migrated from adopting the manual method to the digitalized technology in analyzing and visualizing topographical information. The digitalized topographic dataset of the Earth's surfaces is represented by Digital Elevation Model (DEM) . Information such as topographic properties, geomorphometric parameters, morphometric factors or terrain data can be extracted from the DEM dataset (Donia, 2009). In this research, DEM resolution of 30 m was used to delineate the watershed basin and river network (Arbind & Madam, 2017).

DEM dataset was applied in Geographic Information System (GIS) for analysis. Geographic Information System (GIS) is the computer-based tool which served as a framework to collects, manages, analyses, and visualizes data related to the position of the Earth's surfaces (Vinayak, et al., 2019). GIS tool is simple to utilize and has an effective geo-processing capacities which make it less demanding to visualize, oversee, analyze, alter and compose printable maps. Furthermore, GIS tool processes spatial information effectively and supports both vector and raster layers (Chandra Bose, et al., 2012). There are several open-source GIS software including QGIS, SAGA GIS, gvSIG and others available for watershed delineation. The GIS applications selected in this study are QGIS and ArcGIS in order to compare the accuracy and the efficiency of the software. One of the most important applications of GIS is the ability to delineate river basin & river network (Kaviya, et al., 2017).

Delineation of the river basin is one of the important part in solving flood problems and developing better water resources management (Mudler , 2011). Floods traditionally are predicted using hydrological watershed modeling, in order to achieve the design discharge and calculate water surface elevations and terrain analysis to produce a flood map (Jung & Merwade, 2015). In this study, the Rompin River Basin was delineated from DEM 30 m resolution using two different GIS software. The simulated river network results obtained were validated by comparing the error percentage in reference to topographical map & google satellite images. The results obtained for the delineated basin & river network can be utilized as the input topographic and hydrologic datasets for the hydrological study in water resource management work.

1.2 Problem statement

The Rompin River Basin is a highly potential flooding area due to monsoon or flash flood. In water resources management study, geographical information is important to identify the elevation of the land surfaces. Since Rompin River Basin has an area around 4285 km^2, it is difficult to delineate the river network by using manual method. This is because manual delineation processes can be very time consuming particularly in collecting and managing river network and hydrological information (Kumar & Dhiman, 2014). Thus, new technology is required to fasten the delineation process. With the rapid development of computerized technology, there are several software available capable in speeding up the delineation process. One of the applications that can be implement in this study is GIS application.

Different GIS software provides different levels of accuracy of the data. Generally, flood problems often occur at low lying area. In order to obtain sufficient information, GIS software plays an important role in data collection. Thus, there is a need to validate the DEM resolutions that generated by the different GIS software so that the performance limit of the GIS software can be defined. This helps to improve the quality of the extracted catchment physical characteristics by selecting the suitable application to delineate the watershed basin and river network.

1.3 Objectives

This study aims to:

- To delineate river networks and catchment for the Rompin River Basin using GIS applications.
- To evaluate the performance of GIS applications.

1.4 Scope and Limitation of Study

The Rompin District consists of five subdistricts which are Keratong Sub-district, Rompin Sub-district, Pontian Sub-district, Endau Sub-district and Tioman Sub-district. However, the Rompin River Basin includes only three subdistricts which are Keratong Sub-district, Rompin Sub-district and Pontian Sub-district. River network investigated in this study covers only the Rompin River and its tributaries.

The geographical information system (GIS) tools applied in this study were ArcGIS and QGIS. These GIS tools were selected because ArcGIS is well established and commonly used, while QGIS is a free software that can be easily downloaded from QGIS website. GIS tools were utilized to simulate and delineate the river network and catchment by using topographic datasets from SRTM DEM which has a 30 m x 30 m resolution.

1.5 Significance of Study

This study extracted the geographical information and established the hydrological characteristics of the Rompin River Basin. These results generated are useful in assisting water engineer or authority to analyze and monitor the hydrological characteristics and processes in the catchment. Through this study, water engineer or managers is able to identify and select the most suitable GIS application to be applied in their design processes based on the budget of the project. Despite the financial concern, the engineers can also make their choice according to the level of accuracy required for the project. The extraction of geographical information can be done in an accelerating means when using a more effective GIS application.

Comparing the result obtained from ArcGIS and QGIS to the digitized river network, it is found that ArcGIS application can delineate the river network more accurately at the intermediate and high elevation, while QGIS can only perform better at high elevation. Although QGIS can be downloading for free on website, however it can only perform well on high elevation. Since the flood problem is normally occur in lower elevation, QGIS may not be sufficient to be used to delineate the river network at lower level in this study.

CHAPTER 2

LITERATURE REVIEW

2.1 Watershed

A watershed is an area of land that water flows across, through or under on its way to a stream, river, lake or ocean. It possesses the actual waterway and the all the land that occupied within it. Watersheds exist in various kinds of shapes and dimension and all are interconnected along the landscape. A watershed can also be defined as an area of land in which all of the incoming precipitation drains to the same topographic low area (Edwards, et al., 2015). Sub-basins or sub watersheds can be defined as smaller watersheds located within larger watersheds. The boundaries of a watershed are called divides or ridges, which defined by its topographic high points. The area between those highpoints drain to a common point are classified as the same watershed. Any water that falls outside of a watershed divide enters another watershed and flows to another point because of the fundamental nature of watershed boundaries, Tesfa et al.,2011 describe the watershed as the ”basic modelling element” for hydrological problems (Tesfa, et al., 2011). An example of a watershed is shown in Figure 2.1.

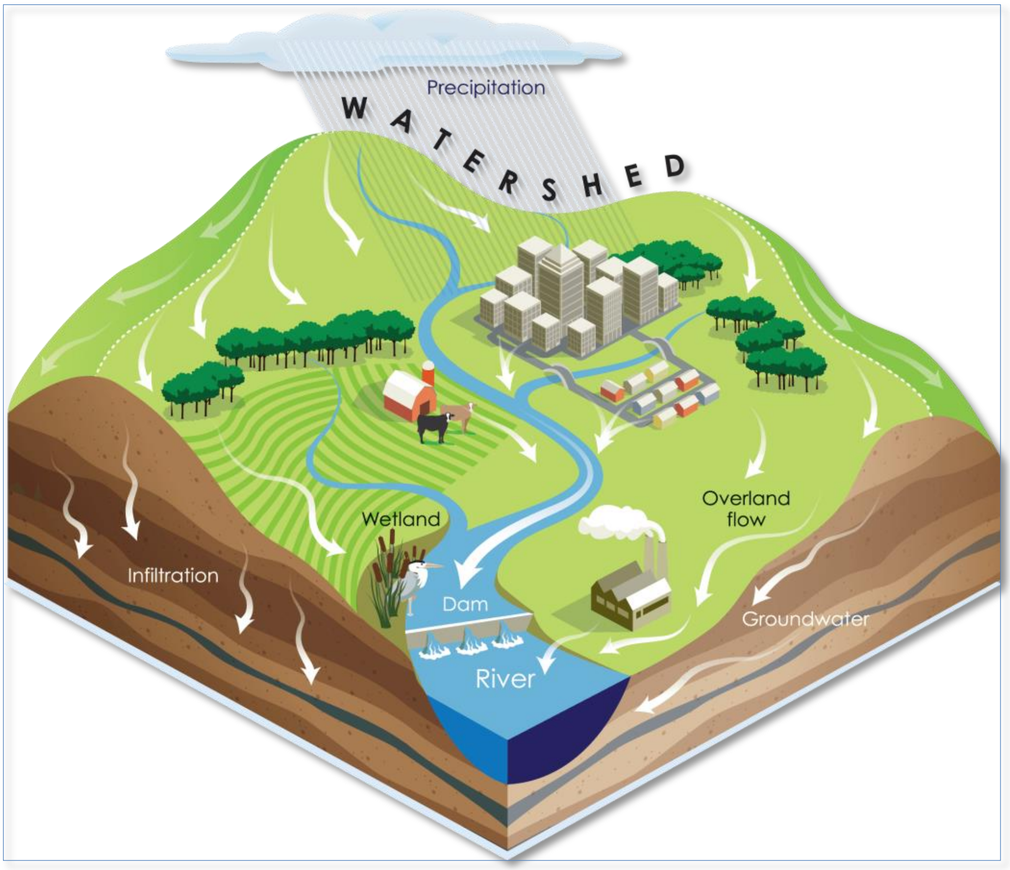

Figure 2.1 Watershed Diagram
Source: (CivicPlus Content Management System, 2019)

2.1.1 Physical Characteristics of the Watershed

There are many physical characteristics that influence the hydrological processes in a watershed. The physical characteristics that can affect the watershed including morphometry (size, shape, and topography), vegetation cover and soil cover. These characteristics show important physical controls such as the surface determine the amount runoff and streamflow processes in the watershed.

For morphometry characteristic, the quantity of rainfall received retained and runoff are determined by the size of watershed. A larger watershed contains larger channel and storage of water in basin. Large watershed characteristics are topography, geology, soil, climate and use and vegetation. The peak flow or runoff in small watershed is mostly determined by the overland surface that exists in the watershed. Meanwhile, the channel characteristic influences the peak flow or runoff in the larger watershed. The watersheds had been classified into different level based in the area of the watershed as the table shown below.

Table 2.1 Area Covered by Each Watershed

NO.	Type of Watershed	Area Covered
1	Micro watershed	0 to 10 ha
2	Small watershed	10 to 40 ha
3	Mini watershed	40 to 200 ha
4	Sub watershed	200 to 400 ha
5	Macro watershed	400 to 1000 ha
6	River basin	Above 1000 ha

Source: (TEAM AGRI INFO, 2018)

In general, watersheds can be divided into three aspects for the morphometric analysis which are (Palaka & Sankar, 2016):

- Linear aspect: one dimension
- Areal aspect: two dimension
- Relief aspect: three dimension

Linear aspect means that the drainage network transport water and the sediments of a basin through a single outlet, which is marked as the maximum order of the basin and conventionally the highest order stream available in the basin considered as the order of the basin. The size of rivers and basins varies greatly with the order of the basin. Ordering of streams is the first stage of basin analysis. Strahler (1952) system of ordering streams has been followed in general because of its simplicity where the smallest, un-branched fingertip streams are designated as 1st order, the confluence of two 1st order channels give a channel segments of 2nd order, two 2nd order streams join to form a segment of 3rd order and so on. When two channel of different order join then the higher order is maintained.

Aerial aspect is also known as shape parameter. The areal aspect is the two dimensional properties of a basin. The properties that can be extracted from aerial aspect include Form Factor (Ff), Elongation Ratio (Re), Circularity Ratio (Rc) and Compactness Coefficient (Cc). Ff may be defined as the ratio of basin area to square of the basin length. The value of form factor would always be less than 0.754 (for a perfectly circular watershed). Smaller the value of form factor, more elongated be the watershed. The watershed with high form factors have high peak flows of shorter duration, whereas elongated watershed with low form factor ranges from 0.42 indicating them to be elongated in shape and flow for longer duration.

Re is defined as the ratio of diameter of a circle of the same area as the basin to the maximum basin length. Strahler states that this ratio runs between 0.6 and 1.0 over a wide variety of climatic and geologic types. The varying slopes of watershed can be classified with the help of the index of elongation ratio, i.e. circular (0.9-0.10), oval (0.8-0.9), less elongated (0.7-0.8), elongated (0.5-0.7), and more elongated (< 0.5).

Rc is the ratio of watershed area to the area of a circle having the same perimeter as the watershed and it is pretentious by the lithological character of the watershed. Miller (1953) has described the basin of the circularity ratios range 0.4 to 0.5, which indicates strongly elongated and highly permeable homogenous geologic materials.

Cc is used to express the relationship of a hydrologic basin to that of a circular basin having the same area as the hydrologic basin. A circular basin is the most susceptible from a drainage point of view because it yields shortest time of concentration before peak flow occurs in the basin.

Relief Aspect which is third dimension introduces the concept of relief. Linear and areal features have been considered as the two dimensional aspect lie on a plan. By measuring the vertical fall from the head of each stream segment to the point where it joins the higher order stream and dividing the total by the number of streams of that order, it is possible to obtain the average vertical fall. There are totally two properties that can be obtained from relief aspect which are Basin Relief (H) and Relief Ratio (RH). H is the elevation difference of the highest and lowest point of the valley floor. Rh is defined as the ratio between the total relief of a basin i.e. elevation difference of lowest and highest points of a basin, and the longest dimension of the basin parallel to the principal drainage line. The high values of Rh indicate steep slope and high relief and vice-versa. Run-off is generally faster in steeper basins, producing more peaked basin discharges and greater erosive power.

For the shape of watershed, it has various types of shapes such as rectangular, square, triangular, leaf shape and other shapes. Shape of watershed determines the shape index which is the ration of the length to the width of the watershed. It brings a great effect to the runoff disposal. If the shape of watershed is larger, the time of concentration becomes longer. Besides, the infiltration and the evaporation of water increase due to the large shape of watershed. The vegetation also obtains more water from the surface runoff.

For the topography, slope of the land affects the disposal of surface runoff and soil loss. The time of concentration and the infiltration of water influence by the degree and the length of the slope. Topography also controls the drainage that exist in the watershed. The slope of the land affects the length and the width of the channel which directly influence the time of concentration.

For the vegetation cover, it may control the hydrology process of watershed since the infiltration, water retention, runoff production, erosion and sedimentation affects to the water that flow to the main river or main basin. Besides, vegetation can also act as a stabilizing force. On the floodplain and along channel banks, roots provide a network of reinforcement to bind the soil matrix and increase soil strength. Although intense flood flows can scour, uproot, and remove young and newly established vegetation, established vegetation can act to stabilize channel bed sediment. As the vegetation matures, it becomes increasingly resistant to removal during flood flows.

For the soil, topographical development and rock types influence degree of water erosion, erodibility of channels and slope faces. Rocks like shale's, phyllites disintegrate effectively whereas igneous rocks don't dissolve. Physical and chemical properties of soil, specially texture, and structure and soil depth affect disposal of water by method for infiltration, storage and surface runoff.

2.2 Watershed Delineation

Watershed delineation is the process of determining the drainage area of any point on a stream or river network. In earlier time, topography normally becomes the main database to identify a river watershed. However, there are some of the physical characteristics of the catchment that are needed which are sometimes not easily available in the topographical map. Therefore, in order to cover the entire study areas, combination of different characteristics topographic maps are utilized. However, some of times these different maps possessed different scaling ratio and this complicates the data extraction processes. Furthermore, it can be a very tired and tough mission if the watersheds are delineated manually by using contour maps especially in flat terrains.

Nowadays, enhanced computer processing that strengthen and allow access to new terrain surface models have led to rapid and more accurate automatic watershed delineation techniques. Geographic Information System (GIS) software are one of the tools that can be implemented for watershed delineation to obtain parameters that are vital for management of water volume and quality, soil conservation, flood control, wild life habitat and other hydrological analyses (Daffi & Ahuchaogu, 2017). Digital Elevation Model (DEM) is the main input for the GIS software to analyse and arrange the watershed delineation. The quality and type of DEM and the computer algorithms used influences the accuracy of the result.

2.2.1 Manual Watershed Delineation

In the earlier days, watershed delineation was mainly conducted by the method of manual delineation. Traditional method for watershed delineation from the topographic map contains drawing lines to connect elevation points and contour lines. Since the work has to be manually done and subject to human objectivity, trivial errors are often unavoidable, especially for flat terrains and large areas (Al-Muqdadi & Merkel, 2011). Hence, it is not an easy task to define watershed boundaries precisely using topographic map (Visharolia, et al., 2017). The procedure of conducting the traditional delineation process including scanning the hard copies of topographic maps, draw and divides water drainage boundaries on the topographic maps under the help of counter lines, and eventually the watershed boundaries were delineated. After the formation of boundaries, the flow direction of water disposal to the basin or main river at low elevation is determined.

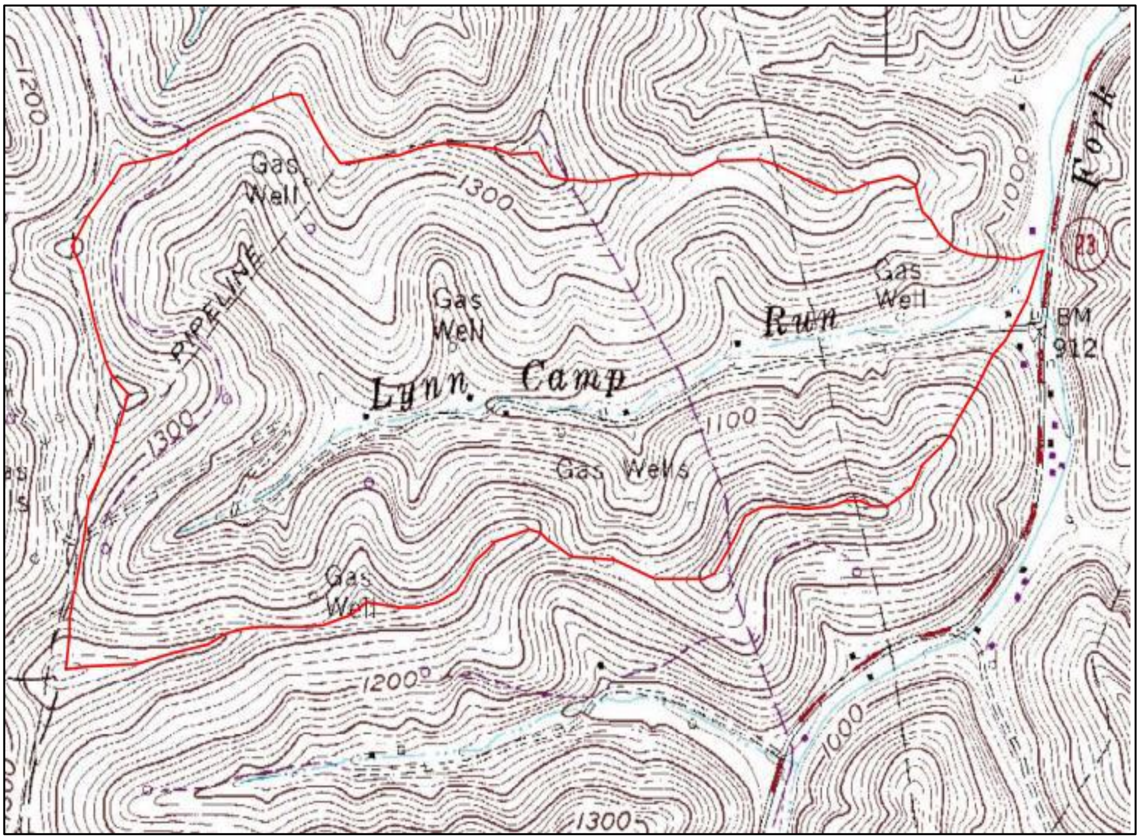

Figure 2.2 Manual Watershed Delineation
Source: (Merwade, 2012)

2.2.2 Watershed Delineation with GIS Applications

The rapid development in technology over the decades has improved the work performance of the watershed delineation processes in term of cost and time consumption. Gis application has been introduced as a new technique to overcome the disadvantages of manual delineation procedures. A key advantage of GIS is its ability to integrate, manage, and analyze large volumes of data, particularly over very large areas. GIS enables data to be integrated and viewed on the scale of an entire watershed, allowing a holistic approach to water resources management. Thus, this tool is widely used for delineation of watershed divide and identifying stream network. There are several GIS software applications that can be implemented to analyse watershed delineation such as QGIS, ArcGIS, GrassGIS, ILWIS and other GIS software. For this study, the GIS application that can be delineate the Rompin River Basin and its network were ArcGIS and QGIS. Both of these software can be implemented to plan for viewing, altering, and analysing geospatial information.

ArcGIS consist of well-established geo-processing framework which that is extensive and solid. However, all the features and extensions provided in ArcGIS required single or multiple licenses to gain access. For the basic license, it allows the access to most of the processing tools, but certain advanced extension would need an advanced license. ArcMap is the main platform for the hydrological analysis in ArcGIS in which all the GIS processes are performed and the results are displayed in this platform. ArcGIS contains spatial analyst extension that can be used for watershed delineation. One of the advantages of ArcGIS is that this application integrated with the HEC-GeoHMS extension. The data that generated in this integrated platform can be directly imported into the hydrology software such as HEC-RAS and HEC-HMS. The ArcGIS Watershed Delineation service provides a quick method for retrieving watershed delineations (Kopp, 2013). This can help to reduce the time to arrange and sorting the data that collect from GIS software.

QGIS is a cross-platform, user-friendly open source geographic data framework. It has no license requirement and restriction which means that there is no limit for the user to utilize all the tools provided in QGIS. Despite the free usage, this platform can also handle numerous databases functionalities and formats providing compatible results obtained from ArcGIS application. The main plugins in QGIS allow it to develop sufficient amount of capabilities. Furthermore, the program avails special, simple to utilize and effective geoprocessing capacities which make it less demanding to visualize, oversee, analyze, alter and compose printable maps. QGIS processes can extract spatial information more effectively and it supports both vector and raster layers.

Despite of the different GIS software platforms, most of the application tools analyse and interpret the watershed delineations by considering the following basic procedures:

I. Fill Sinks Operation: This is used to wash out the DEM to remove sinks, which were areas where water flowed into and not out because all surrounding pixels were higher in elevation.

II. Flow Direction Operation: This operation indicated the pixel, out of the eight neighbouring pixels, in a block of 3 by 3 pixels, towards which water flows naturally.

III. Flow Accumulation Operation: This operation performed a cumulative count of the number of pixels that naturally drain into outlets. It represented the amount of water that would flow into each cell assuming all the water became runoff and there was no interception, evapotranspiration or loss to groundwater. The operation can be used to find the drainage pattern of a terrain.

IV. Drainage Network Extraction: This operation extracted a basic drainage network.

V. Drainage Network Ordering: The operation examined all drainage lines in the drainage network map from the Drainage Network Extraction Operation.

VI. Catchment Extraction Operation: This operation constructed catchments for each stream found in the output map of the Drainage Network Ordering Operation. The operation used a flow direction map to determine the flow path of each stream.

VII. Catchment Merge Operation: The Catchment merge operation merged adjacent catchments found from the Catchment Extraction Operation. Catchments can be merged in two ways:

  - By specifying a point map that contains locations of the stream outlets within a catchment.
  - By simply specifying a Strahler or Shreve ordering value.

2.3 Digital Elevation Model (DEM)

DEM data is the main input for GIS application processes which can be prepared by various methods. A DEM is a quantitative, three-dimensional portrayal of the earth surface got from elevation information. It gives fundamental data with respect to terrain properties. The essential features, which can be obtained from DEMs include slant, perspective, profile curvature and catchment size. Other than that, the data that can be extracted also consists of the upslope region, topographic list, stream power index, radiation index and temperature index (Mukherjee, et al., 2012). A DEM is ordinarily given in one of the three configurations: the raster-based matrix DEM, the vector-based Triangular Irregular Network (TIN) and form based capacity structure. The TIN is considered to be an essential (estimated) DEM while the Raster DEM is viewed as a derived (optional) DEM (Mukherjee, et al., 2012).

Triangulated Irregular Network (TIN) is defined as an efficient and flexible terrain model with multiple resolutions offered by the irregular domain. In TIN, the information on the density may vary from area to area. More points are included to the area where there is more variation in elevation. Oppositely, lesser points are needed in regions with less elevation variation. The benefit of categorizing the density can reduce the computational and storage costs as well as and avoiding data redundancy (Azeredo Freitas & Costa , 2016).

The surface of the terrain in TIN is modeled by several triangles generated from a set of points distributed over space according to certain selected criteria. Each point is defined by a triple (x, y, z) with x and y being the horizontal plane coordinates and z being the elevation. Ideally, these points represent the main characteristics and characteristics of the terrain, so that a TIN can adapt effectively to its irregularities and give a more accurate representation of the original data, since the altitude of each point is not altered and the triangles define linear levels, where new points can be interpolated.

If a TIN contains as many triangles as regular grid cells in some area, the grid's sampling and selection of very important points (VIPs) allows the TIN terrain model to be generated with no detailed loss of the topography spatial information and significant storage savings. On the hand, if the terrain models are more than the regular grids, it is a worthwhile to select specific points from the grid which characterize the surface-specific characteristics such as ridges, hills, tops, saddles, channels, valleys and pits, to be further triangulated.

Raster DEM is known as a derived (optional) DEM because flat areas and closed depressions in raster DEMs are frequent artifacts resulting from inaccuracies and limited resolution, especially DEMs of low-relief terrain. These features contain cells for which there is no downward step to the adjacent cell, as all adjacent cells are at or above the same height. This presents problems for automated drainage methods which are based on simulations of overland flow across DEM raster surfaces.

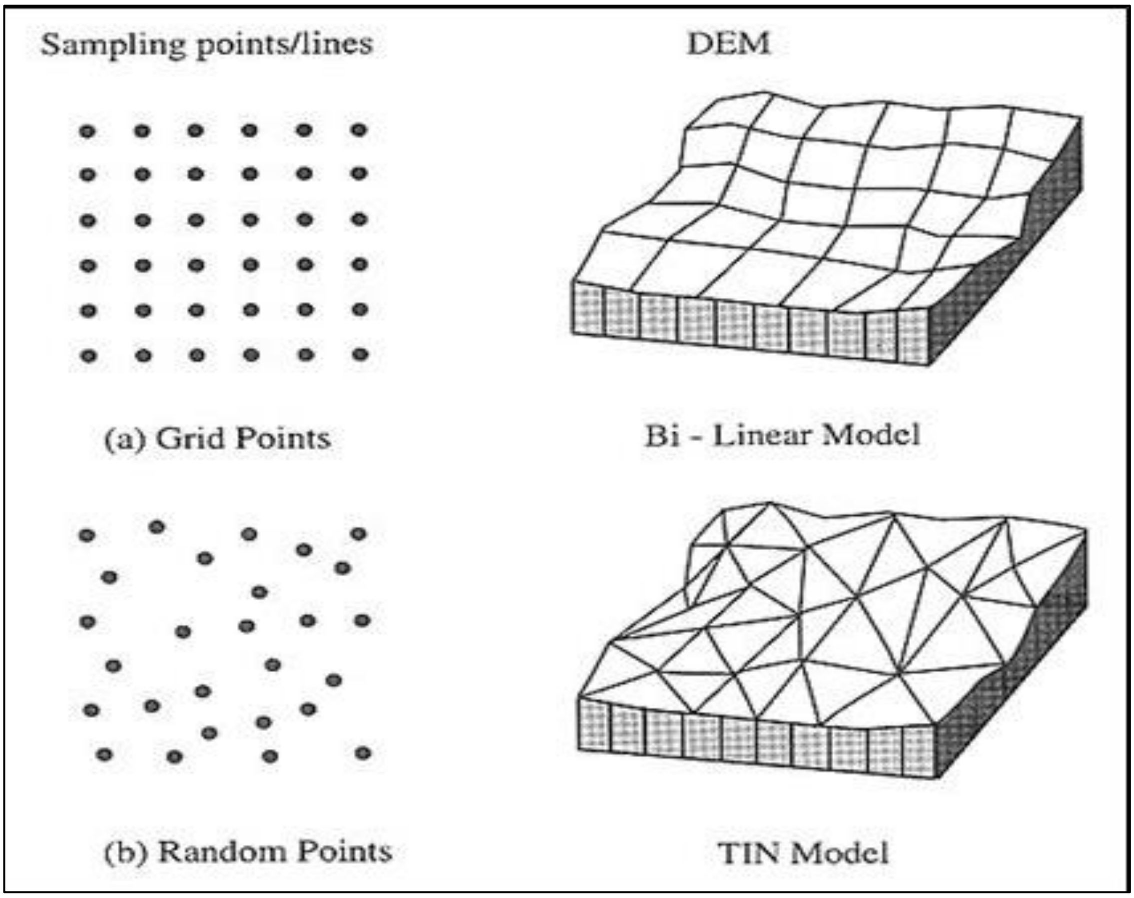

Figure 2.3 Different type of DEMs
Source: **(Murai & Shunji, 1999)**

Whenever a DEM shows the Earth's surface including object stature (tree tallness, building stature and so forth.), it is frequently known as a Digital Surface Model (DSM). A model of the uncovered Earth surface called as a Digital Terrain Display (DTM). A few strategies have been implemented for DEM generation, for example, photogrammetry utilizing stereo information, interferometry, airborne laser filtering and introduction of contour maps.

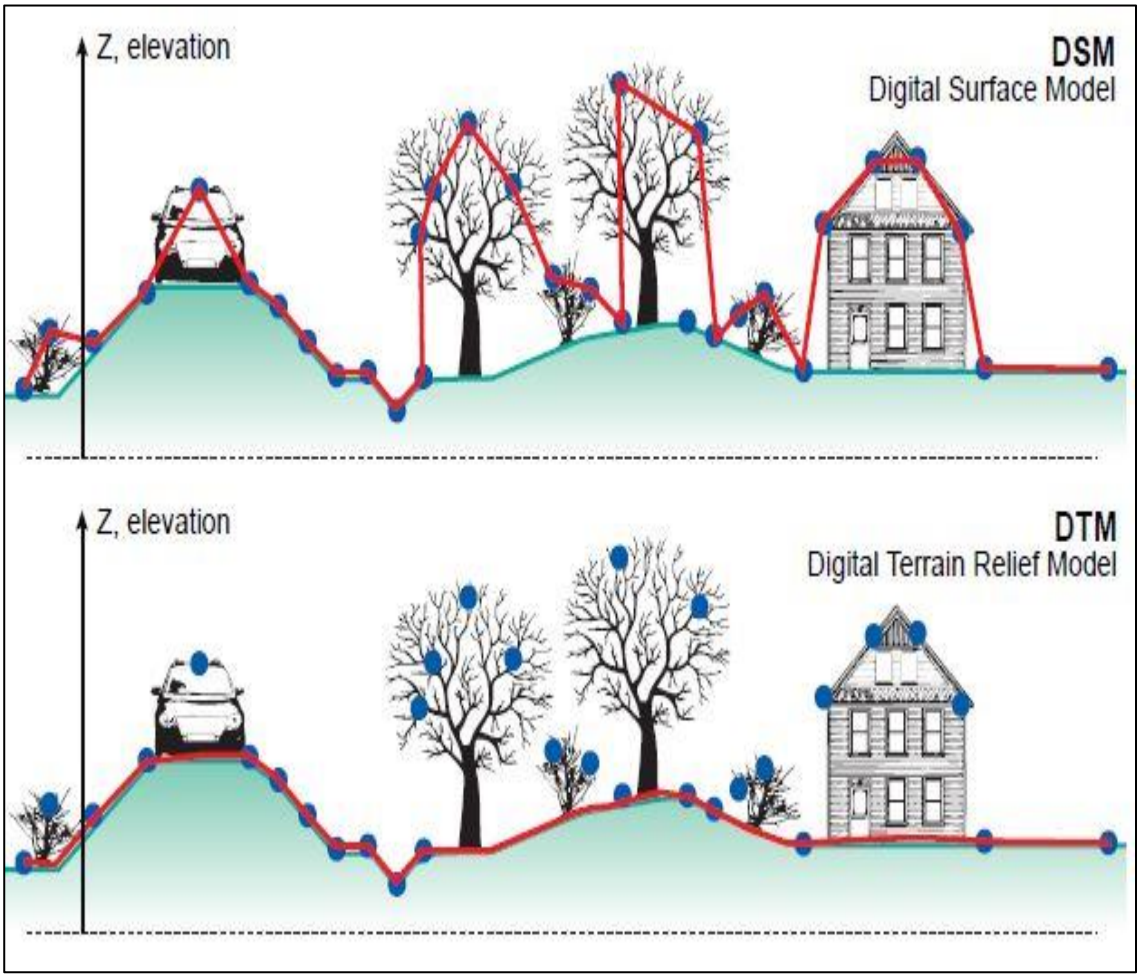

Figure 2.4 Comparison between DSM and DTM
Source: (Feringa & Thomas, 2019)

2.3.1 Application of DEM in Hydrology

Application of DEM plays an important role in determining the drainage network and the associated drainage divided in the creation of a hydrological database system. In hydrological process, DEM can be applied in many aspects to obtain the information relevant as shown below:

- Estimating elevation
- Estimating slope and aspect
- Determining drainage networks
- Determining the watershed

- Terrain stability – Areas prone to avalanches are high slope areas with sparse vegetation, which is useful when planning a highway or residential subdivision.

- Soil mapping – DEMs assist in mapping soils which is a function of elevation (as well as geology, time and climate).

- To create a profile graph from digitized features of a surface.

2.4 Shuttle Radar Topography Mission (SRTM) Data

Shuttle Radar Topography Mission (STRM) is one of the satellite interferometry that is captured with the synthetic aperture radar. The synthetic aperture radar is able to ultilise two radar images simultaneously from antennas to create DEM. STRM is currently the finest source of DEM data worldwide. The STRM DEM data that created by NASA is a great breakthrough in digital mapping of the world. Besides, there are a large number of the tropics and other places of the developing world gains a great advantage on the advance in the accessibility of high quality elevation data.

For most of the world, SRTM data were originally made publicly available at a three-arc-second pixel size which is 1/1,200th of a degree of latitude and longitude. Figure 2.5 shows the comparison between three different resolutions of SRTM data. The figure on the left represents the 90 meters (295 feet) resolution known as three-arc-second pixel size of SRTM data. Meanwhile, the one-arc-second pixel size is shown in middle indicating 30 meters (98 feet) resolution DEM. The right side figure showing the newly released data captured via the Interferometric Synthetic Aperture Radar (IFSAR) which represents 5 meters (16 feet) resolution DEM.

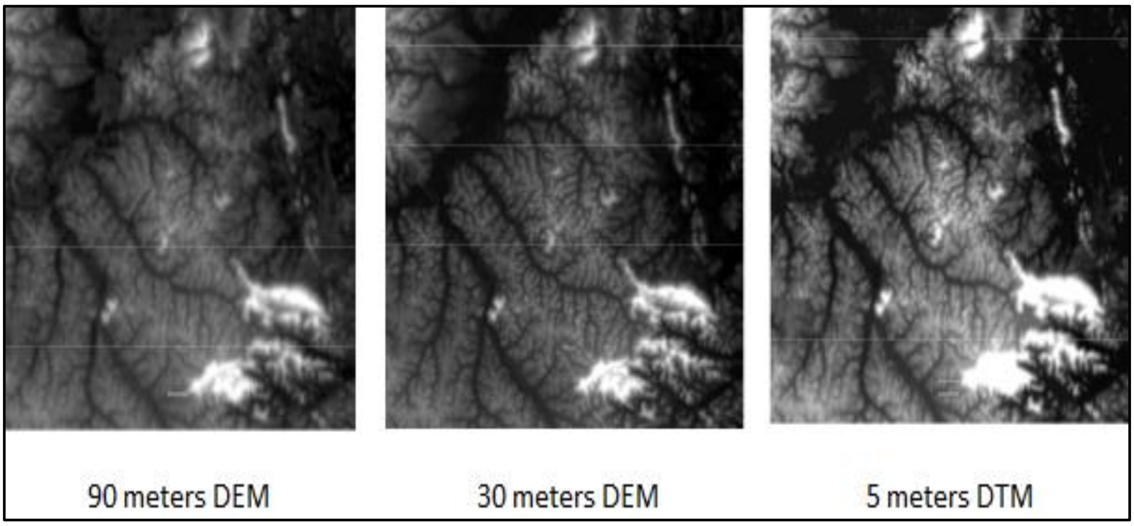

Figure 2.5 Comparison between 5m DTM, 30m DEM and 90m DEM

SRTM Non-Void Filled elevation data were processed from raw C-band radar signals spaced at intervals of 1 arc-second (approximately 30 meters) at NASA's Jet Propulsion Laboratory (JPL). This version was then edited or finished by the NGA to delineate and flatten water bodies, better define coastlines, remove spikes and wells, and fill small voids. Data for regions outside the United States were sampled at 3 arc-seconds (approximately 90 meters) using a cubic convolution resampling technique for open distribution.

SRTM Void Filled elevation data are the result of additional processing to address areas of missing data or voids in the SRTM Non-Void Filled collection. The voids occur in areas where the initial processing did not meet quality specifications. Since SRTM data are one of the most widely used elevation data sources, the NGA filled the voids using interpolation algorithms in conjunction with other sources of elevation data. The resolution for SRTM Void Filled data is 1 arc-second for the United States and 3 arc-seconds for global coverage.

SRTM 1 Arc-Second Global elevation data offer worldwide coverage of void filled data at a resolution of 1 arc-second (30 meters) and provide open distribution of this high-resolution global data set. Some tiles may still contain voids. The SRTM 1 Arc-Second Global (30 meters) data set releases in phases starting September 24, 2014. Users should check the coverage map in Earth Explorer to verify if their area of interest is available. Please note that tiles above 50° North and below 50° South latitude are sampled at a resolution of 2 arc-second by 1 arc-second.

2.5 Geographical Information System

Geographic Information System (GIS) is a computer-based tool that is widely used in watershed physical characteristic extraction. GIS tool is a framework to collects, manages, analyses, and visualizes data related to the position of the Earth’s surface from DEM databases. The subsystems that are available in the GIS software as listed below :

- Data input subsystem: pre-processing, transformations
- Data storage and retrieval subsystem: organizes for retrieval, editing, updating
- Data manipulation and analysis subsystem: aggregation, dis-aggregation, modelling
- Reporting (output) subsystem: output (tabular, graphic, map…)

A characteristic that can distinguish a GIS tool from other general computer mapping or other mapping system is the interconnection between the information database. The correlations between different pieces of data can be interpreted or analysed easily once the database is constructed.

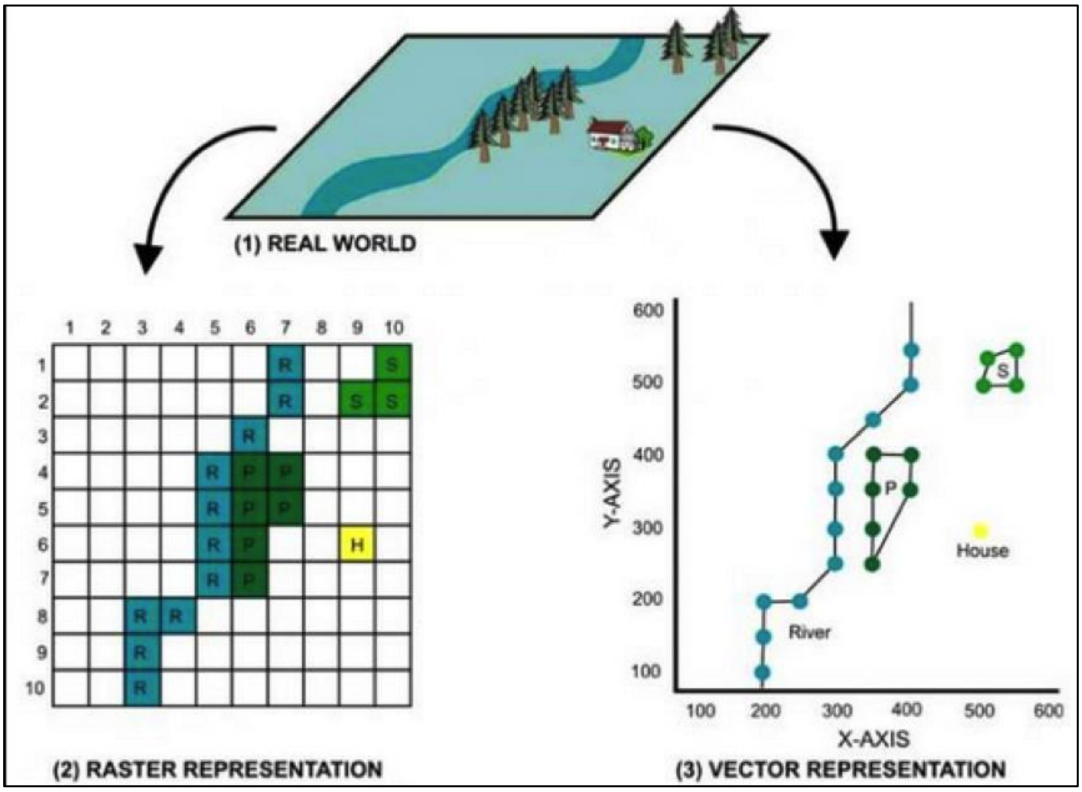

Figure 2.6 Raster and Vector Data Models
Source: (Dhanashri, 2015)

Two major types of spatial data in the GIS tool are raster and vector as display in Figure 2.6. In raster, the entire zone of the map is subdivided into a lattice of small cells. A value is stored in every one of these cells to represent to the idea of whatever is available at the relating area on the ground. Raster information can be thought of as a lattice of qualities. The real utilization of raster information includes storing map data as computerized image, in which the cell value related to the pixel colour of the image. To recreate the image, the computer read every one of these cell values one by one and applies them to the pixels on the screen.

For vector information, the features are recorded one by one, with shape being characterized by the numerical values of the sets of xy coordinates.

- A point is defined by a single pair of coordinate values.
- A line is defined by a sequence of coordinate pairs defining the points through which the line is drawn.

- An area is defined in a similar way, only with the first and last points joined to make a complete enclosure.

Vector data can be thought of as a list of values. In vector data the position and shape of the building is captured as a series of four pairs of numerical coordinates. To reproduce the building in a GIS the computer reads these values and draws a line linking the coordinate positions.

2.6 Previous Case Studies

Vimal, et al. (2012) studied the extraction of Drainage Pattern from ASTER and SRTM Data for the Cauvery River Basin using GIS Tools. The Cauvery River Basin spanning across three states of the Southern India region namely Tamilnadu, Karnataka and Kerala. The study outcome shows that the threshold value for flow limitation in ASTER DEM (30 meter resolution) is higher than SRTM (90 meter resolution) due to the difference in resolution. Correspondingly, drainage density is notably higher in ASTER for scarcely distinguishable watershed boundary obtained as a result. Sinha, et al. (2015) did a study on Watershed Delineation of Narmada Basin- Indira Sagar Dam to Maheshwar Dam of Madhya Pradesh. It is concluded that this methodology can be used to generate faster results for estimation of runoff which are important for basin area planning. These results can be effectively used in hydrological modelling, land use planning and watershed studies, reservoir operation and planning. In the study by Guru & Meher (2016), Delineation of Mahanadi River Basin has been extracted by using GIS and ArcSWAT. In the present work the DEM is taken of the study area and being delineated by the assistance of the ArcSWAT and small watersheds are being shaped according to the release of the water in the study zone. By the assistance of these small watersheds we can get a concrete idea for the flow of water direction and the occurrence of the slope in the watershed.

Viswanathan, et al. (2015) have done a study on Watershed Delineation for Varahanadhi basin using Open source Geospatial Technology. In the present study on Varahanadhi river basin is done by using software QGIS based on digital elevation model. In addition to that various factors like Rain fall, soil condition, geological study and geomorphology of our study area have been analysed. It is found that some of water bodies have been encroached which resulted in Water demand. The awareness of creating watershed at necessary places to use the rainwater efficiently has been created. Bharata, et al. (2015) compared the 30 m ASTER GDEM and topographic sheet with ratio of 1:50,000 to delineate the watershed and drainage network for the River Shimsha by using QGIS. The results show that there is no notable variation on the drainage network and discharge obtained from both methods. Besides, the study concluded that the 30 m resolution DEM is sufficient for large watershed delineation, while topographic sheet is recommend to use in smaller watersheds studies to get more accurate results. Abhishek & Regulwar (2015) has developed and discussed in relation to the watershed modelling using Quantum Geographic Information System (QGIS). This study aimed at understanding the various digitized features such as DEM, watershed delineation, contour maps rainfall and physiographical features and soil erosion risk in the watershed by using QGIS 2.2.2 modelling method with GRASS interface in a GIS framework. The study provided a reliable prediction of soil erosion prone zone within the watershed.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter describes the methodologies adopted to delineate the river network and catchment for the Rompin River Basin. The GIS application software that were applied to perform the delineation processes for this study were ArcGIS version 10.4 and QGIS Desktop version 3.6.0. Data collection was carried out to seek for the available and suitable options for both the GIS software and DEM used for this study. Based on the preliminary survey, SRTM 1 Arc-Second Global DEM with 30m resolution is the most suitable to be used for comparing the performance of the GIS tools selected.

The delineated river network was validated against the digitized river network in reference to the topo map and Google Earth map. The performances of the delineated results were evaluated by performing the average error analysis for the entire river network. For the purpose of determining the suitability of the applications in term of elevation, the error analyses were carried out for 3 categories: low elevation, mid-elevation and high elevation.

3.2 Flow Chart of Methodology

The procedures in conducting this study are presented in the form of chart. Figure 3.1 showed the flow chart for the extraction of river network and river basin from DEM for the Rompin River Basin.

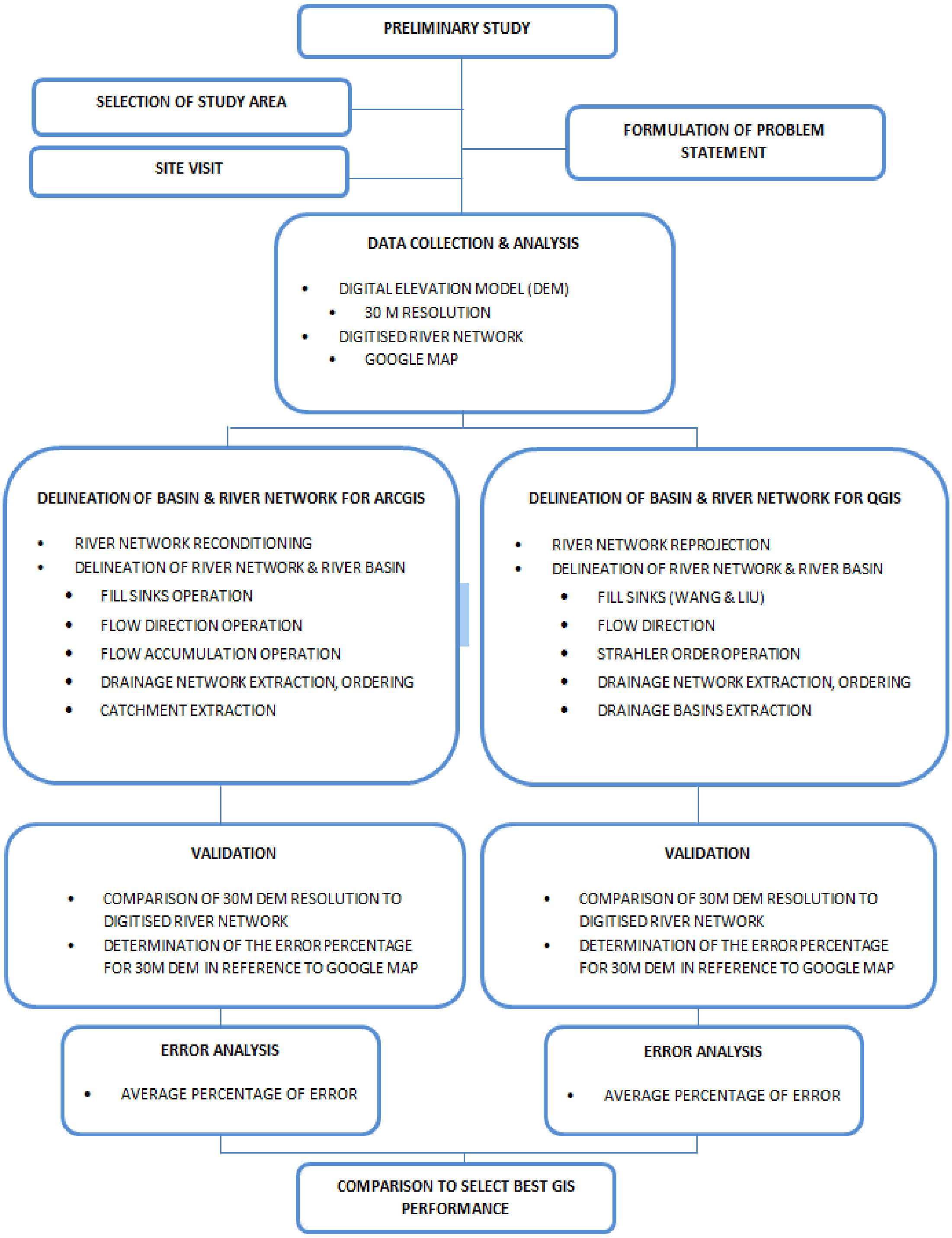

Figure 3.1 Flow Chart Of Methodology

3.3 Preliminary Study

Preliminary survey was carried out to collect all the related information needed to formulate the problem statement and methodology used in this study. Information regarding the research topic was collected through journal articles and online sources. Although it was found the 5m resolution IFSAR DTM is available but the QGIS failed to generate the river network with the default setting. As for the 90m DEM, the data is too coarse. Hence, only 30m resolution SRTM was considered in this study.

3.4 Study Area

The Rompin River Basin (RRB) is located in the South-eastern part of the Peninsular Malaysia. It was one of the biggest river basin in the Pahang State. Figure 3.2 shows the map of the Rompin River Basin. RRB has a total area of about 4,285 km^2. The Rompin-Endau region is a flat coastal plain in the extreme south of the Pahang State. It was surrounded by the Rompin River/Bukit Ibam road in the north, the Endau River in the south, the South China Sea to the east, and the foothills of the central escarpment to the west. Most parts of the downstream basin are swampy and are regularly inundated by the Rompin, Pontian, Anak Endau and Endau Rivers and numerous creeks draining the foothills. By far the major part of the region is covered with jungle, and agricultural lads mainly consisting of primary and secondary forest and scrub, and paddy and oil palm plantation. RRB is highly influenced by the tropical monsoon. The major land uses of the RRB are for agriculture, industrial and domestic activities.

Figure 3.2 The Rompin River Basin
Source: Google Maps (2019)

3.5 Data Collection

The essential data required for this study was the DEM for the Rompin River Basin. For the comparison of the GIS tools performance in extracting the physical basin characteristics from the DEM, the Shuttle Radar Topography Mission digital elevation model (SRTM 1 Arc-Second Global Elevation Data) with 30 m resolution was used in this study. The DEM map was downloaded without charge from the United States Geological Survey (USGS) Earth Explorer. Besides, the satellite base map was captured from the Google Earth to obtained the digitized the river network. QGIS application software was downloaded from the QGIS website and installed for unlimited free usage. As for the ArcGIS application software, the license was readily available.

3.6 Delineation of Basin & River Network

Before any spatial analyses were conducted, all the necessary raw data were imported into the GIS application. The digitized river network imported from Google Earth and SRTM DEM were projected priory to an agreed coordinate system. For this study the coordinate system adopted was the Kertau (RSO) Malaya. After all the raw data were projected accordingly, the SRTM DEM was reconditioned against the digitised river network to ensure the consistency of the coordinate positon. Additionally, the function of reconditioning was also to eliminate voids in the DEM. This was done by adjusting the z values for the sharp and smooth drops. For the delineation of the basin and river network, procedures or steps implemented in this study are described (Daffi & Ahuchaogu, 2017):

I. Fill Sinks Operation: When the 30m DEM resolution tiff file was inserted into the GIS application, the fill sink operation has been operated to fill the voids that occur in the DEM resolution.

II. Flow Direction Operation: This operation indicated the direction of the runoff that flow from high elevation to the low elevation.

III. Flow Accumulation Operation: This operation performed a cumulative count of the number of pixels that naturally drain into outlets. It represented the amount of water that would flow into each cell assuming all the water became runoff and there was no interception, evapotranspiration or loss to groundwater. The operation can be used to find the drainage pattern of a terrain.

IV. Drainage Network Extraction: In this operation, threshold values or Strahler order value had been adjusted and modified to extract a basic drainage network which is similar to the digitised river network.

V. Catchment Extraction Operation: This operation constructed catchments for each stream found in the output map of the Drainage Network Extraction. The operation uses data of the flow direction operation to construct basin according to the elevation of the Rompin River Basin.

3.7 Validation

Validation stage is crucial in determining the performance of the GIS application in delineating the basin and river network for the Rompin River Basin. At this stage, the results generated from the SRTM DEM with 30m resolution that generated both the GIS tools were compared. The best tool that suit the study area was determined based on the spatial average error percentage aalysed and computed from the comparison between the results from GIS and the digitised river network obtained Google Earth.

The delineated river network that has been successfully generated through ArcGIS and QGIS were converted and exported AutoCAD application tool for the percentage error analyses. The analysis began with creating interval lines perpendicular to the digitised river network. The intervals are drawn for each 1000m from the mouth to the most upstream of the river network. There are totally 438 interval lines have been drawn for the entire river networks as shown in Figure 3.3. Due to the difference in the number of streams between the digitised river network and delineated river network, some of the interval lines cannot be created. Therefore, they were not considered and were ignored in the error analyses processes.

The error between digitised river network and SRTM delineated river network were determined by measuring the difference of the interval lines between them. Based on the elevation of the ground surface, the error analyses were conducted in three groups for each GIS tools. The categories are divided into high elevation, intermediate elevation and low elevation.

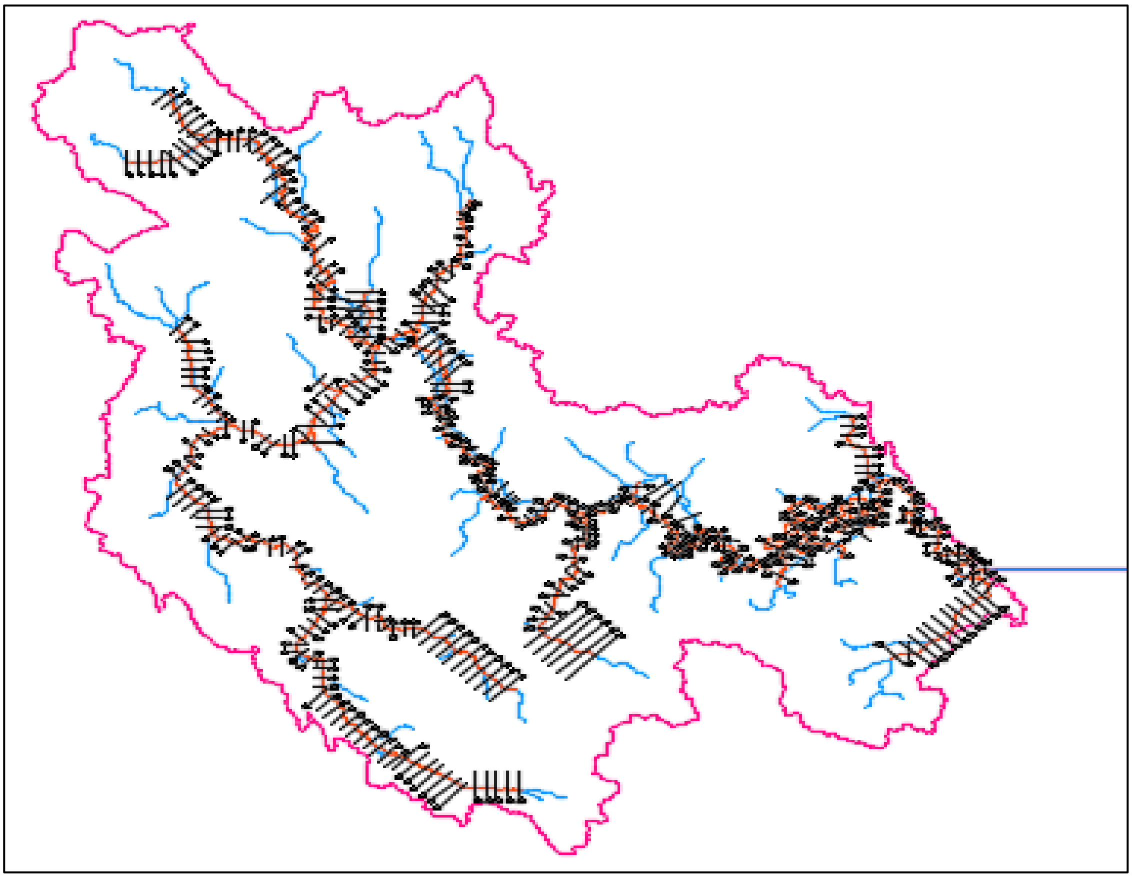

Figure 3.3 Watershed Basin With Interval Lines And Numberings

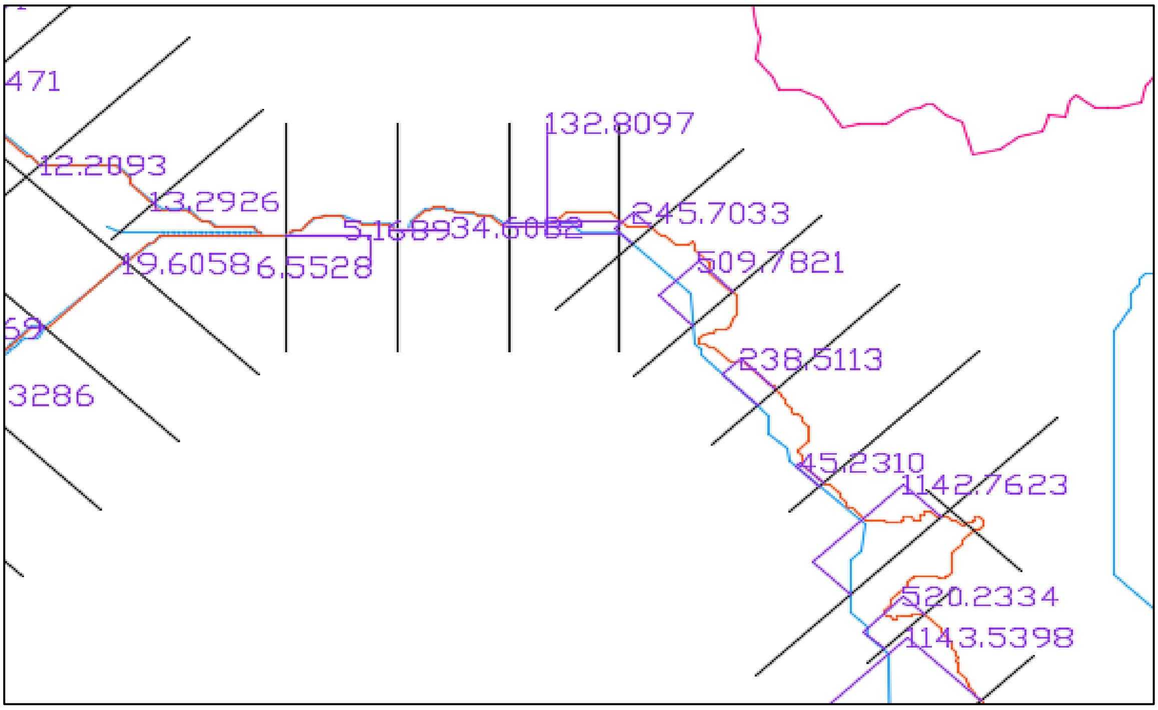

Figure 3.4 Interval Lines And Dimensions That Drawn On Digitized And Simulated Stream

3.8 Error Analysis

For the error analysis, the average percentage of error was implemented in this study to measure performance of the delineated river network and river basin generated by both the GIS tools. The equation used to calculate the percentage error is as follow:

$$\mu = \frac{\sum x_i}{n} = \frac{x_1 + x_2 + \cdots + x_n}{n} \qquad (\text{ Eqn. } 3.1)$$

whereas μ = mean and n = sample size.

Mean is the sum of the values divided by the total number of values. The mean is affected by extremely high or low values and if it occurs, the mean may not be appropriate average to use (Satari, et al., 2015).

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Watershed delineation

The watershed of the Rompin River has been successfully delineated by both ArcGIS and QGIS software. For the results that generated by ArcGIS, the area of watershed is 4185 km^2 and the perimeter is 651 km. On the other hand, the catchment area of the watershed delineated by QGIS is 4184 km^2 and the perimeter of 718 km. As for the digitised river watershed extracted from Google Earth, the total area of the digitised watershed is 4234 km^2 and the perimeter is 535 km indicating larger area but shorter perimeter.

From the comparison, the area of the watersheds extracted from both ArcGIS and QGIS were smaller than the digitized watershed by about 38.65 km^2 (about 0.92%) and 39.43 km^2 (about 0.93%) respectively. The maximum and minimum elevations for the ArcGIS are 988m and -16m, while the maximum and minimum elevations for the QGIS are about 804m and 2m. The physical characteristics obtained from the GIS extraction are summarized in Table 4.1. The digitised watershed basin, watershed basin of QGIS and ArcGIS were shown in Figure 4.1, 4.2 and 4.3 respectively.

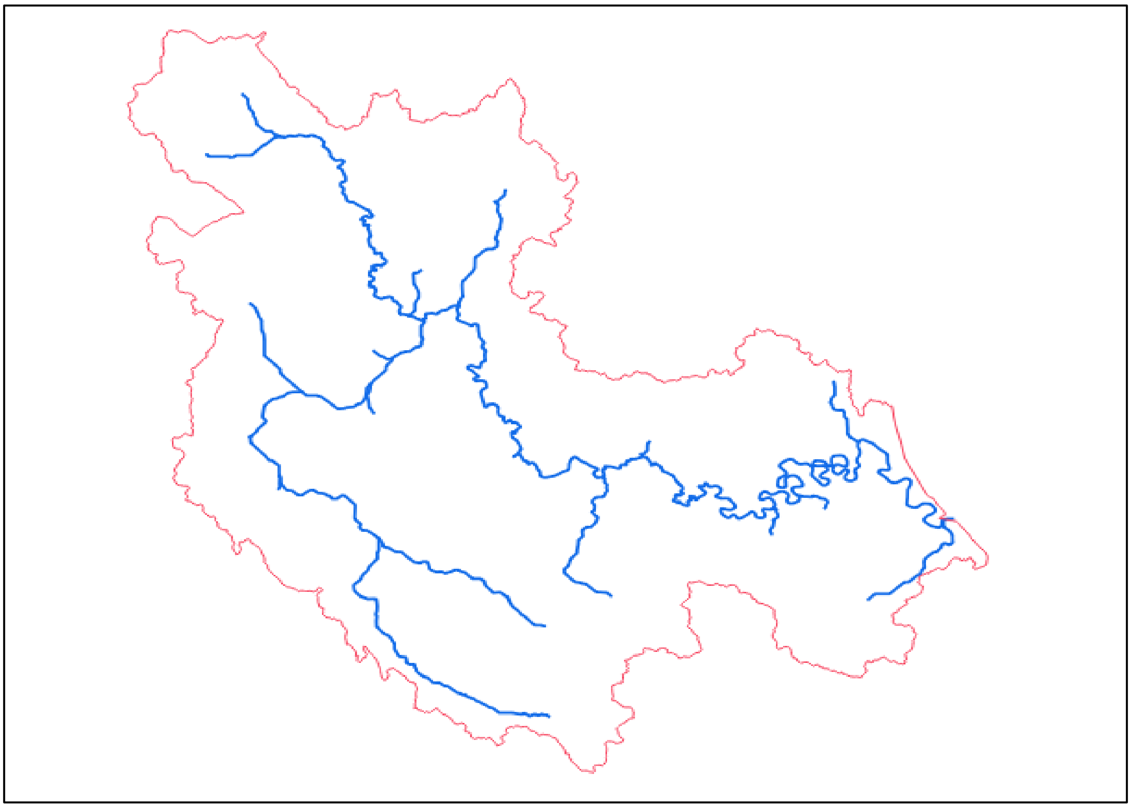

Figure 4.1 Digitized Watershed Basin

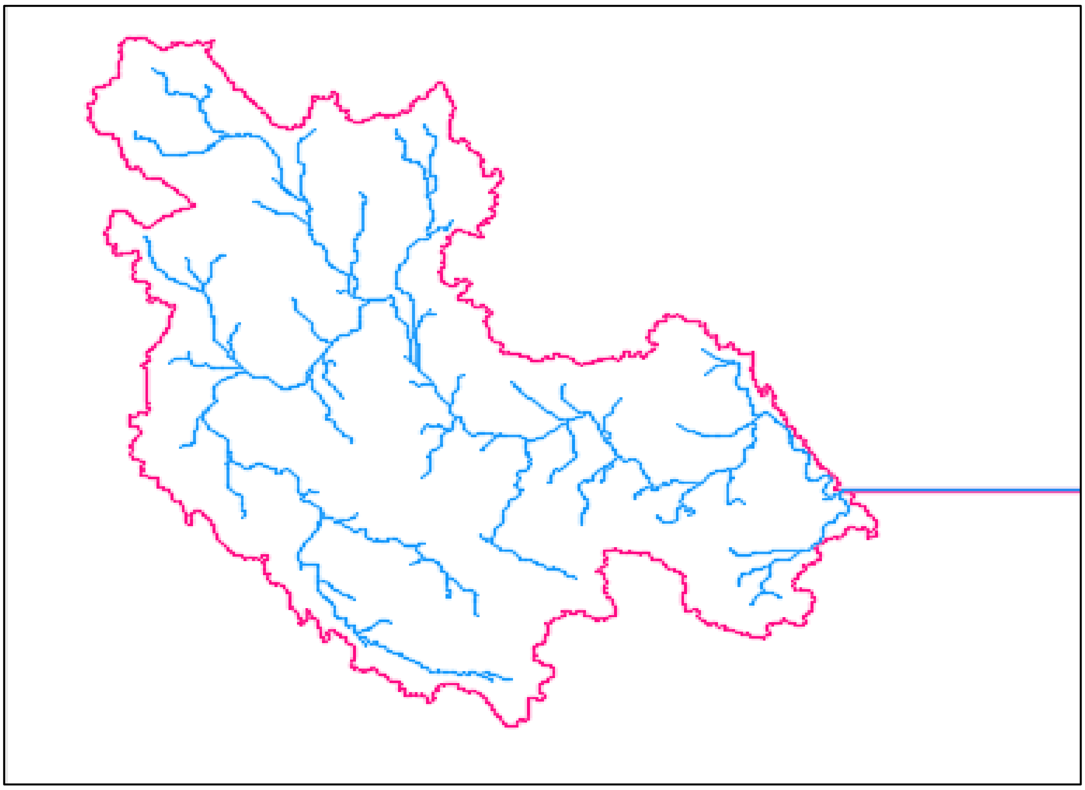

Figure 4.2 Watershed Basin of QGIS

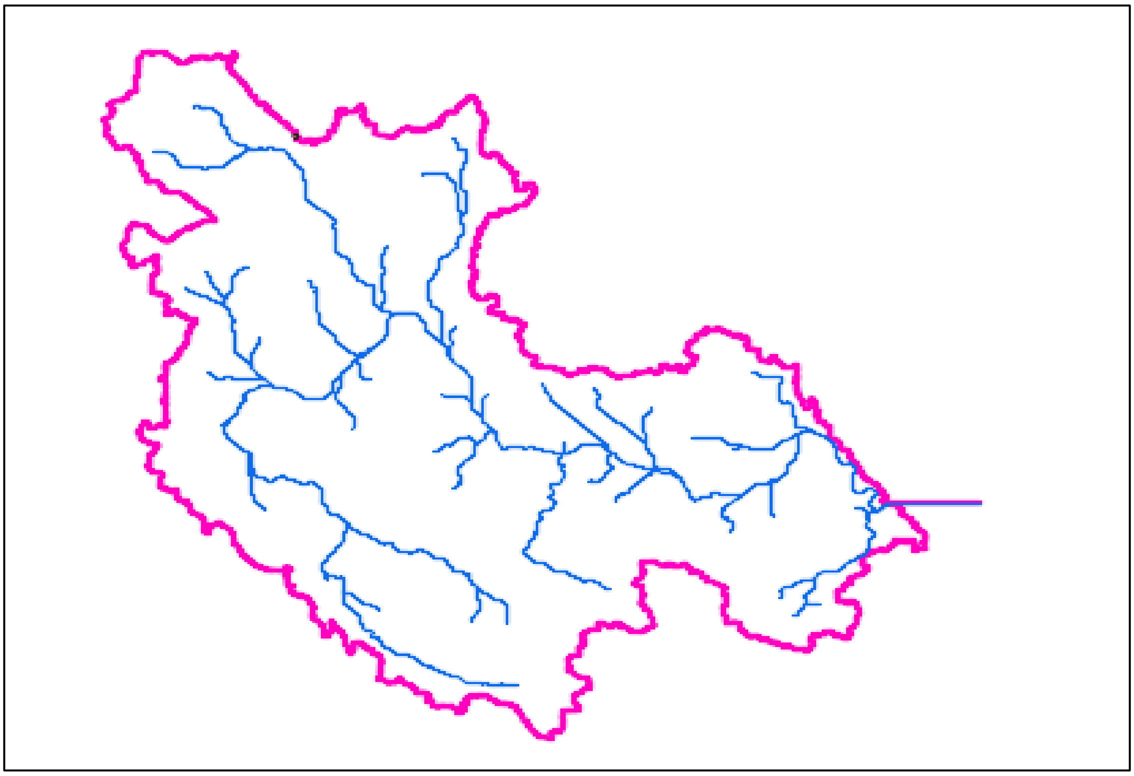

Figure 4.3 Watershed Basin of ArcGIS

Table 4.1 Data characteristics of watershed basin

Type of Watershed	Area (km^2)	Perimeter (km)	Min. Elevation	Max. Elevation
Digitized	4224	535	-	-
ArcGIS	4185	651	-16	988
QGIS	4184	718	2	804

4.2 Delineation of River Network

The delineation of the Rompin river network has been successfully generated through ArcGIS and QGIS application software. Summary of the simulated networks and watershed for both GIS tools has been shown in Table 4.2.

Table 4.2 Summary Of The Simulated Networks And Watershed

Type of software	Threshold value/ Strahler order value	Number of streams	Catchment area (km^2)
ArcGIS	Threshold value 20000	771	4185
QGIS	Strahler order value 8	93	4184

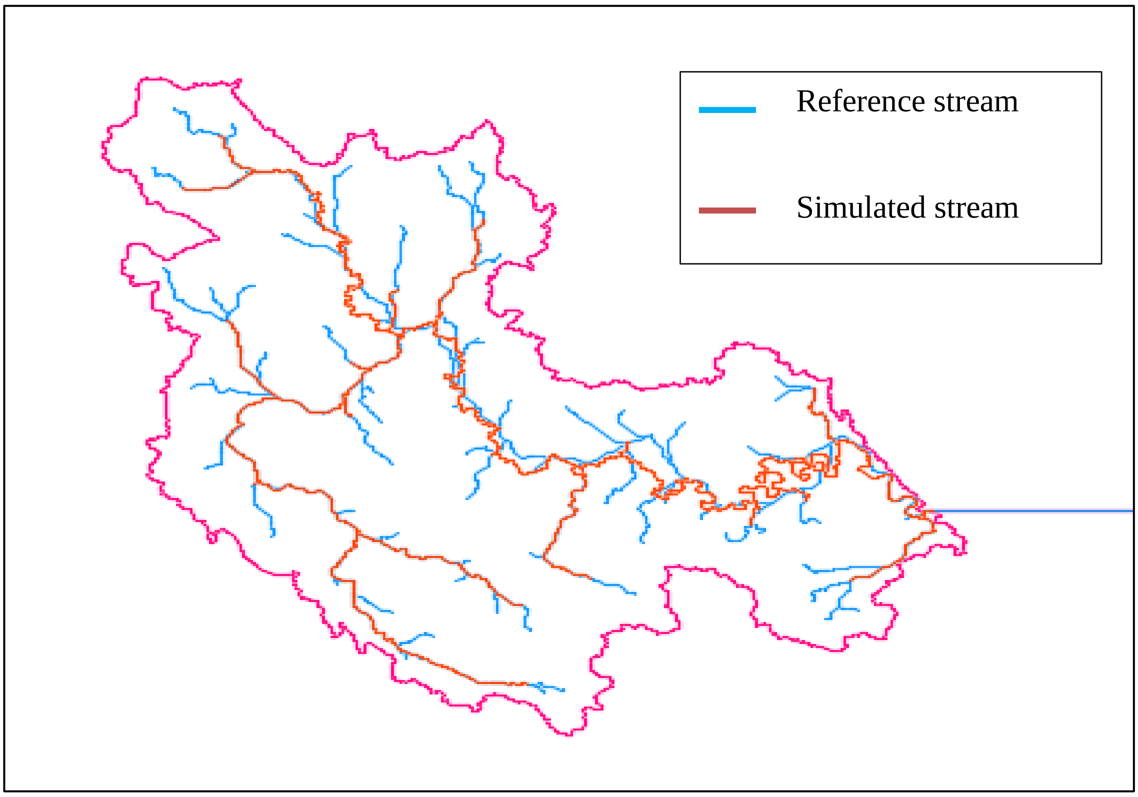

Figure 4.4 Digitized And Simulated River Network (Arcgis)

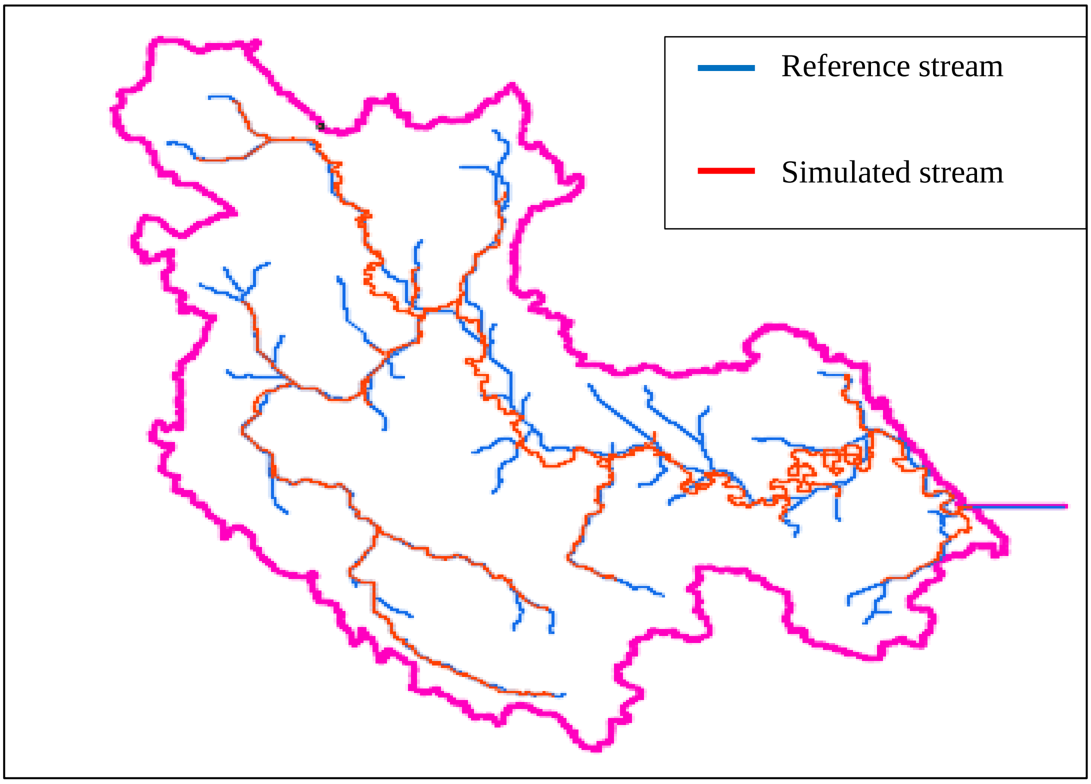

Figure 4.5 Digitized And Simulated River Network (QGIS)

4.3 Threshold Simulation (ArcGIS)

Stream threshold can improve the accuracy of the stream network simulation and watershed delineation. In this study, three simulations under different stream threshold values and the comparison are presented in Figure 4.6, 4.7 and 4.8. The simulations were evaluated by comparing number of streams and catchment area. Summary of the simulated stream networks and watershed are presented in Table 4.3.

Based on the comparison, the differences between the simulated stream networks and watershed were relatively large and noticeable but the catchment areas are almost the same in all three simulations. It can be concluded that the stream threshold values do not have much influence to the catchment area. The stream threshold value of 1000 resulted in the highest stream density and catchment number while the lower the stream threshold values resulted in more detailed stream networks and watershed delineation. This proved that stream threshold values could enhance the performance of stream networks and watershed delineation. Therefore, the result is proved to be reasonable and the consideration of stream threshold values could be further applied to the future work.

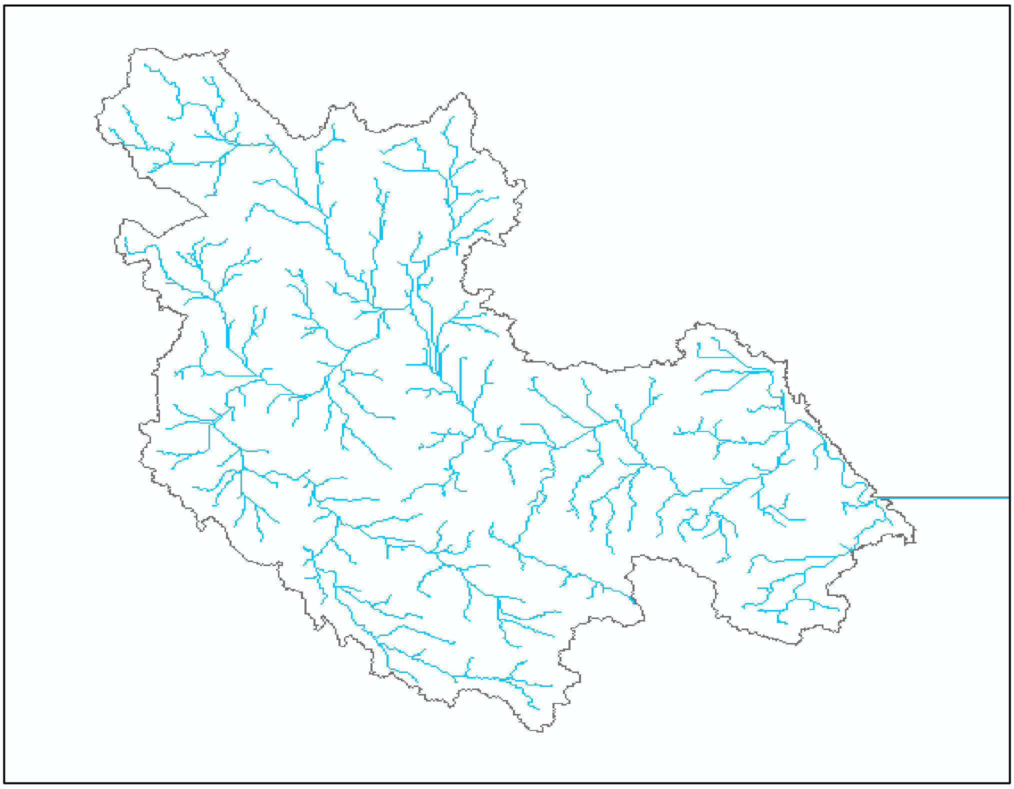

Figure 4.6 Simulated Stream Network With Threshold Value Of 5000

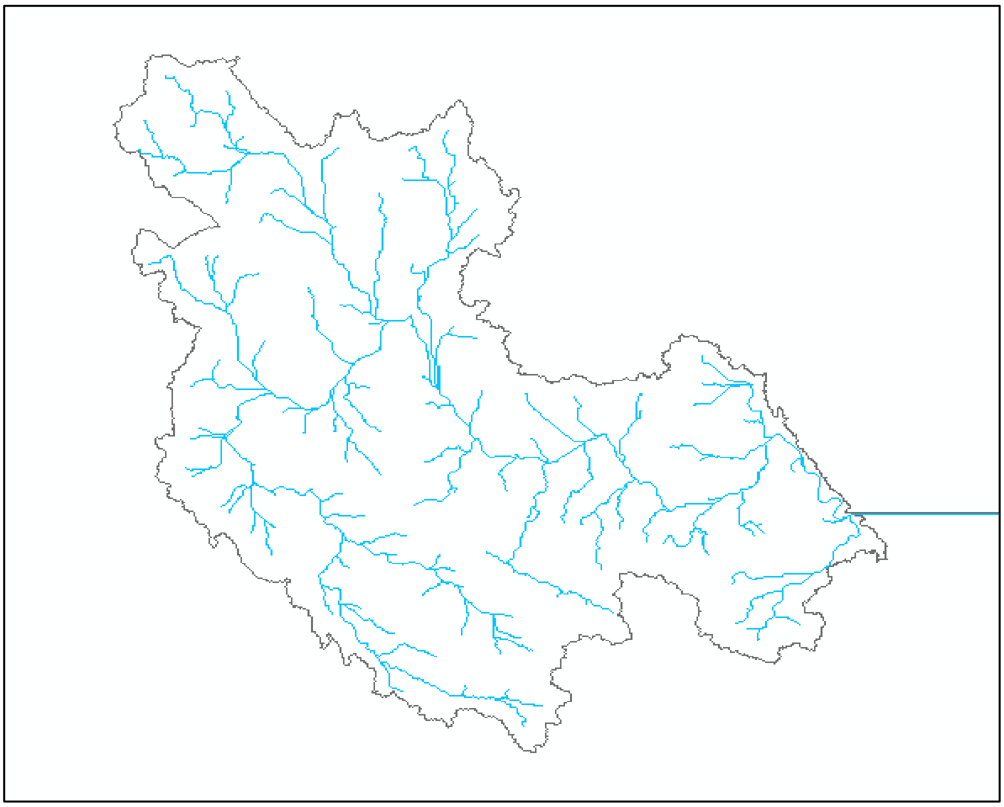

Figure 4.7 Simulated Stream Network With Threshold Value Of 10000

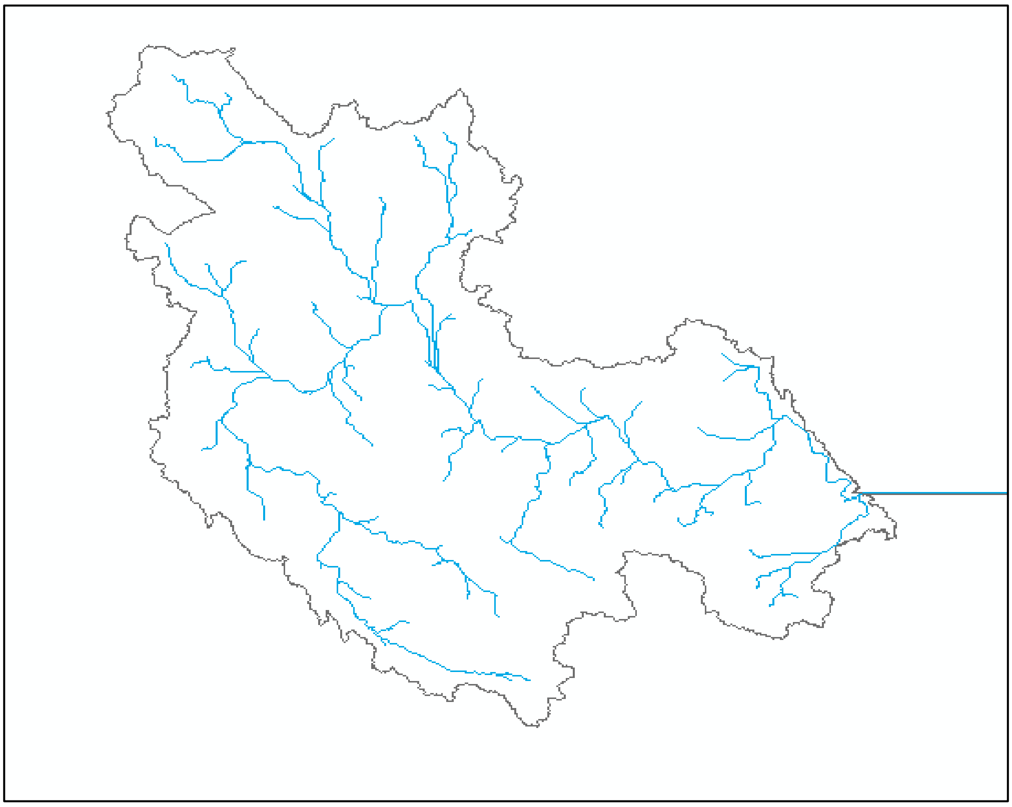

Figure 4.8 Simulated Stream Network With Threshold Value Of 20000

Table 4.3 Summary Of The Simulated Networks And Watershed For Arcgis

Strahler order value	Number of streams	Catchment area (km^2)
5000	1479	4185
10000	1049	4185
20000	771	4185

4.4 Strahler Order Simulation (QGIS)

Strahler order is a tool allows one to calculate the Strahler stream order on basis of a DEM and the steepest descent (D8) algorithm. It can be utilised to modify and adjusting the accuracy of the stream network simulation depending on the needs of the study. There are three simulations under different Strahler order values were shown in Figure 4.9, 4.10 and 4.11. The simulations were evaluated by comparing number of streams and catchment area. Summary of the simulated stream networks and watershed are presented in Table 4.4.

By comparison between delineated stream networks under different Strahler order values, the differences between the delineated river networks and watershed were relatively large and noticeable but the catchment areas maintain the same value in all three simulations. In conclusion, the stream threshold values do not have much influence to the catchment area. The Strahler order value of 6 resulted in more detailed stream network, while the Strahler order value of 8 can only obtain much detailed stream network. This shows that the lower the Strahler order value, the more detailed that can be observed through the delineated stream network.

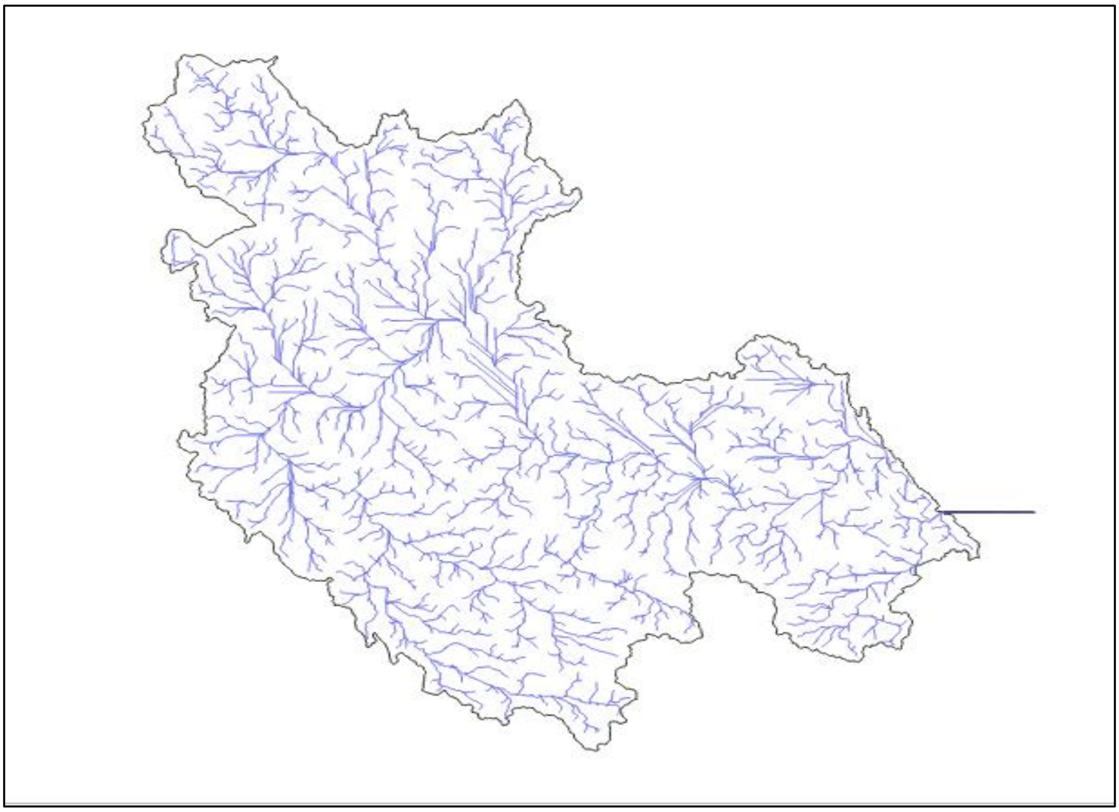

Figure 4.9 Simulated Stream Network With 6 Strahler Order Value

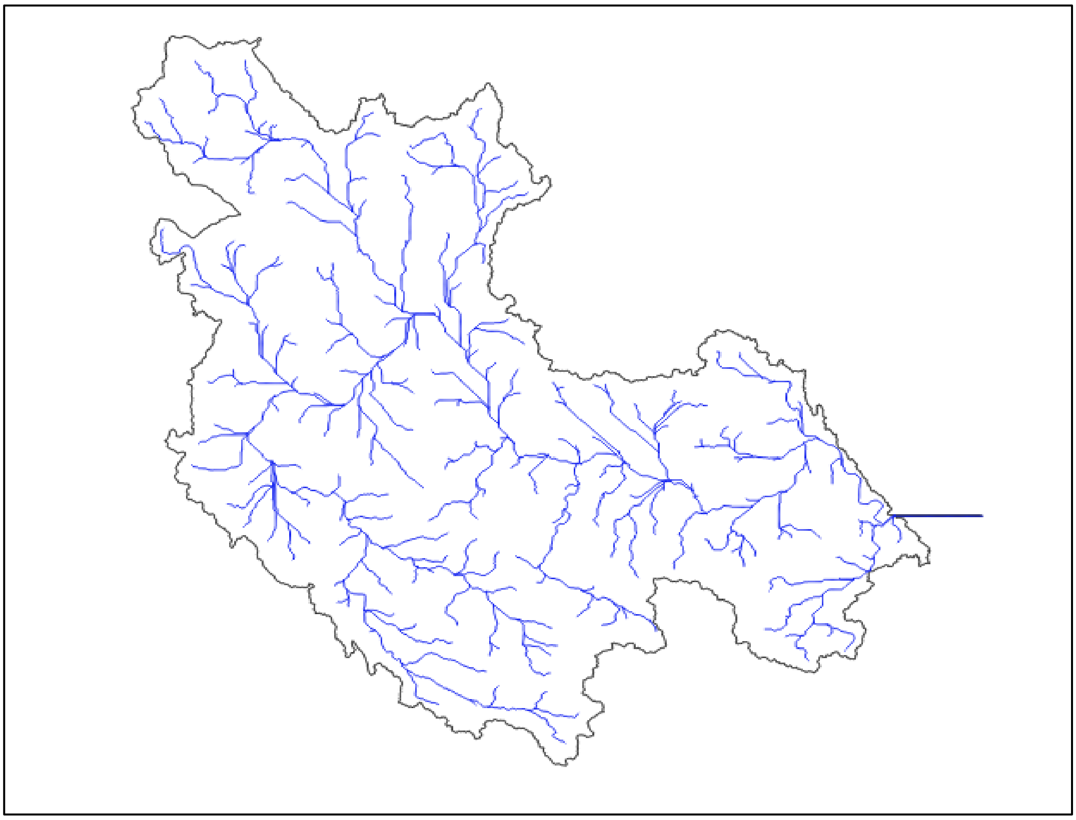

Figure 4.10 Simulated Stream Network With 7 Strahler Order Value

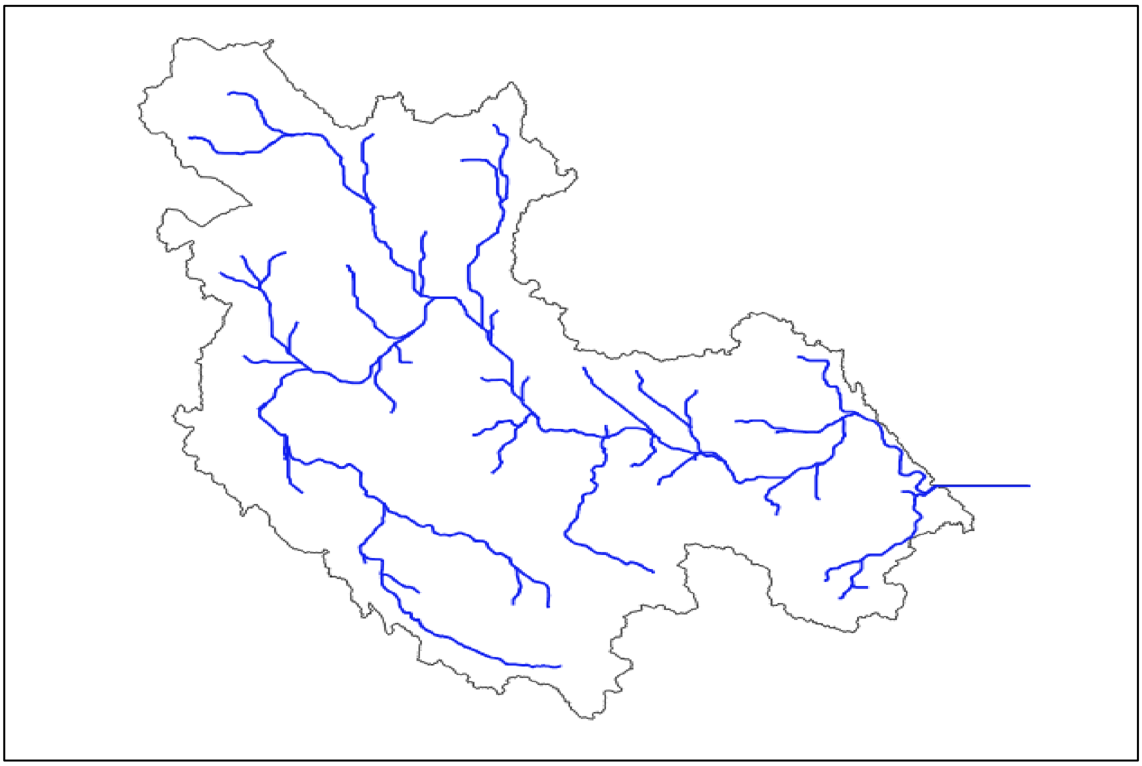

Figure 4.11 Simulated Stream Network With 8 Strahler Order Value

Table 4.4 Summary Of The Simulated Networks And Watershed For QGIS

Strahler order value	Number of streams	Catchment area (km^2)
6	4213	4184
7	408	4184
8	93	4184

4.5 River Network Validation and Error Analysis

The results obtained were exported to the AutoCAD the percentage of error analysis. The error analysis results were presented in accordance to the elevation groups mentioned in previous section.

For high elevation, the interval lines began from interval number 1-58, 80-91, 123-145, 146-183, 188-206 and 260-283. The areas considered for high elevation are displayed in Figure 4.12 for ArcGIS and Figure 4.13 for QGIS. Differences of the horizontal perpendicular distance between the delineated networks and the digitized network have been determined for each of the intervals. Averaging the different values obtained between these data, the percentage error was about 190m for ArcGIS, while for QGIS the percentage of error was near to 220m. The results summary is tabulated Table 4.5. From the result comparison, ArcGIS seems to provide a more accurate data than QGIS.

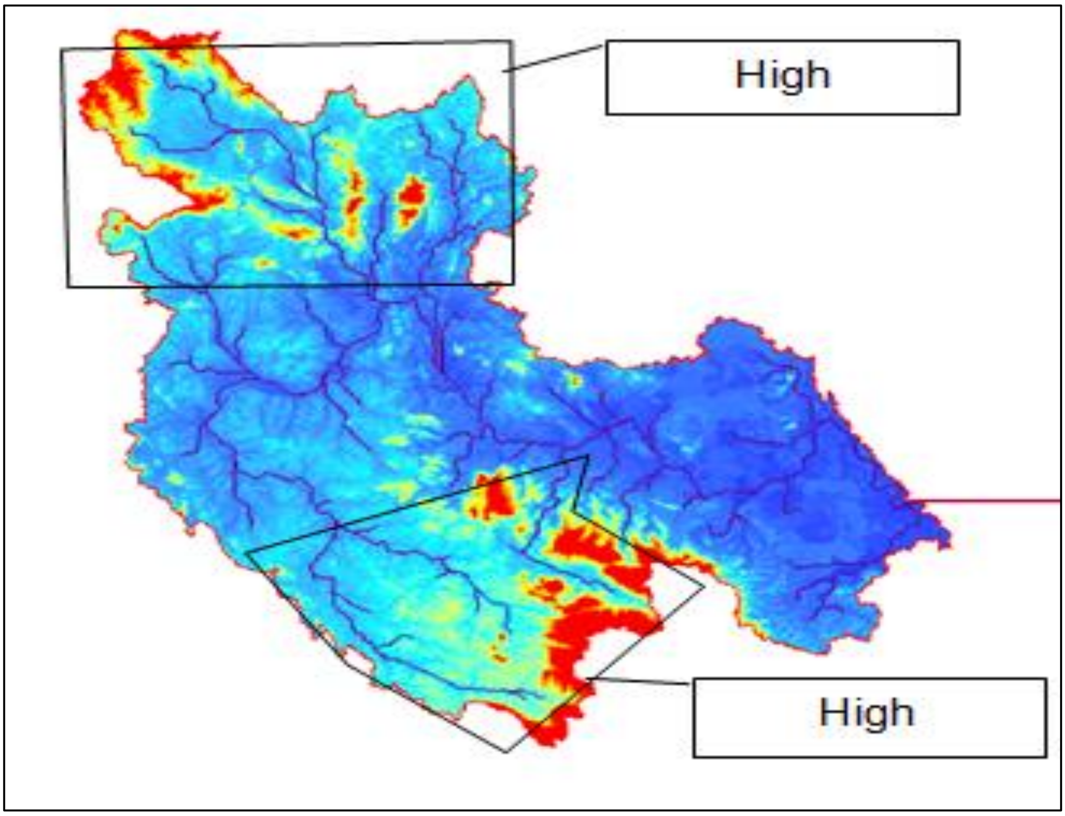

Figure 4.12 Watershed Area (ArcGIS)

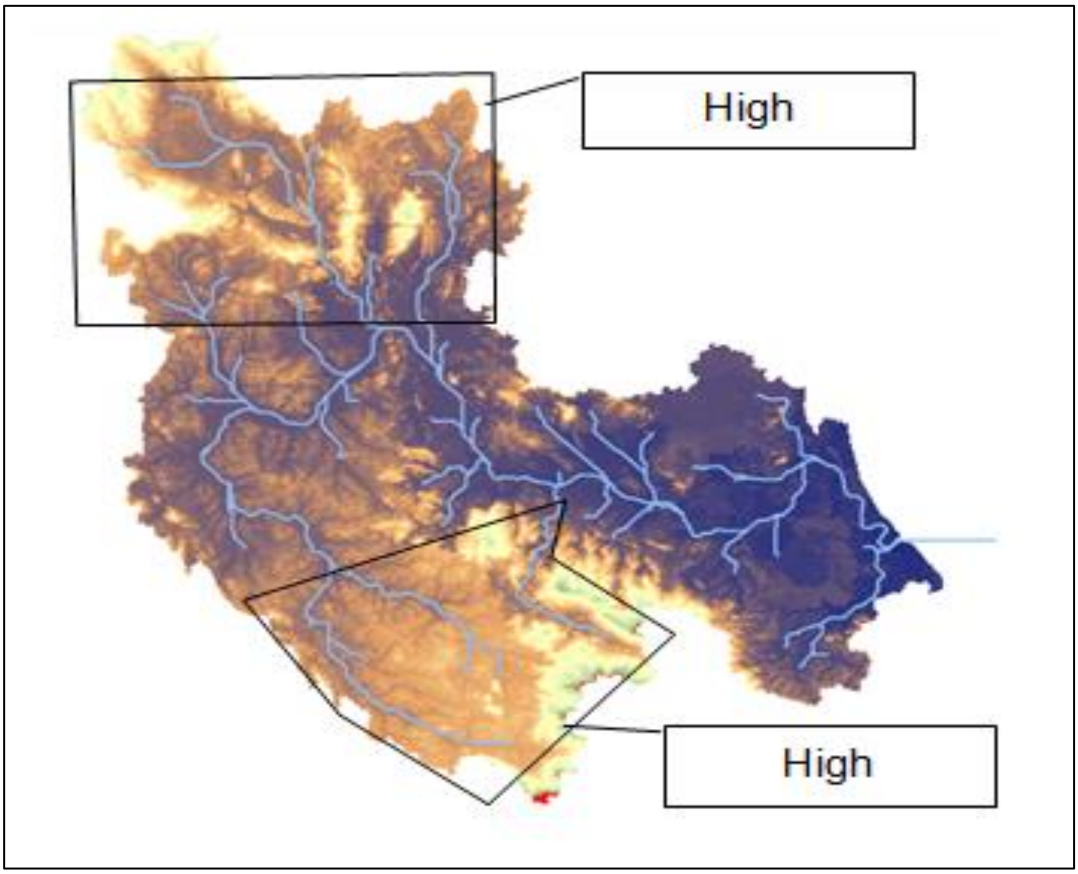

Figure 4.13 Watershed Area (QGIS)

Table 4.5 Average Value Of The Percentage Of Error For High Elevation

Elevation of ground surface	Average value of the percentage of error	
	ArcGIS (m)	QGIS (m)
High	188	217

Intermediate elevation covers the area on the mid-west of the basin. The interval lines for the intermediate level started from interval number 59-122, 184-187 and 207-259. Figure 4.14 and 4.15 show the area that includes intermediate elevation for ArcGIS and QGIS respectively. Based on the comparison between ArcGIS and QGIS, for ArcGIS the percentage of error was about 240 m, while for the QGIS has a percentage of error of 450 m. All the results can be shown in table 4.6. Results obtained for intermediate elevation showed that ArcGIS performed better in delineating the river network in contrast to the results indicated for the high elevation. The river network generated via ArcGIS was approximately close to the digitised river network.

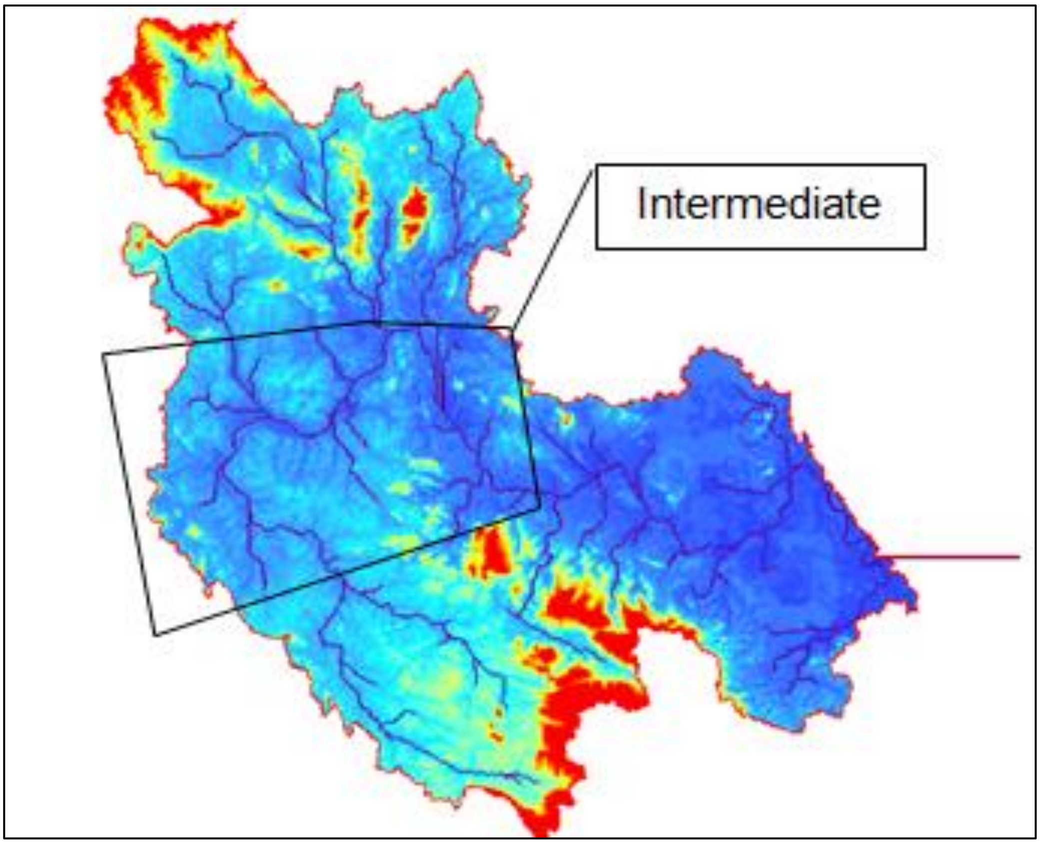

Figure 4.14 Watershed Area (ArcGIS)

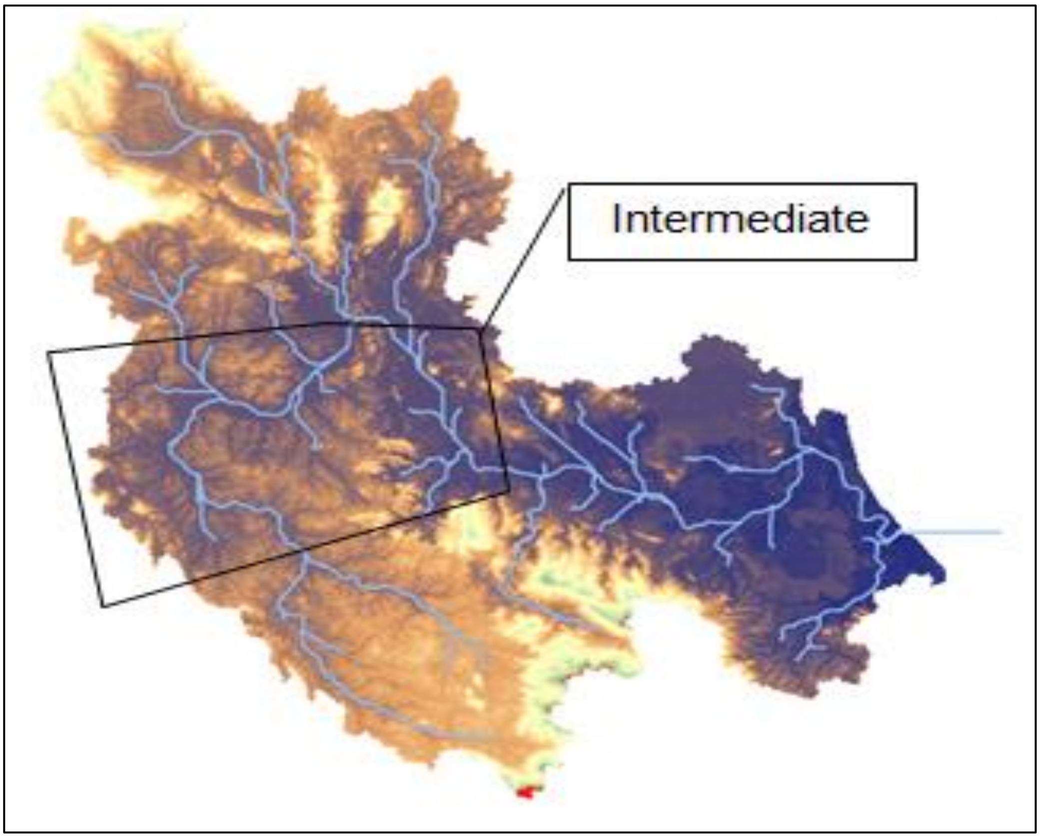

Figure 4.15 Watershed Area (QGIS)

Table 4.6 Average Value Of The Percentage Of Error For Intermediate Elevation

Elevation of ground surface	Average value of the percentage of error	
	ArcGIS (m)	QGIS (m)
Intermediate	241	446

Delineation for the low elevation can be crucial since most of the developments often take place at the downstream catchment also known as low lying areas. The low elevation interval lines began from the Rompin River mouth with the interval number of 284-438. The area that represents low elevation for ArcGIS and QGIS had been shown in Figure 4.17 and 4.18. The percentage of error that obtained from the ArcGIS was around 470m, however QGIS had a percentage of error which is 15m higher than ArcGis (485m). The average value of the percentage of error has been summarised in table 4.7.

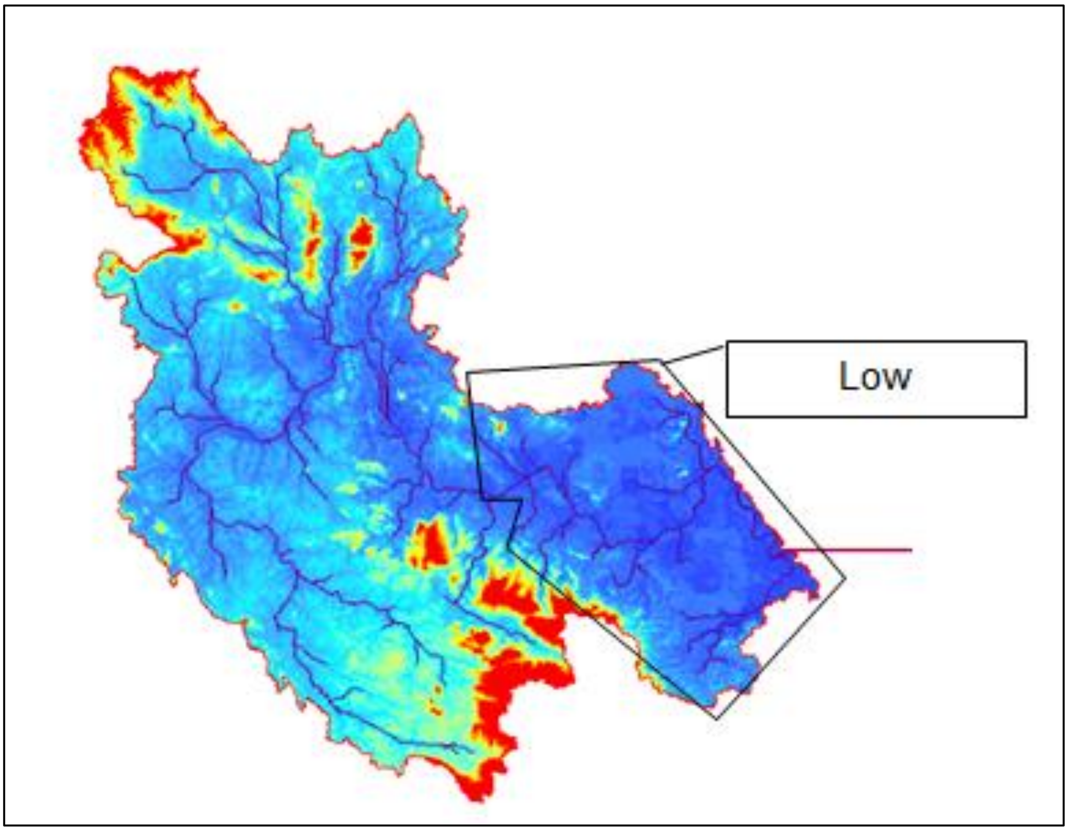

Figure 4.16 Watershed Area (ArcGIS)

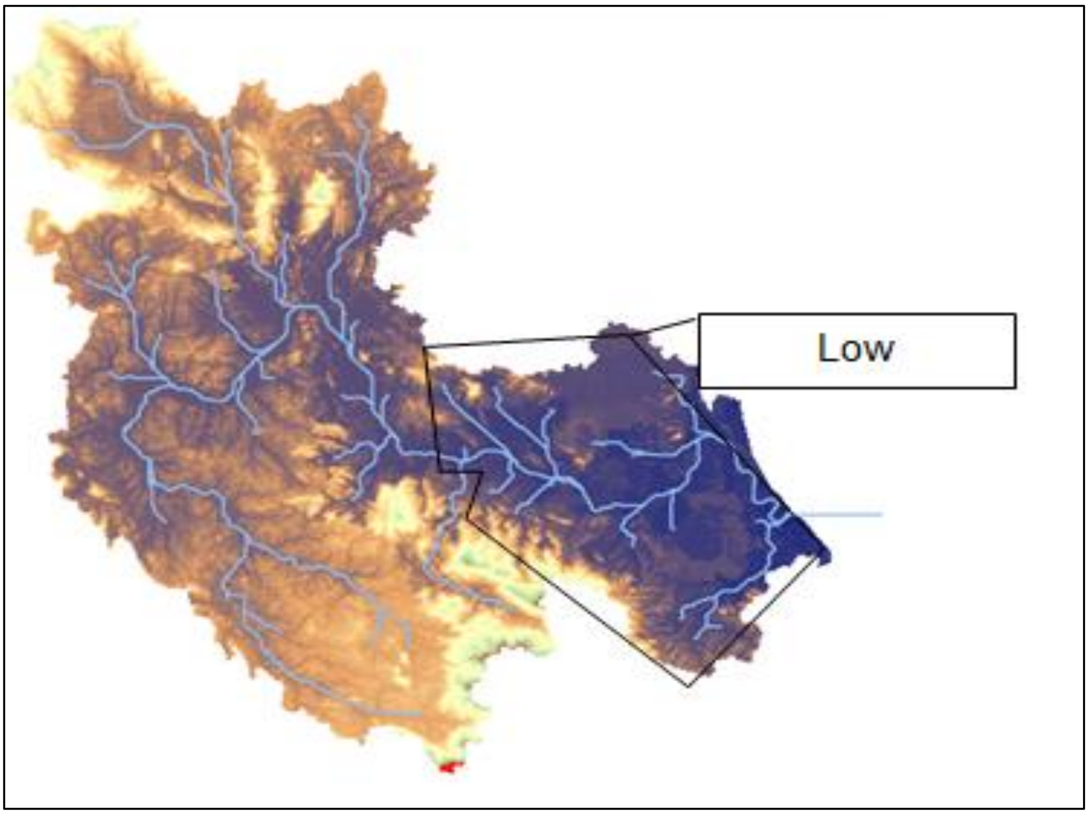

Figure 4.17 Watershed Area (QGIS)

Table 4.7 Average Value Of The Percentage Of Error For Low Elevation

Elevation of ground surface	Average value of the percentage of error	
	ArcGIS (m)	QGIS (m)
Intermediate	470	485

4.6 Summary

In summary, by comparing the difference of percentage of error for different elevation, ArcGIS was able to generate the river network more detailed than QGIS. Comparing the result obtained from ArcGIS and QGIS to the digitized river network, it is found that ArcGIS application can delineate the river network more accurately at the intermediate and low elevation, while QGIS can only perform better at high elevation. Although QGIS can be download for free on website, however the fact that it does not perform better at he lower elevation is a great disadvantage since the low lying or flat areas are always crucial and require more attention. Furthermore, flood problem generally occurs in lower elevated areas, and hence QGIS may not be sufficient to be used to delineate the river network this level. Besides, ArcGIS owned an integrated system and toolbox which can fasten the process of the delineation of watershed basin. For QGIS, although it is free licensed, but due to the lack of the efficient system and extensions that may benefit to the user, it is less recommend to be used unless the user is knowledgeable in coding and programming.

CHAPTER 5

CONCLUSION

5.1 Introduction

The purpose of this study is to delineate the watershed and river network by using Geographical Information System (GIS) software. The GIS applications implemented in this study are ArcGIS and QGIS. Adopting the 30 m resolution SRTM DEM which was downloaded from USGS government website, the watershed and river network have been successfully delineated from each GIS software. In order to obtain the river network close to the digitized river network, repetitive simulations for different stream threshold and Strahler values have been tested for the Rompin River Basin. This procedure helped to eliminate the small tributaries so that the river network can be more specific and accurate towards the digitized river network. The simulated river network from ArcGIS and QGIS has been validated by using the statistical analysis RMSE method to investigate its accuracy and reliability by comparing it to the digitized river network.

5.2 Conclusion

The objectives of this study have been successfully carried out and the results have been analyzed and noted. Based on the results, the watershed area and perimeter delineated from ArcGIS were 4185.31 km^2 and 650.95 km, while, QGIS has an area of 4184.53 km^2 and 717.57 km of watershed perimeter respectively. These results can be useful as the input for in hydrological modelling and watershed studies on the Rompin River Basin.

For the validation of the simulated river network, the results obtained have been compared with the digitized river network from Google Earth. The simulated river networks from ArcGIS and QGIS were compared according to three elevations which are high, intermediate and low elevation. Based on the average values obtained for the different elevation, the simulated river network from ArcGIS has lower percentage of error in two of the elevations. This indicates that the SRTM based river network delineated by ArcGIS is more accurate in representing the digitized river network. Thus, the simulated river network from ArcGIS is recommended for Rompin River Basin as it is highly desirable and can be applied for the further studies on water resource management.

In conclusion, the SRTM DEM of 30 m resolution is more precise to delineate the river network and watershed through ArcGIS software. The physical characteristics of the watershed extracted show acceptable results except for the lowest elevation. In contrast, QGIS is less suitable to be implementing to delineate the Rompin River basin although it is licensed free.

5.3 Recommendation

Based on the current study, there are some aspects that have to be considered in order to improve the simulation performance. The followings are the recommendations listed for future enhancement:

i) Without HEC-GeoHMS extension, ArcGIS can only simulate the total basin which is the same as QGIS. Thus, it recommend to apply the HEC-GeoHMS extension so that sub-basins can also be generated.

ii) Threshold value is important in delineating river network. By adjusting the threshold value, the drainage network with different number of river network tributaries can be simulated according to the need of the study.

iii) In order to improve the accuracy of delineated watersheds, higher quality and resolution of the DEM should be utilised. Higher resolution of the DEM can provide more accurate results than the coarser resolution DEM. Therefore, the simulation can be improved by taking into consideration higher resolution DEMs sources such as the

Interferometric Synthetic Aperture Radar (IFSAR) or Light Detection And Ranging (LIDAR).

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APPENDIX A
DATA FOR THE PERCENTAGE OF ERROR OF THE ARCGIS AND QGIS

Average percentage of error for high elevation

NO.	ArcGIS	QGIS
1	4	12
2	18	23
3	6	13
4	7	8
5	16	15
6	12	16
7	13	18
8	6	44
9	7	12
10	8	11
11	10	21
12	11	23
13	10	2
14	37	5
15	18	6
16	20	3
17	7	1
18	5	77
19	35	30
20	133	130
21	246	233
22	510	460
23	239	231
24	45	35
25	1143	1109
27	520	512
28	1144	1120
30	711	664
31	104	57
32	28	24
33	25	29
34	388	375
35	456	509
36	283	229
37	237	187
38	67	49
39	131	149
40	42	25
41	1666	2198
43	1880	1932
44	4249	4266
45	3844	3772
48	3844	2285
49	1920	1818
50	1360	1394
51	5	8
52	138	343
53	18	54
54	33	86
55	283	335
56	334	421
57	904	961
80	26	56
81	9	15
82	13	16
83	18	12
84	2	12
85	10	166
86	9	108
87	8	106
88	2	107
89	1	77
90	12	146
91	10	34
123	6	13
124	4	2
125	41	9
126	12	4
127	6	2
128	9	2
129	1	32
130	11	36
131	3	3
132	3	33
133	2	89
134	0	35
135	8	12
136	11	36
137	7	11
138	11	18
139	5	20
140	11	1
141	11	29
142	13	4
143	5	28
144	6	73
145	8	252
146	3	14
147	2	12
148	7	26
149	3	22
150	11	19
151	18	16
152	5	18
153	27	26
154	33	18
155	12	36
156	9	23
157	13	18
158	4	4
159	7	3
160	20	2
161	3	13
162	1	11
163	0	9
164	10	11
165	5	8
166	9	18
167	18	69
168	12	3
169	14	37
170	8	126
171	7	215
172	4	115

173	4	77
174	3	11
175	4	28
176	1	59
177	4	227
178	4	442
179	2	33
180	1	35
181	10	31
182	34	13
183	5	91
260	7	47
261	8	75
262	5	133
263	11	113
264	14	112
265	14	88
266	23	107
267	7	156
268	14	49
269	7	177
270	6	124
271	9	120
272	13	118
273	14	144
274	1	135
275	3	153
276	10	137
277	8	134
278	1	63
279	4	65
280	2	29
281	3	70
282	6	18
283	7	76
Average	**188**	**217**

Average percentage of error for intermediate elevation

NO.	ArcGIS	QGIS
59	72	64
60	132	63
61	16	126
62	8	376
63	5	98
64	2	483
65	17	523
66	0	189
67	4	124
68	22	73
69	0	28
70	6	34
71	18	2554
72	10	59
73	15	61
74	27	52
75	6	269
76	2	340
77	9	197
78	3	29
79	1	56
80	26	15
81	9	16
82	13	12
83	18	12
84	2	166
85	10	108
86	9	106
87	8	107
88	2	77
89	1	146
90	12	34
91	10	36
92	12	37
93	10	28
94	4	15
95	11	497
96	0	785
97	2	375
98	21	2
99	7	63
100	19	28
101	26	84
102	6	4
103	4	16
104	3	100
105	6	55
106	7	56
107	116	335
108	11	79
109	4	33
110	20	9
111	20	52
112	16	6
113	5	5
114	13	3
115	12	2
116	7	1
117	2	4
118	5	10
119	2	6
120	5	80
121	8	41
122	5	11
184	115	409
185	102	50
186	488	655
207	104	245
208	408	315
209	1543	1548
210	1172	1177
211	1235	720
212	1146	39
213	1004	122
214	904	260
219	110	1891
220	381	3486
223	341	2299
224	258	
225	728	3320
226	1357	3098

227	22	-
228	13	98
229	366	437
230	597	1352
232	782	975
233	153	289
234	328	463
235	2	138
236	18	117
237	440	-
238	552	-
241	880	1451
242	228	171
243	1860	2272
244	1361	1642
245	1067	1141
246	1139	1122
249	109	2227
250	500	1828
251	550	-
252	113	508
253	224	107
254	68	67
255	661	177
256	856	406
Average	**241**	**446**

Average percentage of error for low elevation

NO.	ArcGIS	QGIS
284	107	12
285	29	1
286	511	482
288	1022	977
289	689	367
290	886	290
291	689	-
292	8	832
293	3646	241
294	3344	46
296	2569	39
297	2496	126
310	1260	-
313	46	333
314	8	586
315	171	366
316	770	1036
320	71	199
323	1509	1945
326	628	666
327	110	-
328	16	170
329	151	74
330	969	732
332	35	40
333	35	9
334	7	281
335	727	1117
338	3827	-
343	463	-
344	452	-
345	1	7
346	441	24
347	184	352
367	2436	2686
378	1651	-
379	671	359
380	720	435
382	812	479
383	964	693
385	25	339
386	14	257
387	13	288
388	83	144
389	30	9
390	15	283
391	14	160
392	12	8
393	25	282
394	424	41
395	35	66
396	211	293
397	61	286
398	149	428
399	1621	476
403	870	1253
405	1040	-
407	38	255
408	159	161
409	89	408
410	54	373
411	85	403
412	18	85
413	54	20
414	50	326
415	10	113
416	56	61
417	47	149
418	241	140
419	302	4
420	86	370
421	25	-
422	95	126
423	491	148
424	35	83
425	1	-
426	1	-
427	6	2889
428	9	2197
429	13	27
430	32	191
431	13	301
432	11	242
433	5	270
434	4	265
435	22	262

436	13	100
437	4	70
438	13	272
Average	470	485