PERFORMANCE OF DIFFERENT DIGITAL ELEVATION MODEL RESOLUTION FOR THE ROMPIN RIVER BASIN

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ABSTRAK

Model Elevasi Digital (DEM) sesebuah garis batas air atau lembangan membentuk asas utama untuk pemodelan hidrologi dan resolusinya memainkan peranan utama dalam ramalan tepat mengenai pelbagai proses hidrologi. Kajian ini menilai kesan DEM berbeza dengan resolusi spatial bervariasi iaitu 5m Interferometric Radial Aperture Radar (IFSAR) - Digital Terrain Model (DTM) dan 30m Shuttle Radar Topography Mission (SRTM) - Digital Elevation Model (DEM) menggunakan aplikasi perisian ArcGIS untuk kajian kes Lembangan Sungai Rompin di Rompin, Pahang. Objektif kajian ini adalah untuk menggambarkan rangkaian sungai dan tadahan lembangan, dan untuk menilai prestasi SRTM-DEM 30m dan IFSAR-DTM 5m dalam menyediakan maklumat fizikal dan topografi untuk lembangan Sungai Rompin. Dari hasil kajian kes itu, diperhatikan bahawa resolusi DEM yang berbeza menghasilkan ketepatan yang berbeza. Perbezaan ralat purata berbanding dengan rangkaian sungai digital untuk IFSAR-DTM 5m didapati lebih besar berbanding dengan 30m SRTM-DEM. Kesalahan besar disebabkan oleh nilai z yang diberikan semasa proses pemulihan. Memandangkan prestasi 30m SRTM-DEM adalah berhampiran dengan 5m IFSAR-DTM, ia menunjukkan bahawa resolusi 30m cukup boleh dipercayai dalam menyediakan maklumat fizikal dan topografi Lembangan Sungai Rompin.

ABSTRACT

Digital elevation model (DEM) of a watershed forms key basis for hydrologic modelling and its resolution plays a key role in accurate prediction of various hydrological processes. This study appraises the effect of different DEMs with varied spatial resolutions namely 5m Interferometric Synthetic Aperture Radar (IFSAR) - Digital Terrain Model (DTM) and 30m Shuttle Radar Topography Mission (SRTM) - Digital Elevation Model (DEM) using ArcGIS software application for the case study of Rompin River Basin in Rompin, Pahang. The objectives of this study are to delineate river network and basin catchment, and to evaluate the performance of the 30m SRTM-DEM and 5m IFSAR-DTM in providing physical and topographical information for the Rompin river basin. From the result of the case study, it was observed that the different DEMs resolution produced different accuracies. The average error difference compared to the digitised river network for the 5m IFSAR-DTM was found out to be larger compared to the 30m SRTM-DEM. The large error was caused by the z-value assigned during the reconditioning process. Since the performance of 30m SRTM-DEM is close to the 5m IFSAR-DTM, it indicates that 30m resolution is sufficiently reliable in providing physical and topographical information of the Rompin River Basin.

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LIST OF SYMBOLS

GIS	Geographical Information System
SRTM	Shuttle Radar Topography Mission
DEM	Digital Elevation Model
IFSAR	Interferometric Synthetic Aperture Radar
DTM	Digital Terrain Model
HEC-GeoHMS	Geospatial Hydrologic Modeling Extension

LIST OF ABBREVIATIONS

GIS	Geographical Information System
SRTM	Shuttle Radar Topography Mission
DEM	Digital Elevation Model
IFSAR	Interferometric Synthetic Aperture Radar
DTM	Digital Terrain Model
HEC-GeoHMS	Geospatial Hydrologic Modeling Extension

CHAPTER 1

INTRODUCTION

1.1 General

Flood problem has been a common issue in Malaysia. This country receives abundant of rainfall every year with the mean annual rainfall in the entire Peninsular Malaysia was approximately 2300mm (Wong et.al, 2009). There are two types of floods that frequently occurred in Malaysia, flash flood and monsoon flood. Monsoon usually happen from May to August at the West Coast, and November to February at the East Coast (Suhaili. et.al, 2010). Meanwhile, flash flood occurred due to high intensity of rainfall in short duration. Additionally, improper maintenance of drainage system such as drainage clogging, and under-design drainage capacity increases the chances of flash flood. Cities and towns in the East Coast of Malaysia including the Rompin district are prone to the Northeast Monsoon which induces monsoon flood. However, the areas also encounter occasional flash flood. Hence, hydrological modelling study is essential to obtain an insight on the flood event simulation of an area. Before the hydrological modelling can be performed, physical and topographical information have to extracted from the Geographical Information System (GIS).

Geographical Information System (GIS) is a new computerised technology in retrieving physical and topographical information captured by remote sensing technology. There are many GIS software applications available in the market such as ArcGIS, QGIS, GRASS GIS, TerraView, and SAGA GIS. Some of this software require annual licensing and some can be downloaded without charges. In this study, ArcGIS has been selected to delineate the Rompin river network and basin catchment. Shuttle Radar Topography Mission (SRTM) - Digital Elevation Model (DEM) and Interferometric Synthetic Aperture Radar (IFSAR) - Digital Terrain Model (DTM) were used as the raw topographical dataset for the Rompin river basin. SRTM-DEM has a resolution of 30m x

30m, while IFSAR-DTM has resolution of 5m x 5m. Larger cell grid able to work well in areas with larger variation in elevation but poorly captures detailed information at low land areas. (Reddy & Janga, 2015) stated that different resolution affects the watershed delineation, stream network and sub-basin classification Thus, for low land area higher digital model resolution is required.

The two different resolution of digital model used to delineate the river network and catchment of the Rompin River Basin were compared and their performances were evaluated. Before the delineation process, the river network was digitised based on Google satellite image. The elevation model was then reconditioned to ensure the stream position is parallel with the digitised river network. The final aim of this study is to evaluate the performance of different digital model resolution by executing the statistical analysis. The result obtained was used to identify the applicability of the different digital resolution in different topographic level to be utilised for hydrological modelling purposes.

The findings of this study can benefit engineers or water manager to extract the physical and topographical information digitally which can save time and manpower as compared to the traditional method. Several extensions that are integrated into the ArcGIS software application can assists engineers and water managers in designing matters that are related to hydrology such as drainage design. Meanwhile, local authorities and planners can also benefit from the findings which can assists them in urban planning.

1.2 Objectives

The main objective of this research is to generate geographical information mapping for the Rompin River Basin supporting by these objectives:

i) To delineate river network & basin catchments.

ii) To evaluate the performance of the 30m DEM and 5m DTM in providing physical and topographical information.

1.3 Problem Statement

Few detailed studies on the Rompin River network and basin catchments have been conducted up to this date. This is because Rompin District is still considered as a less developed area and not much economically sound activities. Nevertheless, there are several paddy schemes available throughout the river basin in which some of the plantation areas are affected by floods especially during the monsoon season. Thus, it is important to map the location of the paddy schemes area and the surrounding physical characteristics. For example, some paddy schemes maybe located at the lowland area and near to the river. When the river level rises and overflow, the access runoff floods the plantation region causing damages to the crops.

Before the introduction of digital GIS application, engineers extract the topographical information manually which is time consuming and requires manpower. In the recent decades, advancement in computer technology has ease the information extraction tasks drastically. Therefore, the used of GIS can fasten the extraction work and provide more accurate outcome. However, the level of accuracy is highly depending on the remote sensing data generated in term of digital model. For example, the larger cell grid only able to work well in areas with larger variation in elevation but tends to provide missing information in lowland areas. For this reason, the selection of digital model is important. Thus, this study compared the performance of different digital model in delineating the river network and basin catchments.

1.4 Scope of Work

This study covers only the Rompin River network and basin catchments where the boundary is within the Rompin District. The Rompin District consist of five sub-districts including Keratong, Rompin, Tioman, Pontian, and Endau. However, this study only considers three sub-district which are Keratong, Rompin, and Pontian where the Rompin River network is located.

For the delineation process, this study only applied two resolution of digital model, 30m DEM and 5m DTM. For the 30m SRTM, the model can be downloaded without charges from the USGS website, while the 5m DTM data was applied from the authority. Although, there are types of data resolution, this study only covers these two because for example the 90m DEM data was too coarse to be analysed for this study.

The main reason for choosing ArcGIS for this study is because it is a well-established software and widely used. ArcGIS is a software which enable the user to map and transfer all the data of the real world into the computer. Developments have been made and more than 20 updated versions up to date. However, ArcGIS requires licenses.

For verification purpose, the Rompin River network was digitised priory based on Google Earth. It was then converted to GIS compatible format and imported into the ArcGIS software application. Along with the results obtained from the SRTM and DTM, the digitised river network was exported to AutoCAD for comparison and model performance analysis. The average distance errors of the different models against the digitised river network were determined for best model selection.

Delineation of the catchment and river network for the Rompin River Basin from the SRTM and DTM in ArcGIS were done with the integrated extensions namely the Geospatial Hydrologic Modelling Extension (HEC-GeoHMS). This extension has been developed to provide the sets of tools that suit the hydrological network extraction. The outcome obtained from the analysis provides the catchment characteristics which enable engineers and water engineers to plan the drainage and also have the exact information about the study area.

1.5 Significant of Study

Generation of the Rompin River network and basin catchments can provide useful information for flood mitigation work. Information such as the area of catchments, stream network, flood prone area, and the location of the paddy schemes were demarcated in the digital geographical mapping to allow better assessment.

The utilisation of digital model was found to be more efficient than the traditional measures in term of time and energy. Apart from that, more physical and topographical information can be extracted with higher accuracy.

From this study, it is found that the 30m resolution SRTM-DEM is sufficiently reliable in delineating the topographical characteristics of the Rompin River Basin as compared to the 5m resolution DTM. This finding is important especially for projects that with limited finding. Hence, water engineers or managers, and authorities can benefit from the utilisation of the free version of SRTM-DEM to extract the related topographical information particularly when involved in decision making.

CHAPTER 2

LITERATURE REVIEW

2.1 Watershed

A watershed is an extent or an area of land where surface water from rain, melting snow, or ice converges to a single outlet at a lower elevation, usually the exit of the basin, where the water join another water body, such as a river, lake, reservoir, estuary, wetland, sea, or ocean (Rahaman et. al., 2015). Chandra Bose et. al. (2011) also stated that the watersheds are natural hydrological entities that cover a specific aerial expanse of land surface from which the rainfall runoff flows to a defined drain, channel, stream or river at any particular point. The term watershed is often used as synonymous with drainage basin, catchment area, and river basin (Chandra Bose, et. al, 2010). Watershed is bounded by a ridgeline or continuous contour line of higher elevation where all the surface water and underlying groundwater are collected and drained to a common outlet (Figure 2.1) (Bharata et. al, 2014). Sub-basins are separated topographically from adjacent watersheds by high elevation point in the area such as hillslopes. Mountain ridges and hills that delimit two watersheds are called the drainage divide.

Watersheds come in different shapes and sizes. Watersheds can be immense or very small. Large watersheds can be subdivided into smaller watersheds known as sub-watersheds or sub-basins. For example, large watershed such as the Mississippi river basin covers an area approximately 3.1 million km^2 (Edwards et. al, 2015). Watershed management and planning is often diverse and complex for large watersheds. A small watershed is usually part of a larger watershed and nested within the larger one. For example, the Illinois river watershed is a sub-watershed of the Mississippi river basin.

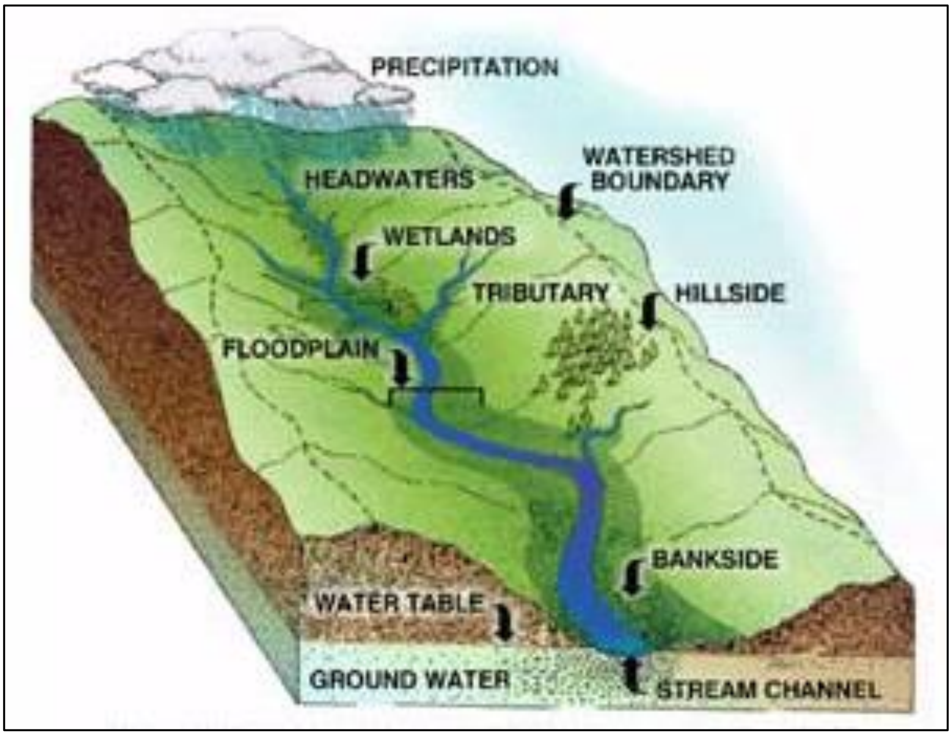

Figure 2.1 Watershed diagram
Source: Gualala River Watershed Council (2012)

Watersheds can be categorized into 2 major types: open and closed. For open watersheds, all water eventually drains into the ocean. Closed watersheds usually retain water and cannot be discharged into other external water bodies, such as rivers or oceans (Dorsaz et. al., 2013). It is also known as an endorheic basin. The surface water can be removed through evaporation or by seeping into the ground to discharge into the sea. There are five important functions are exhibited by watershed. The hydrological functions are water capture, water storage, and water release as runoff. Ecologically, there are two additional watershed functions. It allows the occurrence of various chemical reactions and also provides habitat to numerous plants and animals that constitute the biological elements of ecosystems.

Vazquez & Uribe, (2013) developed a keen understanding of the significance of this basic ecological unit which described the watershed as “area of land, a bounded hydrologic system, within which all living things are inextricably linked by their common water course and where, as human settled, simple logic demanded that they become part of a community.” The rim of the bowl or the watershed boundary is sometimes referred to as the ridgeline or watershed divide. This ridge line separates one watershed from another. Watersheds sometimes have sub watersheds within the Basins. Rivers, large streams, lake, and wetland watershed often have more than one sub watershed (usually smaller tributary watersheds). Watersheds have been classified into different categories based on area viz Micro Watershed (0 to 10 ha), Small Watershed (10 to 40 ha), Mini Watershed (40 to 200 ha), Sub Watershed (200 to 400 ha), Watershed (400 to 1000 ha) and Sub basin (above 1000 ha) (Chandra Bose et al., 2011).

The watershed is eventually delineated into four types of catchments including lakes, reservoirs, polders, and overland catchments based on the flow direction matrix and the location of river nodes. Multiple flow directions of grid cells are represented using a multi-direction encoding method, and multiple outflows of catchments are also reflected in the topology of catchments (Lai. et. al., 2016).

2.2 Watershed Delineation

Watershed delineation is the process of identifying the drainage area of any point on a stream or river network. Topography is usually the main input in determining a river watershed therefore its delineation requires the use of topographic maps which are sometimes not easily available and outdated in most places (Daffi, 2017). Delineation is part of the process known as watershed segmentation, i.e., dividing the watershed into discrete land and channel segments to analyse watershed behaviour (Palaka & Sankar, 2015).

Chandra Bose et al, (2011) also stated that geographical information systems (GIS) with its ability to gather spatial data from different sources into an integrated environment emerged as a significant tool for delineation of watersheds. Other aspects to be carefully addressed when computing watershed delineation include the precision and minimum resolution of DEMs, and the threshold value of upstream contributing area to determine the stream network (Jankowfsky. et. al., 2013)

The sub catchments are delineated using a combination of an object-oriented approach in the urban zone and GIS based terrain analysis with flow direction forcing in the rural zone (Jankowfsky et al., 2013). Watershed delineation is a required step when conducting any spatially distributed hydrological modelling. Automated approaches are often proposed to delineate a watershed based on a river network extracted from the digital elevation model (DEM) using the deterministic eight-neighbour (D8) method. A watershed can be delineated into four types of catchments: lakes, reservoirs, polders, and overland catchments (Lai et al., 2016). Watershed boundaries and stream networks (Figure 2.2) were delineated from each DEM and were compared to reference data (Yang et al., 2014).

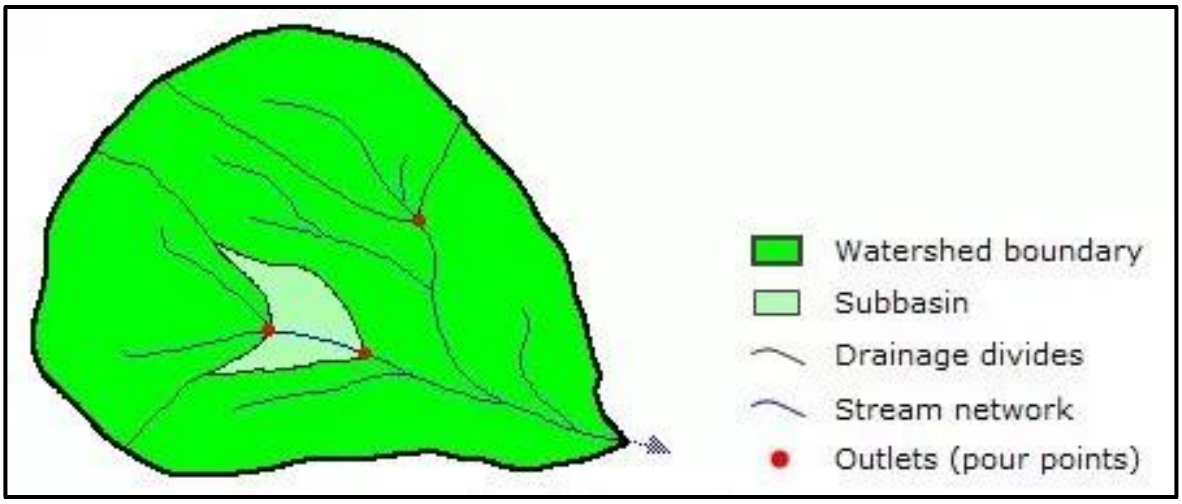

Figure 2.2 Watershed components

Source: San (2018)

In the last two decades, watershed management has gained the top most priority in water resources sector necessitating delineation of watersheds up to mini watershed level in order to take up watershed development and management programmes. Present study demonstrated that GIS is found to be flexible and is relatively easy to apply on large areas enabling gathering of all data and information in a common data base for watershed delineation and stream network analysis (Bose et al., 2011).

Watershed prioritization has gained importance in natural resources management, especially in the context of watershed management. Delineation of watersheds within a large drainage basin and their prioritization is required for proper planning and management of natural resources for sustainable development (Rahaman et al., 2015). Watershed delineation requires a threshold area (or number of DEM cells) to form a stream (Dile. et. al, 2016).

2.3 Digital Elevation Model (DEM)

Hydrogeologists have devised a very clever technique from satellite images to represent river networks, called digital elevation map (DEM) that allows us to determine the average height of areas (pixels) of the order $10^{-2}\ km^2$.

DEM is a subset and fundamental component of the Digital Terrain Model (DTM). In practice, these terms (SRTM, DSM, and DTM) are often assumed to be synonymous but sometimes they actually refer to different products. In some countries, a DTM is actually synonymous with a DEM. This means that a DTM is simply an elevation surface representing the bare earth referenced to a common vertical datum. DEM of a watershed forms key basis for hydrologic modelling and its resolution plays a key role in accurate prediction of various hydrological processes (Reddy & Reddy, 2015).

A DEM is a raster representation of a continuous surface, usually referring to the surface of the earth (Figure 2.3). The DEM is used to refer specifically to a regular grid of spot heights. It is the simplest and most common form of digital representation of topography (Chandra Bose et al., 2010).

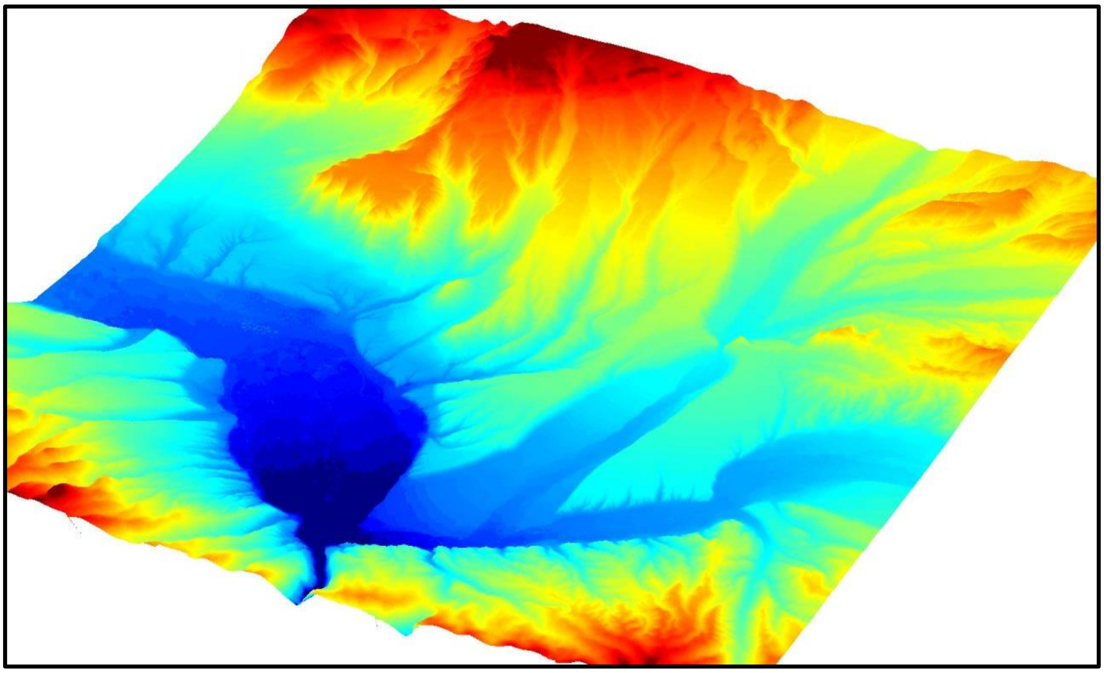

Figure 2.3 Digital Elevation Model (DEM)
Source: EO Miners

DEM is a specialised database that represents the relief of a surface between points of known elevation. By interpolating known elevation data from sources such as ground surveys and photogrammetric data capture, a rectangular digital elevation model grid can be created. In the other words, DEM is actually a model created from the data of elevation based on the longitude and latitude at the actual location, or even said as the digitalised layout of the study area. These DEM's is important for us to survey the selected study area. The quality of DEMs influences the derived stream network, and even small errors in accuracy can greatly affect the geographic location of the stream.

These findings indicate that while higher resolution DEM grids may result in more accurate representation of terrain characteristics, such variations do not necessarily improve watershed scale simulation modelling (Yang et al., 2014). Different DEM data resolutions may result in different accuracies of drainage network flow direction; the general law is: with a decrease in DEM resolution, the delineation of the drainage network becomes clearer, and the main stream and tributary streams gradually become distinct (Wu. et. al., 2017).

The resolution of the DEM greatly impacts the watershed delineation, watershed size, and results in varying stream network system, number of sub- watersheds and HRUsCounty, Arkansas, USA. Chaubey et al. (2005) showed that DEM resolution affects the watershed delineation, stream network and sub-basin classification in SWAT. A coarser DEM resolution resulted in decreased runoff, sediment, NO3–N and TP load predictions with short-term fluctuations (Reddy & Reddy, 2015).

Due to the fact that DEM includes abundant information regarding the topography and geomorphology, it is widely used in hydrological and geomorphological fields, with the advancement of digital watershed modelling and relevant technologies. In hydrology, DEM is mainly used for hydrological characteristic extraction and hydrological process modelling. The uncertainties of DEM and the extraction algorithm are the main factors which influence the hydrological characteristic extraction results (Wu et al., 2017).

Numerous studies have shown that the reliability of the derived topographic and hydrologic attributes depends on the resolution and accuracy of the input digital elevation model (DEM), a common format for representing topography digitally (Zhang. et. al., 2009).

Different studies highlighted the influence of the DEM grid cell size on the accuracy of the extracted network. Coarse and medium- resolution DEMs, for example, do not allow the resolution of topographic features such as hollows, low-order channels and hillslope characteristic.

Though watersheds can be delineated manually using topographic (contour) maps, it can however prove to be a very tedious and difficult task especially in flat terrains. Digital Elevation Models (DEM) and Geographic Information System (GIS) software are tools that can be used for modelling of stream networks, delineation of watershed to obtain parameters that are important for management of water volume and quality, soil conservation, flood control, wild life habitat and other hydrological analyses. The accuracy of the result mostly depends on quality and type of DEM and the computer algorithms used (Daffi, 2015).

2.4 Geographical Information System (GIS)

Since early ’90 GIS has become a sophisticated system for maintaining and analysing spatial and thematic information on spatial objects. The need for 3D information is rapidly increasing. The Geographic Information System (GIS) has unique features to relate to the point, linear and area features in terms of the topology as well as connectivity as shown in Figure 2.4.

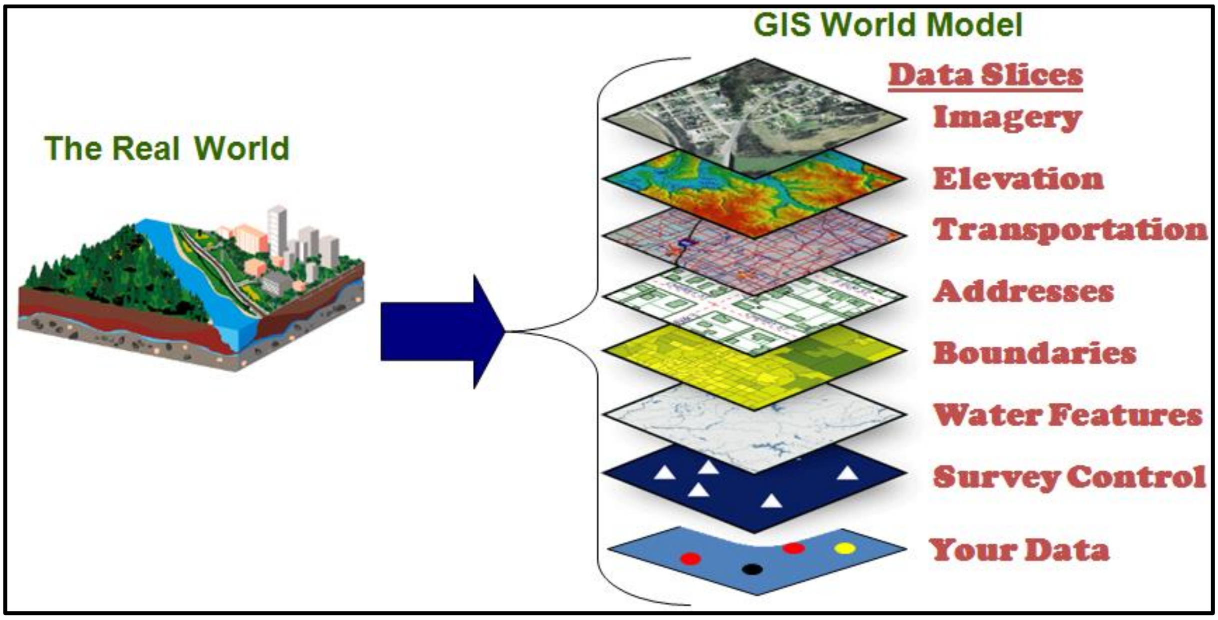

Figure 2.4 Geographical Information System (GIS)

Source: PE & RC

GIS has been used to collect, digitize, organize, model and analyse data on watershed delineation and to create a geo-database to incorporate physical, environmental and socio-economic information on the watersheds. Field data such as rainfall and evapotranspiration are very difficult to obtain making the use of remote sensing and Geographic Information System (GIS) very useful to study water availability in the basin. (Comair. et. al., 2012). Geographical Information System (GIS) is an effective tool to perform many operations such as digitization, delineation of streams of a watershed and carry out a variety of spatial analysis. This tool can be efficiently used to carry out hydrological analysis and hence used for sustainable watershed management projects (Bharata et al., 2014).

Manual catchment delineation which was subjective, error-prone, costly and time-consuming preceded automated catchment extraction or mapping within Geographic Information Systems (GIS) (Maherry et al., 2013). Digital data on the position and characteristics of river networks and catchments are important for the analysis of pressures and impacts on water resources. GIS tools allow for the combined analysis of digital elevation data and environmental parameters in order to derive this kind of information.

The remote sensing and GIS technique is a convenient method for morphometric analysis as the satellite images provides a synoptic view of a large area and is very useful in the analysis of drainage basin morphometry. GIS and remote sensing (RS) techniques are proved to be proficient tools for morphometric characterization of sub- watersheds (Rahaman et al., 2015). The benefits associated with the use of GIS in watershed and hydrologic analysis include the improved accuracy, less duplication, easier map storage, more flexibility, ease of data sharing, timeliness, greater efficiency and higher product complexity (Chandra Bose et al., 2010). Advancements in geographic information system (GIS) technology and increased availability of regional and national river survey databases have improved the acquisition of representative data needed to extrapolate data to entire river networks (Wang. et. al., 2012).

2.5 ArcGIS Application Software

ArcGIS is developed and sold by Environmental Systems Research Institute, Inc (ESRI). It has a long history and has been through many versions and changes (Western Oregon University, 2010). ArcGIS, released in 2001, is a synthesis of the powerful Arc/Info system with the easy-to-use interface of ArcView, updated to use the latest advances in desktop computing and database technology. It contains two programs, collectively referred to as ArcGIS Desktop.

1. ArcMap provides the means to display, analyse, and edit spatial data and data table.

2. ArcCatalog is a tool for viewing and managing spatial data files. It resembles Microsoft Windows Explorer, but it is designed to work with GIS data.

In addition, ArcGIS Desktop contains ArcToolbox, a collection of tools and functions for operations in ArcCatalog and ArcMap, such as converting between data formats, managing map projections, and performing analysis.

2.6 River Network and Basin Catchment

Drainage basin of water as the part of the territory where all the rainfall is collected by the same river and transferred to one or more outlets. River basins are the fundamental natural system which consist of several paths connecting to one main river. The extraction of drainage networks and catchment boundaries from digital elevation models (DEMs) has received considerable attention in recent years. (Vogt et al., 2003).

Watershed, catchment and drainage basin are terms that are used interchangeably to refer to, 'the topographic area that collects and discharges surface streamflow through one outlet (Daffi, 2015). Total watershed or catchment area is often used as a critical parameter in hydrologic and water resources simulation models.(Yang et al., 2014).

Watersheds are natural hydrological entities that cover a specific aerial expanse of land surface from which the rainfall runoff flows to a defined drain, channel, stream or river at any particular point. The terms region, basin, catchment, watershed etc are widely used to denote hydrological units. Even though these terms have similar meanings in popular sense, technically they are different (Chandra Bose et al., 2011).

2.7 GIS Application in Malaysia

The development of Geographical Information System (GIS) software has been rapidly increases. Pradhan (2010), used GIS in the study of landslide hazard analysis and cross-validation using multivariate logistic regression model on three test areas in Malaysia. For the landslide hazard analysis and the establishment of a landslide-related GIS database of all three study areas landslide locations were mapped using aerial photographs, field surveys and technical reports. A new attempt at landslide susceptibility mapping using fuzzy logic relations and their cross application of membership values to three study areas in Malaysia using a GIS. The possibility of capturing the judgment and the modelling of conditioning factors are the main advantages of using fuzzy logic (Pradhan, 2011).

Kia et al. (2012), in the study stated that Geographic information system (GIS) was used to model and simulate flood-prone areas in the southern part of Peninsular Malaysia. Integration of GIS and neural network techniques in the field of water resource has opened various new approaches in hydrological modelling, improved our ability to create more accurate flood models, and helped to present the results in a spatial environment. Manap. et. al. (2013), stated that due to the growing importance of groundwater for urban area in Malaysia, it is important to collect a groundwater expert opinion survey as well as to utilize the capabilities of remotely sensed imagery coupling with GIS modelling technique for predicting groundwater potential zones in the Upper Langat Basin, Selangor.

Shirazi. et. al. (2013) undergo the study to illustrates the groundwater vulnerability map for the Melaka State using the DRASTIC model together with remote sensing and geographic information system (GIS). The data which correspond to the seven parameters of the model were collected and converted into thematic maps by GIS. Toriman et al. (2009) study has successfully demonstrated the integration of GIS, hydrology and hydraulic simulations to model the FHMUA in the Damansara River at TTDI, Selangor.

The generated river flood hazard was based on water depth and flow velocity maps which were prepared according to hydraulic model results in GIS environment. The results show that, magnitude of rainfall event (ARI) and river basin land-use development condition have significant influences on the river flood hazard maps pattern (Alaghmand. et. al., 2010). GIS has shown to be beneficial by providing a more flexible way to display and integrate a wide range of information such as sampling stations, WQI, land use, point and non-point sources of pollution. GIS has also shown its strength in predicting WQI in un-sampled locations, thereby helping to make informed decisions and thus attaining sustainable tourism development (Aminu. et. al., 2015).

Based on the studies above, it is clearly shown that the Geographic Information System (GIS) software have been widely used in many fields such as hydrological studies, landslide studies, and also environmental studies. However, despites all of these studies, the study on the Rompin River Basin were still lacking. Therefore, it is important for this study to provide the information of the Rompin River Basin especially on the topographical information of the area which helps the water engineers and managers.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter describes the methodologies involved in extracting the river network and physical characteristics of the Rompin River Basin (RRB). The application tool selected for this study is ArcGIS 10.4 application integrated with HEC-GeoHMS extension. Data collection was carried out to select the suitable DEM used for this study. Two types of data selected are 30m SRTM and 5m DTM. The analysis is then proceeded with data pre-processing where the raw DEM and digitized river network were projected to a consistent coordinate system. The coordinate system utilized is the Kertau RSO Malaya (meters). Reconditioning process is necessary because to make sure the digitised river network is aligned with the delineated river network.

The process of delineating the RRB consists of few steps. First, the raw SRTM-DEM and IFSAR-DTM were reconditioned in reference to the digitized river network to adjust the alignment of the stimulated river network for higher accuracy. In order to overcome the depressions, fill sink function was used to fill the voids in the DEM. Then, with the stream definition function, a stream network was delineated based on the stream threshold value. Finally, the watershed and sub-basins were delineated by generating a new project on the selected outlet. In this study, the watershed and river network delineation were repeated with different stream threshold value to compare the extend of the delineated river network. The complete steps involved is described in Appendix A.

Lastly, the simulated river network was validated against the digitised river network. The reliability and the performance of the simulation were evaluated by performing the error calculation of average distance error between the delineated river network and digitised river network. The process repeated twice with the other set of

DEMs. From the results, the more accurate DEM is acquired. The detailed flowchart of the study shown in Figure 3.1.

3.2 Flow Chart

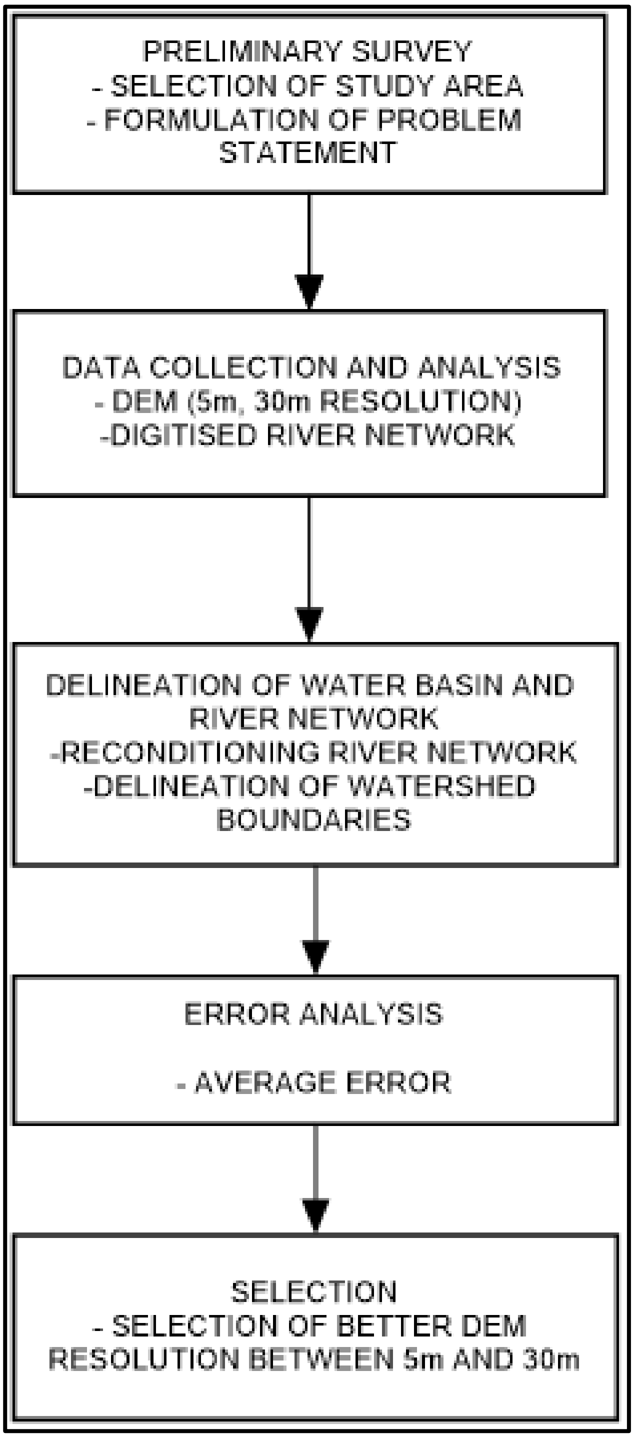

Figure 3.1 Flowchart of methodology

3.4 Preliminary Survey

The Rompin River Basin (RBB) is located in the South-eastern part of the Peninsular Malaysia in the state of Pahang. Figure 3.2 shows the map of the Rompin River Basin. RBB has a total area of about 4,000 km^2 with the main Rompin river length of 83 km. The Rompin River originates from the mountain range, which run parallel to the coast line and flows in a south-eastern direction of Pahang passing along the major town of Kuala Rompin before discharging into the South China Sea (Ranhill Consulting Sdn. Bhd., 2011 as cited in San, 2018). RBB is highly influenced by the tropical monsoon (November-February) and the dry season (March-October). The major land uses of the RBB are for the agriculture, industrial and domestics activities.

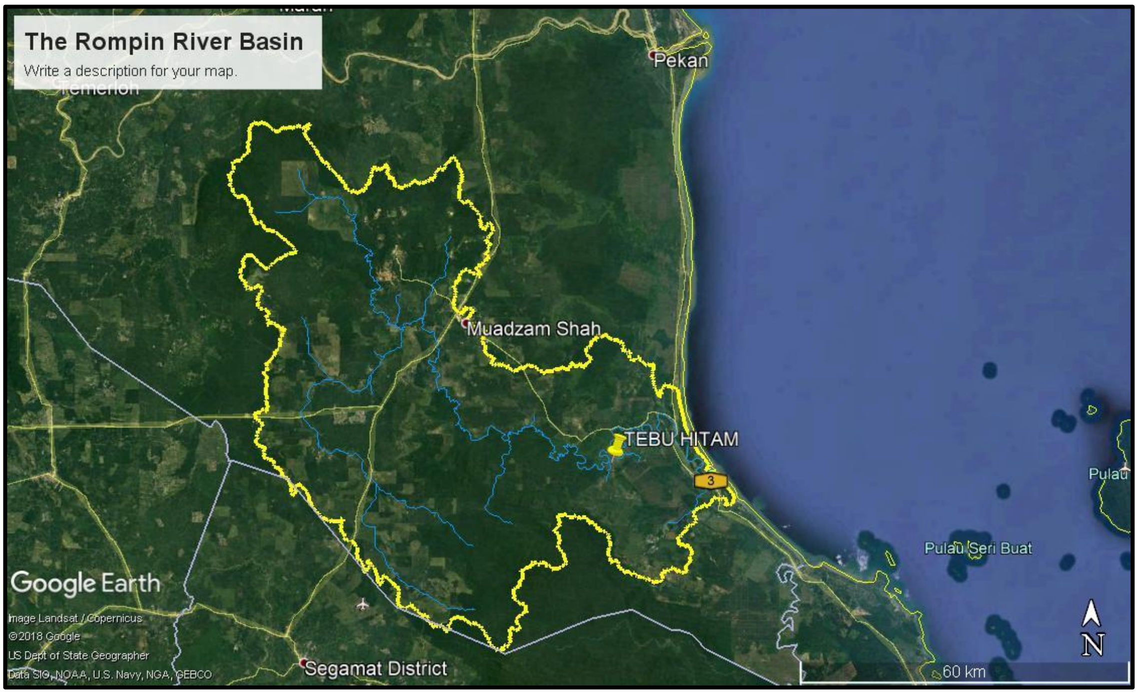

Figure 3.2 The Rompin River Basin

Source : Google Earth Pro (2018)

3.6 Data Collection and Analysis

In this study, the two main datasets required are the Shuttle Radar Topography Mission (SRTM) - Digital Elevation Model (DEM) and Interferometric Synthetic Aperture Radar (IFSAR) - Digital Terrain Model (DTM) for the Rompin River Basin. SRTM-DEM with 30m resolution and IFSAR-DTM with 5m resolution were used in this study to effectively avoid the low-resolution accuracy issue, the. The 30m DEM data was downloaded from the United State Geological Survey (USGS) Earth Explorer (Figure 3.3) which is free while the 5m DTM (Figure 3.4) data was obtained from the authority.

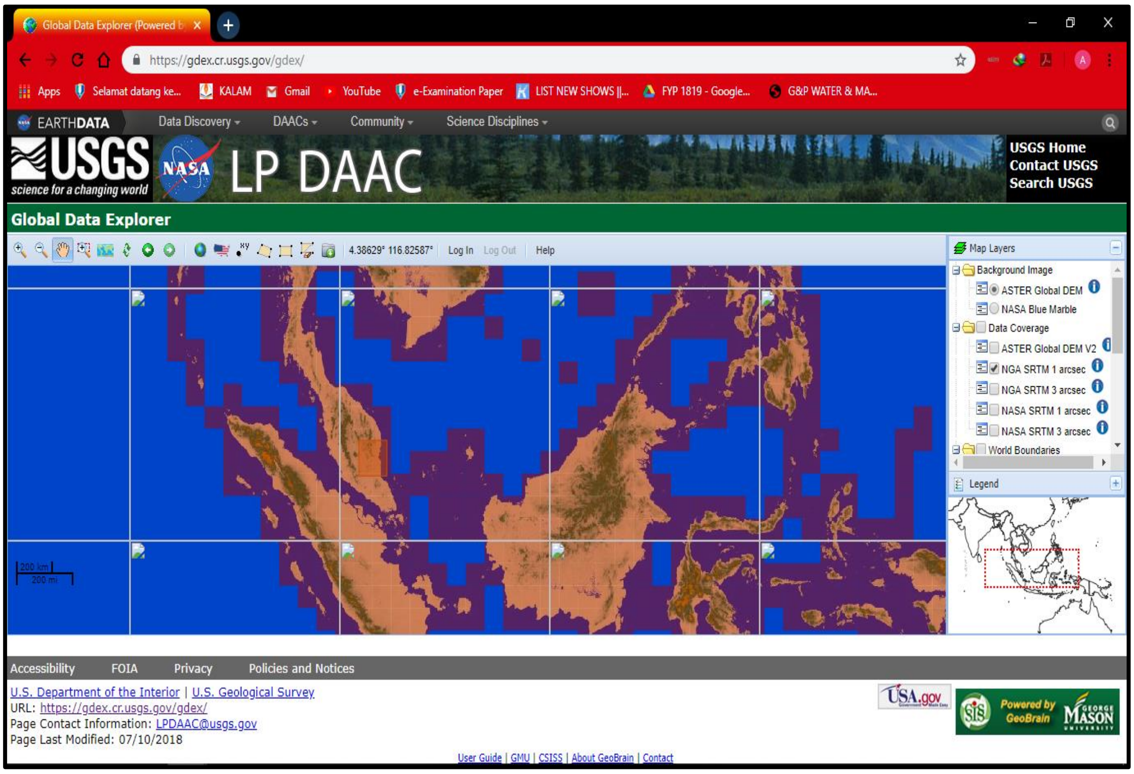

Figure 3.3 DEM map

Source : LP DAAC

Figure 3.4 DTM map

Source: Jurukur Perunding Services Sdn Bhd. (2016)

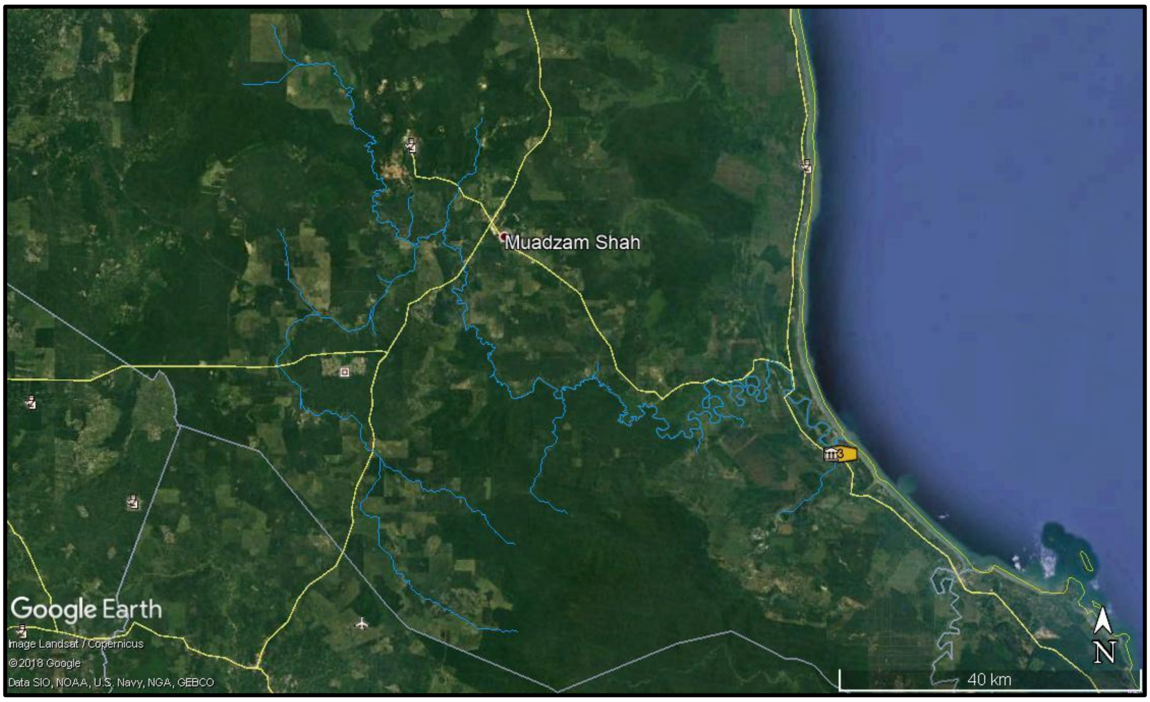

Figure 3.5 Google Earth satellite image and traced streamline

The digitized river network was converted from KML (Google Earth) (Figure 3.5) format to GIS shapefile format. Coordinate system for both SRTM-DEM and IFSAR-DTM together with the digitized river network were projected from WGS 1984 into the same coordinate system which is Kertau RSO Malaya (Meters). Kertau RSO Malaya

(Meters) was selected because it is suitable to be used in the Peninsular Malaysia ("The Malaysian CRS Monster", n.d.). Both SRTM-DEM and IFSAR-DTM are set as the raw DEM whereas the projected river shapefile is the reference streamline for DEM reconditioning. Both the projected and reconditioned layers were imported into Google Earth Pro to ensure there is no misalignment and mismatch of location as shown in Figure 3.6.

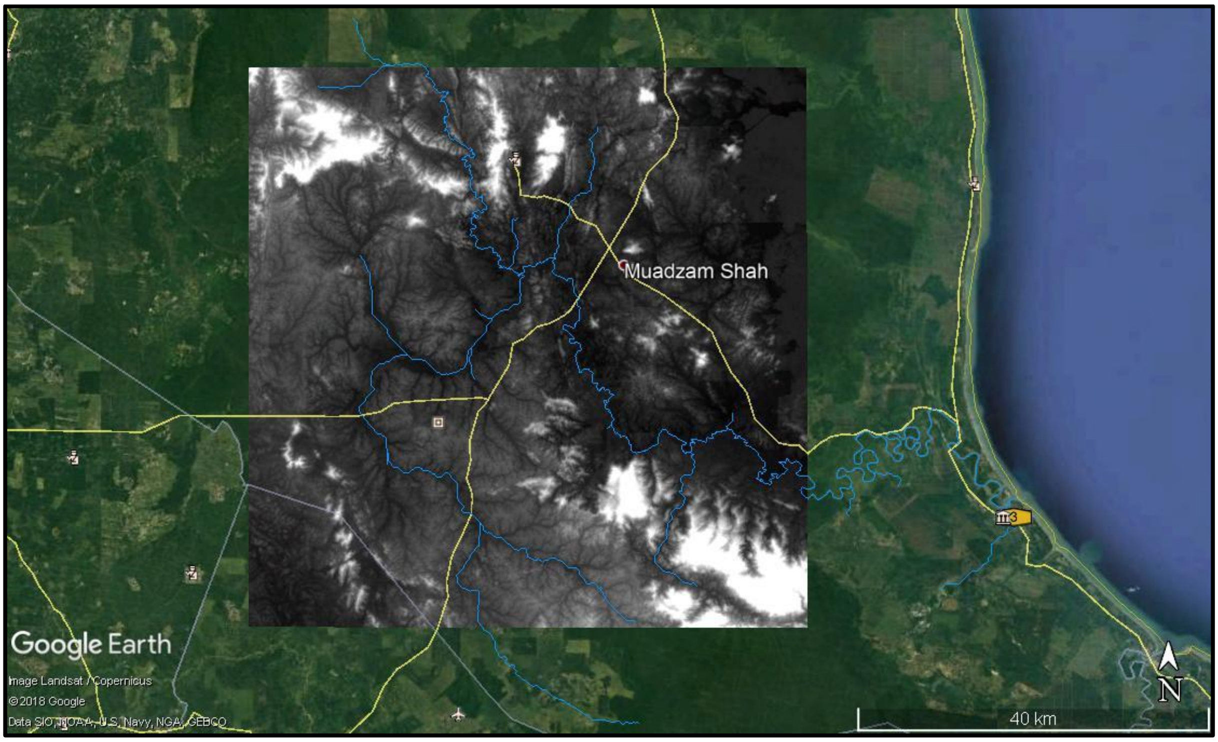

Figure 3.6 Projected SRTM DEM and river network in Google Earth

3.7 Delineation of Water Basin and River Network

Watershed and river network delineation for RRB were carried out by using ArcGIS software (version 10.4) application integrated with HEC-GeoHMS extension. The delineation process involves a sequence of steps in ArcMap platform accessed through the terrain pre-processing component in HEC-GeoHMS extensions. Figure 3.7 shows the procedures adopted to delineate watershed and river network in RRB.

The reconditioning process is important to ensure the coordinate alignment is matched accordingly. Values for the sharp and smooth drops were adjusted to prevent the existence of void and depression in the raw datasets (Table 3.1). Examples of the depressions identified in the raw DEM resulted from the improper reconditioning outcome are as shown in Figure 3.8 (the scattered points). Before the delineation process begin, it is essential to check and ensure there is no void in the raw DEM after the reconditioning process.

The following steps after reconditioning are as follow:

1. Fill Sinks: The Fill function fills the sinks in a grid. If cells with higher elevation surround any cell in a DEM, the flow gets trapped in that cell and cannot go downstream. The Fill function modifies the elevation values to eliminate this problem.

2. Flow Direction: This function computes the flow direction for a given grid. The value in any given cell of the flow direction grid indicates the direction of the steepest descent from that cell to one of its neighbouring cells using the eight direction pour point (D8) method. In the D8 method, the steepest descent for each cell is computed by looking at the slope between the target cell and its 9 neighbours.

3. Flow Accumulation: The Flow Accumulation function uses the flow direction grid to compute the accumulated number of cells that are draining to any particular cell in the DEM.

4. Stream Definition: stream definition displays the river’s threshold. Stream definition is used to break a large watershed up into smaller sub-basins or catchments.

5. Stream Segmentation: Stream segmentation breaks the waterway into stream segments which connect junctions to junctions, outlets, or drainage divide.

6. Catchment Grid Delineation: Shows the raster data based on the stream segmentation result.

7. Catchment Polygon Processing: Catchment polygon processing converts the raster data to vector format.

8. Drainage Line Processing: Drainage line processing converts the raster data for stream segments into a vector format.

9. Adjoint Catchment Processing: adjoint catchment processing speeds up the point delineation process.

10. Project Setup: Start and name the new project to produce the catchment area results.

Table 3.1 Default number of cells for stream buffer, smooth drop, and sharp drop

Default characteristics	value
Number of cells for stream buffer	5
Smooth drop in Z value	10
Sharp drop in Z value	1000

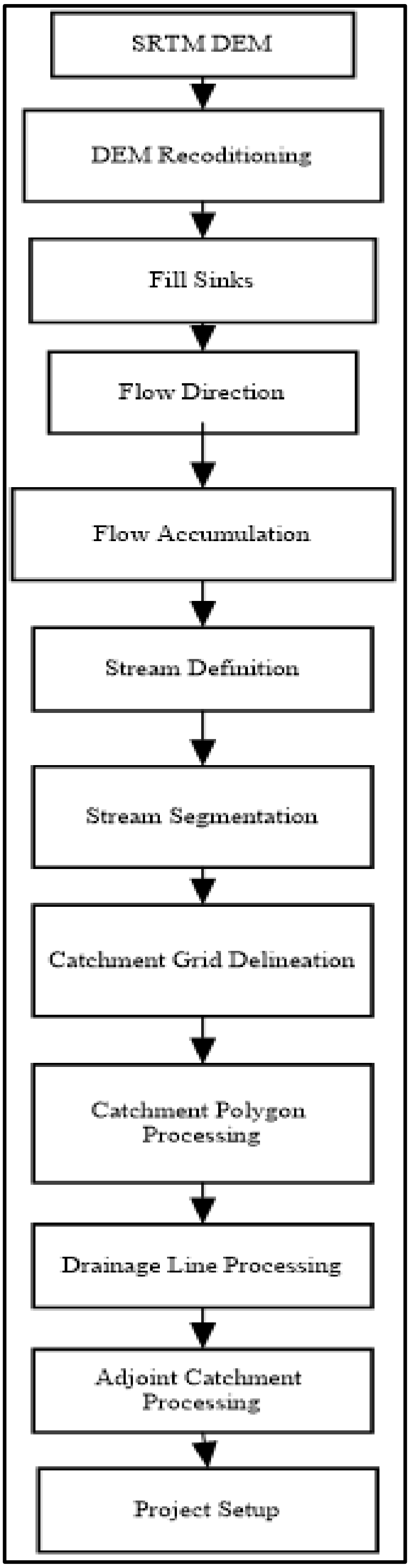

Figure 3.7 Flowchart of Method of River Basin Delineation

Figure 3.8 Depressions in raw DEM

3.8 Error Analysis

In this study, the difference in the accuracy of the SRTM-DEM and IFSAR-DTM were compared with the digitized river network. Performance of the different DEMs were evaluated using the average spatial error of the digitised river network from Google Earth as compared with the delineated river network in ArcGIS. The spatial error was analysed according to the elevation groups. Both the results of the 5m resolution and 30m resolution of DEM were compared to the digitised river network. The average error values can be used to distinguish simulation performance for the validation purpose as well as to compare the individual simulation performance to that of another simulated model.

3.9 DEM Selection Criteria

The best model performance was determined based on the computed average error analysis. Criteria for the selection was in reference to the lowest error obtained from the validation procedure. Besides that, the outcome of the finding was examined and compared to similar previous research available.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Watershed Delineation

The watershed of the Rompin River Basin utilising both the 5m IFSAR-DTM and 30m SRTM-DEM have been successfully delineated using ArcGIS application with the integration of HEC-GeoHMS extensions. Results of the delineated Rompin River Basin are shown in Figure 4.1 and Figure 4.2. For the delineated river network, the results are displayed in Figure 4.3 and Figure 4.4. By default, the 5m IFSAR-DTM shows 65 number of sub-basins and the 30m SRTM-DEM shows 57 number of sub-basins. (Table 4.1)

From the figures, there are no significance difference for both the 5m IFSAR-DTM and 30m SRTM-DEM. Hence, statistical measure was adopted to differentiate the performance of these DEM resolutions. For this study, the default threshold simulation and the average spatial error in distance from the digitised river network and the delineated river network were evaluated to determine the better performing DEM resolution in delineating the Rompin River Basin.

Table 4.1 Default number of sub-basin for respective DEMs

DEM	Number of sub basins
30m SRTM-DEM	57
5m IFSAR-DTM	65

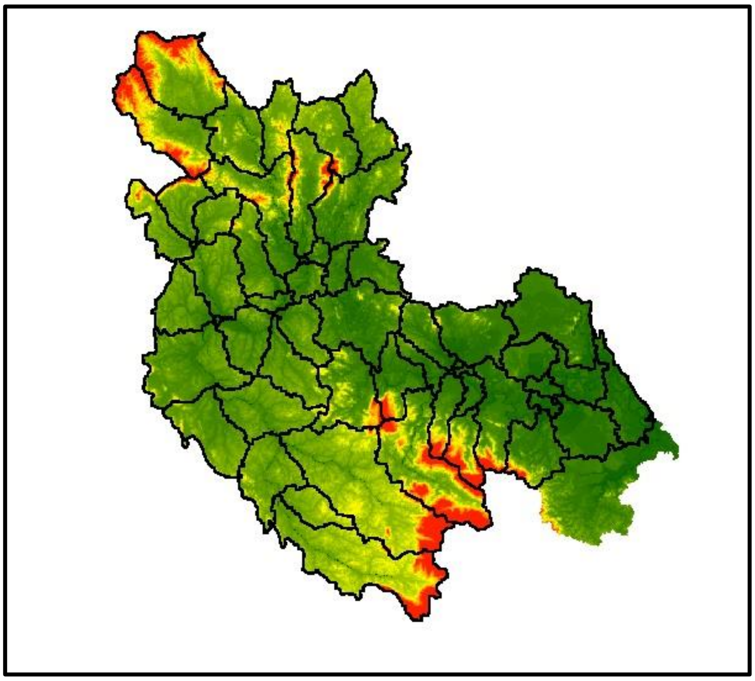

Figure 4.1 The delineated 30m SRTM-DEM

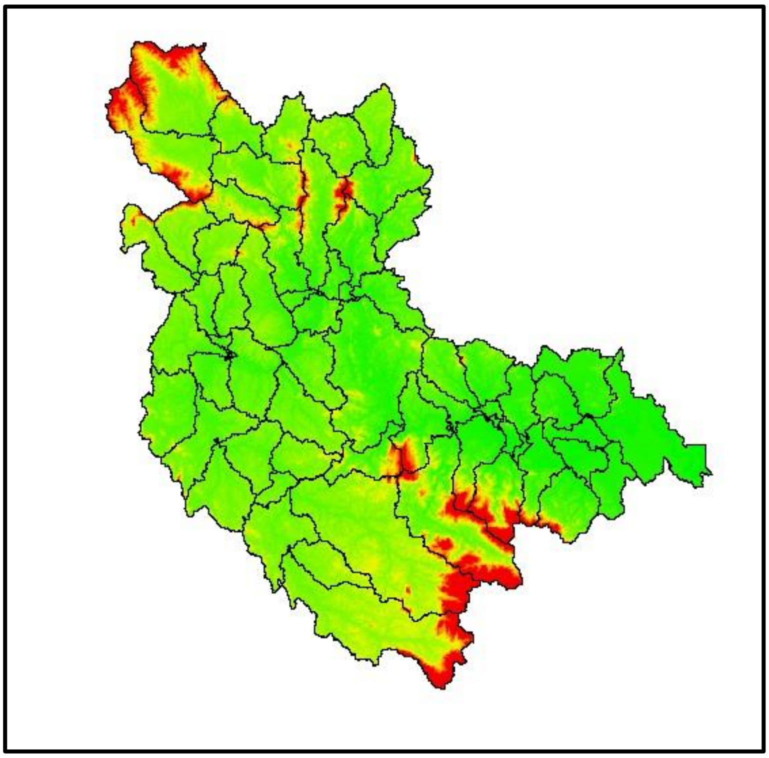

Figure 4.2 The delineated 5m IFSAR-DTM

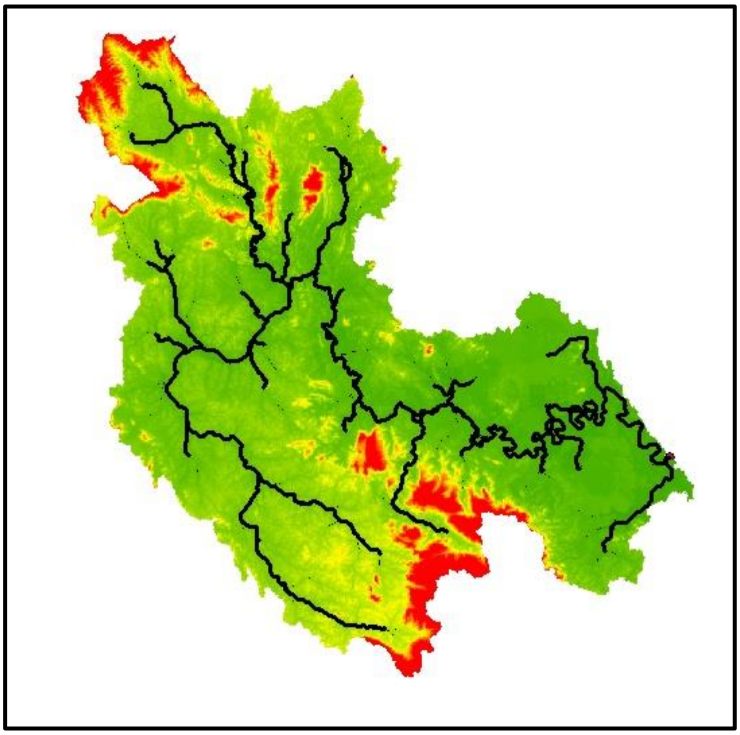

Figure 4.3 The delineated river network (30m resolution)

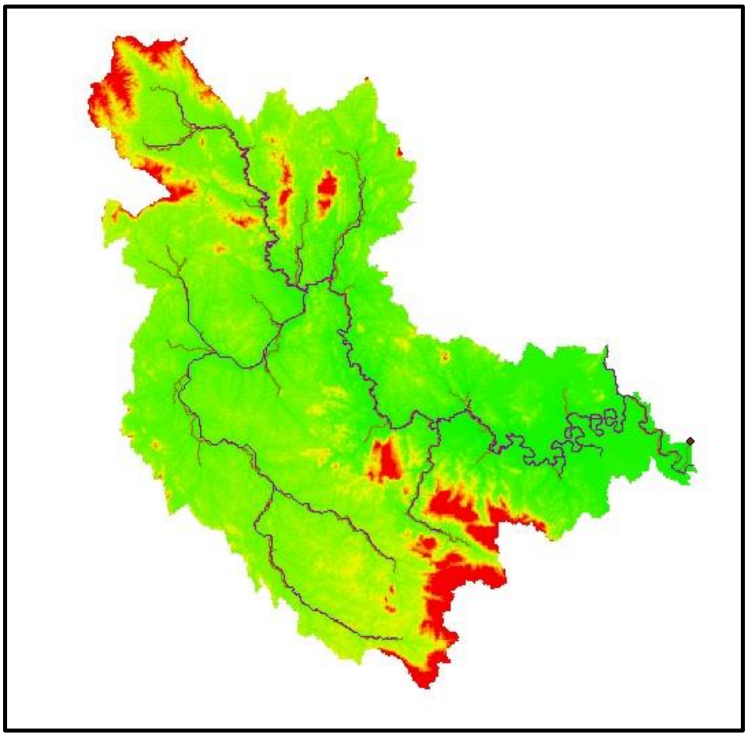

Figure 4.4 The delineated river network (5m resolution)

4.2 Threshold Simulation

Stream threshold can improve the accuracy of the stream network simulation and watershed delineation. In this study, three simulations under different stream threshold values for both the 30m SRTM-DEM and 5m IFSAR-DTM are presented in Figure 4.5 to Figure 4.10. For the 30m SRTM-DEM, the threshold value was differed in the area per square kilometre which are, 19, 38, and 57 respectively (Figure 4.5, 4.6, 4.7). For the 5m IFSAR-DTM, the threshold values are 20, 40, and 60 square kilometres respectively (Figure 4.8, 4.9, 4.10). The simulations were evaluated by comparing the number of sub basin for each of the threshold. Summary of the simulated stream networks and watershed are presented in Table 4.1 and Table 4.2.

Based on the comparison, there are difference in the number of sub basin for both the 30m SRTM-DEM and 5m IFSAR-DTM. The smaller threshold value resulted in the higher number of sub basins, while the bigger threshold value resulted in the lower number of sub basins. This proved that stream threshold values could enhance the performance of stream networks and watershed delineation depending on the purpose of usage. The finding in this study was supported in the study of Li (2014) which proved that the lower stream threshold value could lead to a desirable match with the actual stream network and watershed. Therefore, the results are proved to be reasonable and the consideration of stream threshold values could be further applied to the future work.

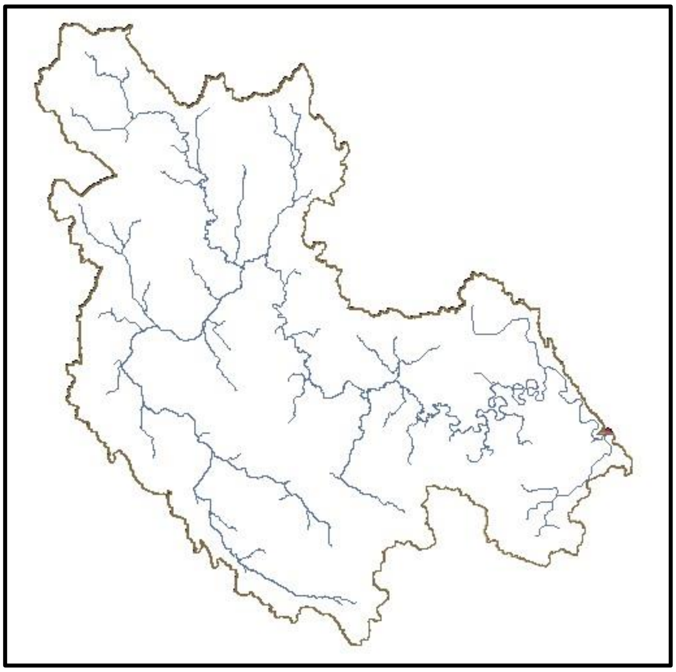

Figure 4.5 19 threshold value of 30m SRTM-DEM

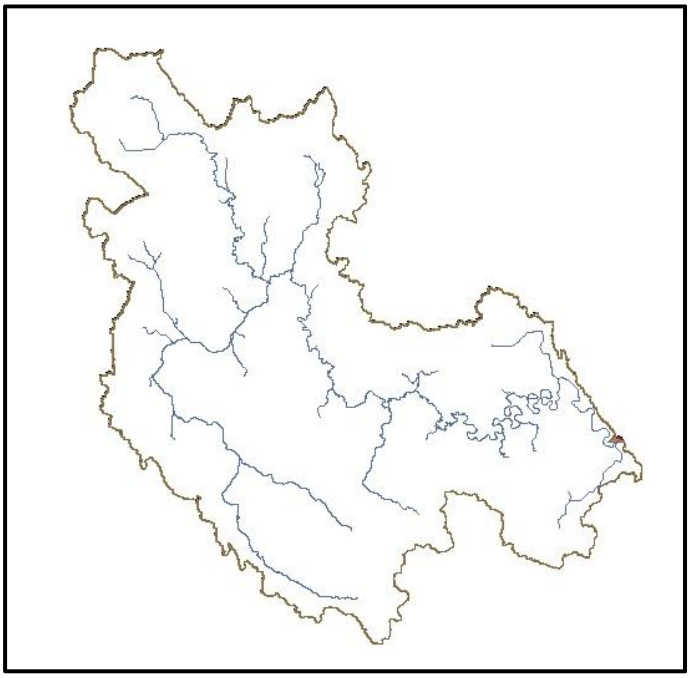

Figure 4.6 38 threshold value of 30m SRTM-DEM

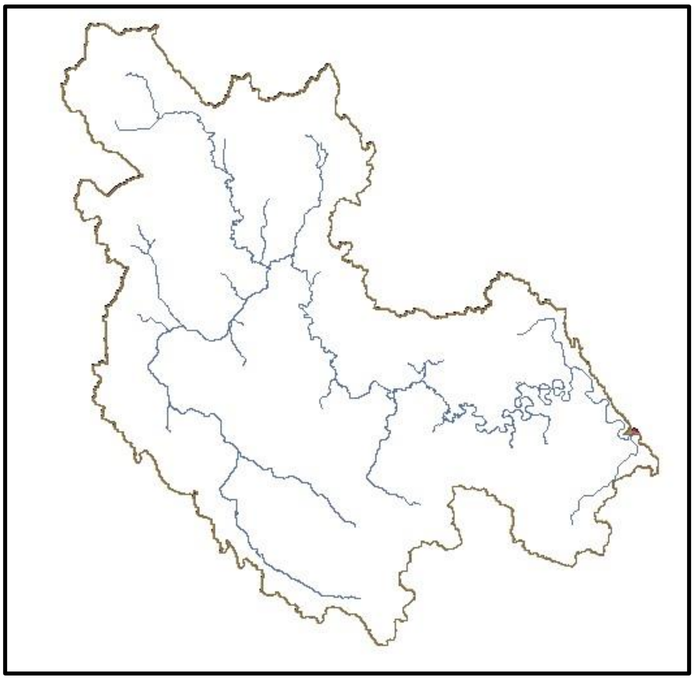

Figure 4.7 57 threshold value of 30m SRTM-DEM

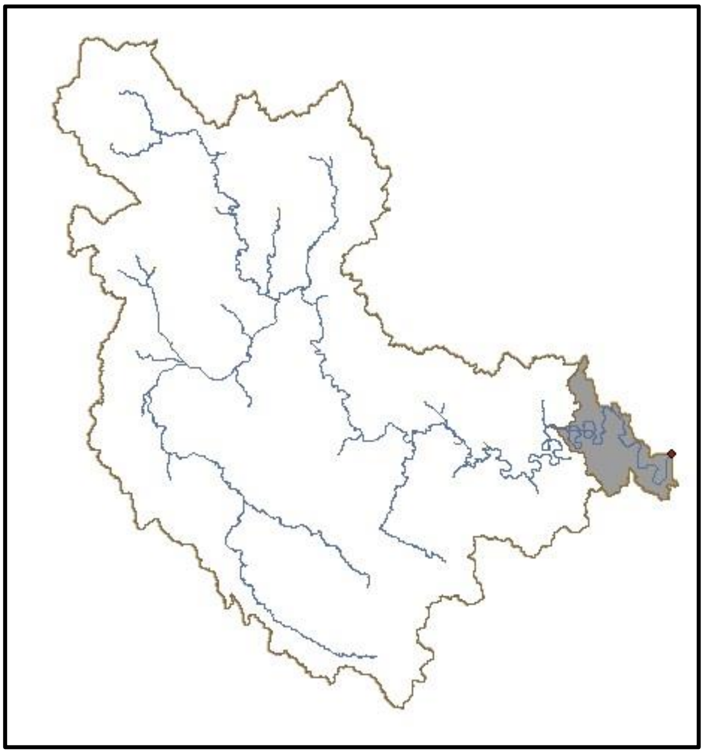

Figure 4.8 20 threshold value of 5m IFSAR-DTM

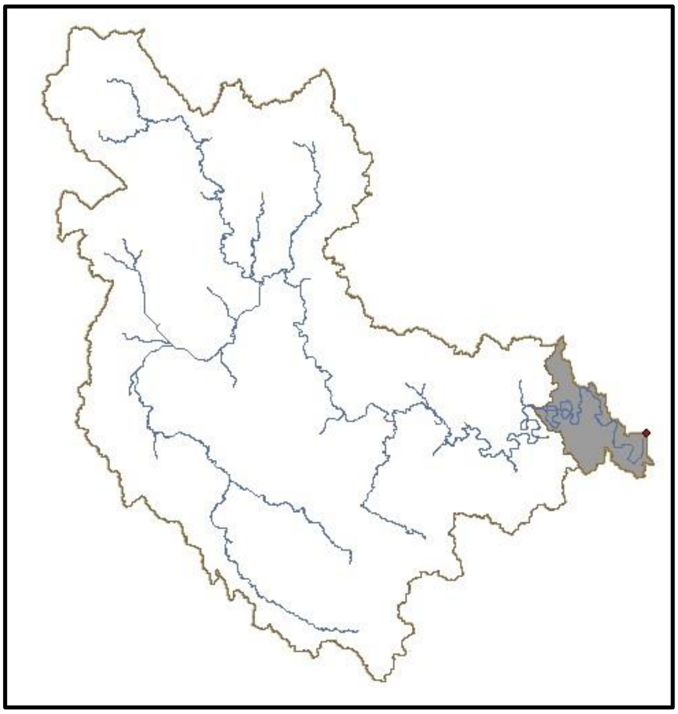

Figure 4.9 40 threshold value of 5m IFSAR-DTM

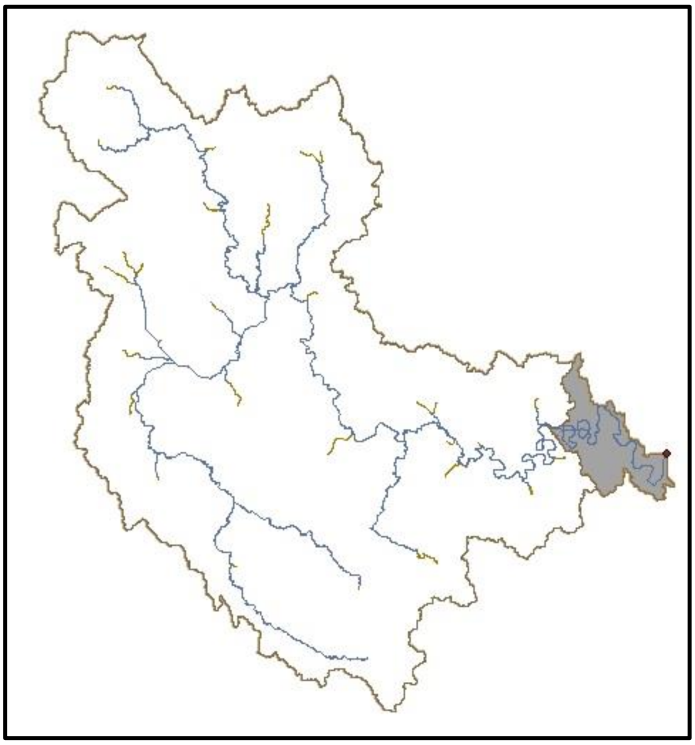

Figure 4.10 60 threshold value of 5m IFSAR-DTM

Table 4.2 Summary of the simulated stream networks and watersheds for 30m SRTM-DEM

Stream threshold value	Number of sub basins
19	63
38	34
57	28

Table 4.3 Summary of the simulated stream networks and watersheds for 5m IFSAR-DTM

Stream threshold value	Number of sub basins
20	30
40	30
60	17

4.2 Validation of River Network

For the validation of the delineated river network, the result obtained was compared to the digitised river network from Google Earth. The delineated and digitised river networks were aligned together and exported to the AutoCAD. In the AutoCAD, perpendicular horizontal lines against the digitised river network were placed along the river network at the interval distance of 5000m. The DEMs were classified into different groups according to the respective elevation; low elevation, intermediate elevation, and high elevation as shown in Figure 4.11 and Figure 4.12.

The respective interval lines in the AutoCAD were then calculated to find the distance between the digitised river network and the delineated river network. Then, the average distance was calculated and the results are tabulated in Table 4.3 and Table 4.4. The overall data of error distance was tabulated in Appendix B.

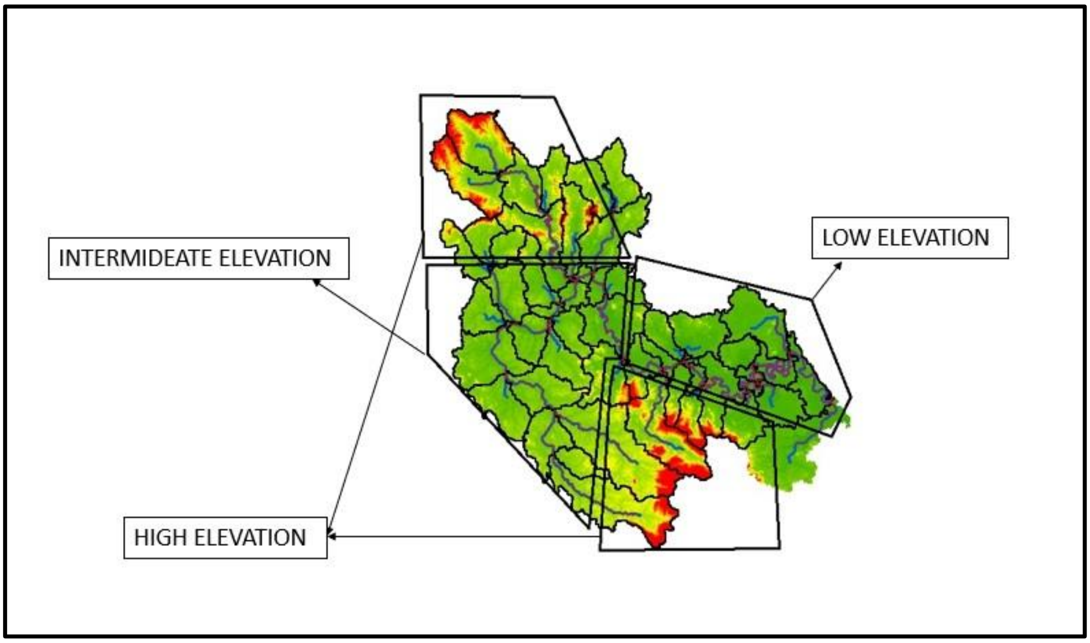

Figure 4.11 The 30m SRTM-DEM classified according to the elevation

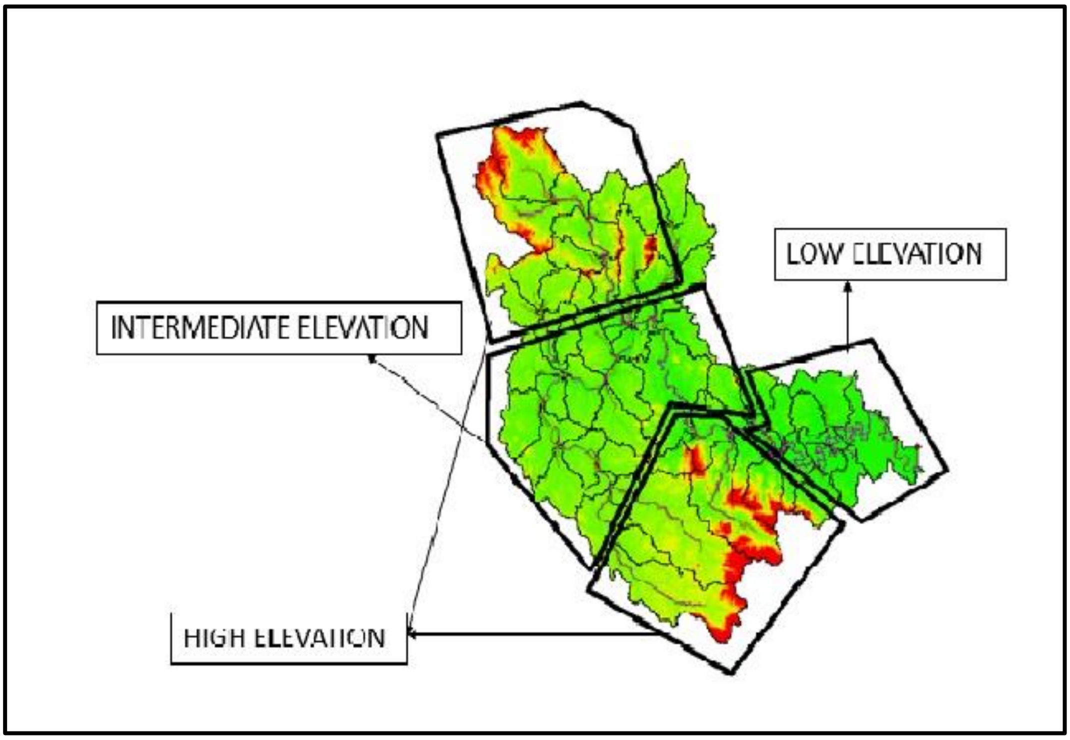

Figure 4.12 The 5m IFSAR-DTM classified according to the elevation

Table 4.4 The average distance error for 30m SRTM-DEM

ELEVATION	AVERAGE DIFFERENCE DISTANCE (m)
HIGH	24.6316
INTERMIDEATE	22.8071
LOW	19.3414

Table 4.5 The average distance error for 5m IFSAR-DTM

ELEVATION	AVERAGE DIFFERENCE DISTANCE (m)
HIGH	82.5576
INTERMIDEATE	190.0989
LOW	169.1754

From the tabulated result, the 5m IFSAR-DTM was found to have a bigger distance error compared to the 30m SRTM-DEM. Even though the error for the 5m IFSAR-DTM is big, the 5m IFSAR-DTM is still considered as a better performing DEM as supported by Zhang et. al (2009) which stated that the reliability of the derived topographic and hydrologic attributes depends on the resolution and accuracy of the input digital elevation model (DEM). These errors were due to the z-value assigned during the delineation process. The z-value is the value of elevation for the DEM. As the 5m IFSAR-DTM has a high accuracy, the z-value may be differed from the digitised river network from the Google Earth. All in all, the 30m SRTM-DEM performed better on low elevation while the 5m IFSAR-DTM performed better on high elevation.

4.4 Summary

In overall, both the 30m SRTM-DEM and 5m IFSAR-DTM managed to extract the physical and topographical information for the Rompin River Basin. Both DEMs performed well in delineating the Rompin River Basin and Rompin River network. Results of the threshold simulation shows that a lower stream threshold resulted in more detailed stream network and watershed delineation. Thus, it indicated that the stream threshold values could be considered to improve the performance of stream networks and watershed delineation. Lastly, the validation result for the delineated and digitised river network shows that a low error for 30m SRTM-DEM while a high error for 5m IFSAR-DTM, indicating that the river is well delineated by both DEMs. In conclusion, the 5m IFSAR-DTM is a better performing DEM. However, the 30m SRTM-DEM was found to be sufficiently reliable if there is no other available source.

CHAPTER 5

CONCLUSION

5.1 Introduction

The present study demonstrates the delineation of watersheds and river networks based on Digital Elevation Model (DEM) using the application of Geographical Information System (GIS) with the extension of HEC-GeoHMS. In this study, the watersheds and river network have been successfully delineated from 30m resolution SRT-DEM, and 5m resolution IFSAR-SRTM. Repetitive simulations for different stream threshold values have been conducted in the Rompin River Basin, with the objective to identify and evaluate the effect of the stream threshold values on the delineated river networks and watershed. The delineated river network has been validated by using the average distance error to investigate its accuracy and reliability by comparing it to the digitised river network.

5.2 Conclusion

The objectives of this study have been achieved accordingly.

The watershed and river network were successfully delineated by using ArcGIS application with the integration of HEC-GeoHMS extensions. Based on the results, both the 30m resolution SRTM-DEM and 5m resolution IFSAR-DTM does not show a visible difference.

The physical and topographical characteristics of stream and sub basins were also successfully extracted and estimated. In this study, the physical and topographical characteristics that have been extracted were the number of sub basins, the length of the river stream, and the elevation of the river network and sub basins.

For the validation of the delineated river network, the results obtained has been compared with the digitised river network from Google Earth. For the 30m resolution

SRTM-DEM, the results are; for high elevation, 24.63m, intermediate elevation, 22.81m, and low elevation 19.34m respectively. Meanwhile, for the 5m resolution IFSAR-DTM, the results are; for high elevation, 82.56m, intermediate elevation, 190.09m, and low elevation, 169.18m respectively. The results indicated that the 30m resolution SRTM-DEM performed better on low elevation, while the 5m resolution IFSAR-DTM performed better on high elevation. Thus, the delineated river network is considered as highly acceptable and can be applied for the further studies on water resource management.

Finally, it is concluded that the 5m resolution IFSAR-DTM is a better performing resolution based on previous studies. However, the 30m resolution SRTM-DEM is sufficient enough in delineating the Rompin River Basin if there are no other source of data.

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 following are the recommendations listed for the future enhancement of this simulation:

i) The value of threshold simulation for 5m resolution IFSAR-DTM and 30m resolution SRTM-DEM are not same. The value differed due to the difference accuracy of each of the resolution. The 5m resolution was found to be more accurate making the number of cells too big. Thus, there are slightly distally in the result obtained. Therefore, for further study need to make sure the threshold value to be the same.

ii) Researchers have found that the 5m resolution IFSAR-DTM does required a high performing computer in order to delineate the river network and watersheds. Thus, making the whole process of delineating the Rompin River Basin to take a longer time to delineate compared to the 30m resolution SRTM-DEM. Therefore, it is recommended to delineated a higher resolution DEM with a high performing computer to prevent from any problem.

iii) Researchers found that the other type of software application should be consider to make the analysis to be clearer. Therefore, it is recommended to delineated the river network with other software application.

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APPENDIX A
DELINEATION OF WATERSHED FROM A DIGITAL ELEVATION MODEL

Step 1 - Start ArcMap and add data

- Make sure the Spatial Analyst extension is turned on. (Customize → Extensions)
- Add your Elevation DEM and mask shapefile.

Step 2 – Set Geoprocessing Environment

- Under Geoprocessing, choose Environments
- Set the following environment settings:
  a) Workspace
  Scratch Workspace: Set this to a location you want you're your temporary files to be located
  b) Raster Analysis Settings
  - Cell Size: same as Layer
  - Mask
  - Click OK

Step 3 – Check data properties

- Right-click the raster data and choose *Properties*, then click the *Source* tab.
- Scroll down to review the properties of the raster. Check that there is a spatial reference.
- If there is not, open Toolbox → Data Management Tools→ Projections and Transformations → Define Projection . You'll have to know how the projection of your raster should be defined. This information can be found in the metadata information for the raster.
- Once you have confirmed that your raster has a spatial reference, close the Properties dialog box.

Step 4 – Use the Con tool

- It's important to be sure that all elevation values are reasonable. One possibility is that a group of unusually high values represents the ocean mask value in the original image. Using the Identify tool, click around on your area to see if this is a reasonable assumption.

- To make sure that this value does not create problems during the data creation and analysis processes, you'll use the Con tool to change it to 0.
- Expand the Conditional toolset in the Spatial Analyst Tools toolbox. Open the Con tool.
- The Con tool allows you to change the values of cells based on a conditional statement. For example, if the ocean is currently represented by a value of 65036, it will be replaced with a value of 0. Otherwise, the cell will retain its elevation value.

Step 5 – Set flow direction

Your first step in creating the watersheds is to set flow direction for the elevation raster. Determining the direction of flow through each cell is always the first step in surface hydrology analysis, because all the other hydrology tools need this information to work.

- The Flow Direction tool finds the flow direction for a cell by comparing its elevation to those of its neighbors. The output is a code that identifies the neighbor into which water will flow.
- Expand the Hydrology toolset.
- Double-click Flow Direction.
- For Input surface raster, choose raster data.
- Name the output flow direction raster.

Step 6 – Locate sinks

With the flow direction set, you can check your data for sinks.

- A sink is a group of one or more cells that have lower elevations than all the surrounding cells. When water flows into a sink, it cannot flow out and contribute to the flow downstream; therefore, flow direction cannot be assigned one of the eight valid values in a flow direction grid.
- Sinks in elevation data are most commonly due to errors in the data. These errors are often due to sampling effects and the rounding of elevations to integer numbers.
- From the Hydrology toolset, open the Sink tool.
- For Input flow direction raster, choose the named flow direction raster data.
- Name the output raster.
- Click OK.
- When processing is complete, turn off all other layers to see the sinks.
- You'll need to fill the sinks before creating the watersheds.

Step 7 – Fill sinks

- From the Hydrology toolset, double-click the Fill tool.
- The Fill tool finds the sinks (their elevation is lower than all the surrounding cells) and then "fills" them to the elevation of their lowest neighbor.
- For Input surface raster, choose surface raster file.
- Name the output raster.
  - Tip: If there are depressions in the terrain that represent real sinks (e.g., lakes), they can be excluded from sink filling by setting the Z limit.
  - All sinks that are less than the z-limit lower than their lowest adjacent neighbor will be filled to the height of their pour points.
- Click OK.

Step 8 – Set flow direction for filled elevation layer

Now you'll need to determine the direction of flow for the new elevation raster.

- Open the Flow Direction tool.
- Choose fil sink file for the input raster.
- Name the output raster.
- Click OK.

Step 9 – Create watersheds (Raster)

Now you're ready to create the watersheds.

- From the Hydrology toolset, double-click Basin.
- Why use the Basin tool instead of the Watershed tool?
  i. ArcGIS includes two surface hydrology tools that create watersheds for pour points—Basin and Watershed. Pour point data (either vector or raster) represent locations above which the contributing area will be determined.
  ii. The Basin tool finds its own pour points and creates watersheds for the whole map.
  iii. The Watershed tool creates watersheds for the pour points that you provide.
- Choose the flow direction file as the input raster.
- Name the output.
- Click OK.

APPENDIX B
THE DIFFERENCE DISTANCE BETWEEN DELINEATED RIVER NETWORK AND DIGITISED RIVER NETWORK

a) The 30m resolution SRTM-DEM

HIGH ELEVATION	
POINT	**DISTANCE BETWEEN DIGITIZED RIVER NETWORK & DELINEATED RIVER NETWORK (m)**
1	9.3066
2	8.7691
3	9.6053
4	8.7505
5	17.0182
6	11.2779
7	18.6779
8	16.438
9	47.729
10	13.7501
11	2.4223
12	136.6738
13	39.838
14	15.3255
15	3.146
16	4.7787
17	15.9785
18	7.2477
19	7.8839
20	20.8875
21	29.3758
22	1.7004
23	21.7109
24	13.0786
25	48.9803

26	5.7066
27	19.8168
28	20.9573
29	137.4864
AVERAGE	24.63164138

INTERMIDEATE ELEVATION	
POINT	DISTANCE BETWEEN DIGITIZED RIVER NETWORK & DELINEATED RIVER NETWORK (m)
1	12.8772
2	4.3128
3	12.1859
4	11.507
5	15.7608
6	14.8518
7	10.1414
8	10.1132
9	6.3732
10	1.9593
11	2.0588
12	3.4725
13	28.2243
14	20.9558
15	31.7439
16	41.409
17	15.6773
18	5.1749
19	6.3588
20	3.175
21	23.8256
22	17.7316
23	6.0412
24	21.4066
25	401.9665
26	20.8507
27	8.2406
28	12.9801
29	17.9696
30	13.8684
31	21.9935
32	14.0076
33	1.0772
34	15.0629

35	26.6605
36	10.7124
37	10.4138
38	10.0389
39	8.9481
40	3.9144
41	9.0478
AVERAGE	22.80709512

LOW ELEVATION	
POINT	**DISTANCE BETWEEN DIGITIZED RIVER NETWORK & DELINEATED RIVER NETWORK (m)**
1	123.9854
2	38.7846
3	33.6776
4	5.0224
5	6.4303
6	30.4412
7	6.6169
8	13.1217
9	12.5841
10	10.0811
11	12.4306
12	18.7345
13	10.0173
14	43.3908
15	12.7293
16	8.8607
17	8.9204
18	18.0759
19	11.4093
20	16.5761
21	9.8164

22	10.9315
23	1.1607
24	9.0916
25	14.2711
26	15.7169
AVERAGE	19.34147692

b) The 5m resolution IFSAR-DTM

HIGH ELEVATION	
POINT	**DISTANCE BETWEEN DIGITISED RIVER NETWORK & DELINEATED RIVER NETWORK**
1	46.6727
2	126.3075
3	75.8876
4	86.1724
5	115.7346
6	101.165
7	49.1555
8	148.5629
9	13.013
10	54.4427
11	4.5689
12	5.3098
13	25.9015
14	80.0344
15	71.2062
16	40.0249
17	71.7669
18	194.0946
19	76.7614
20	92.586
21	65.3417

22	27.0418
23	37.0492
24	206.8659
25	248.2738
AVERAGE	82.557636

INTERMIDEATE ELEVATION	
POINT	**DISTANCE BETWEEN DIGITISED RIVER NETWORK & DELINEATED RIVER NETWORK**
1	2.1728
2	279.2569
3	63.0285
4	19.8586
5	266.9194
6	7.7373
7	293.9164
8	639.4797
9	18.5249
10	1209.4758
11	21.1015
12	81.8784
13	88.6163
14	56.3212
15	1.675
16	3.112
17	4.2914
18	21.4529
19	157.1387
20	548.7582
21	364.8229
22	16.7128
23	18.765
24	0.4838

25	80.5356
26	143.3851
27	150.542
28	48.0333
29	458.7532
30	576.657
31	183.8579
32	1004.1776
33	114.906
34	130.5415
35	13.0356
36	13.6788
37	193.9434
38	187.1804
39	206.5896
40	32.7931
41	69.9471
AVERAGE	190.0989659

LOW ELEVATION	
POINT	**DISTANCE BETWEEN DIGITISED RIVER NETWORK & DELINEATED RIVER NETWORK**
1	2.1937
2	11.0565
3	7.9262
4	103.1193
5	19.2762
6	75.0254
7	11.1003
8	13.581
9	14.1626

10	7.2166
11	8.7792
12	8.3958
13	13.6521
14	12.308
15	7.4982
16	14.4776
17	12.186
18	17.8253
19	6.4912
20	15.1981
21	5.6068
22	11.9134
23	5.4187
24	9.2268
25	255.6694
26	188.344
27	304.0685
28	394.4605
29	3349.9097
AVERAGE	169.1754172