EXTRACTION OF RIVER NETWORKS FROM DIGITAL ELEVATION MODEL FOR THE ROMPIN RIVER BASIN

CHONG POI SAN

B. ENG (HONS.) CIVIL ENGINEERING

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CHONG POI SAN

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ABSTRAK

Pemetaan dan visualisali topografi telah menjadi lebih mudah kerana kemajuan teknologi dalam sistem informasi geografi (GIS). Peningkatan kemajuan dalam teknologi pemetaan melalui pertambahan ketersediaan Model Elevasi Digital (DEM) yang juga dikenali sebagai penyedia data spatial digital. Ciri-ciri hidrologi yang diekstrak daripada DEM adalah tepat dan ianya boleh dilakukan dengan lebih cepat berbanding kaedah tradisional. Tujuan kajian ini adalah untuk menggambarkan jaringan sungai dan mengekstrak ciri-ciri hidrologi daripada DEM bagi Sungai Rompin. Shuttle Radar Topografi Misi DEM (Data Elevasi SRTM 1 Arc-Global) dengan resolusi 30 m digunakan sebagai DEM untuk kajian ini. Pengekstrakan ciri-ciri fizikal yang diperlukan telah dilakukan dengan menggunakan aplikasi bersepadu ArcGIS-HEC-GeoHMS. Validasi jaringan sungai simulasi dibuat dengan membandingkan dengan ianya bersama jaringan sungai digital daripada Google Earth. Berdasarkan hasil validasi dapat disimpulkan bahawa DEM 30 m adalah mencukupi untuk menggambarkan dan menganggarkan jaringan sungai dan ciri-ciri fizikal Sungai Rompin dengan ketepatan yang dapat diterima.

ABSTRACT

Mapping and topography visualization of an area of interest has become more convenient due to the advancement of technology in the geographical information system (GIS). The advancement in the mapping technology is enhanced by the increasing availability of the Digital Elevation Model (DEM) also known as the digital spatial data provider. The hydrological features of a basin extracted from the DEM is precise and can be done faster compared to the traditional method. The purpose of this study are to delineate the river network and extract the physical hydrological characteristics from DEM dataset for the Rompin River Basin. Shuttle Radar Topography Mission digital elevation model (SRTM 1 Arc-Second Global Elevation Data) with 30 m resolution was used as the DEM for this study. The extraction of the physical characteristics required was performed by using ArcGIS application integrated with HEC-GeoHMS extension. For the validation of the simulated river network, the results obtained were compared with the digitized river network from Google Earth. Based on the validation outcome, it is concluded that DEM of 30 m is sufficient to delineate and estimate the river network and physical characteristics of the Rompin River Basin with acceptable precision.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

O_i	Observed coordinate (meter)
S_i	Simulated coordinate (meter)
n	Number of points

LIST OF ABBREVIATIONS

ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
DEM	Digital Elevation Model
DID	Department of Irrigation and Drainage
DSM	Digital Surface Model
DTA	Digital Terrain Analysis
DTM	Digital Terrain Model
GDEM	Global Digital Elevation Map
GIS	Geographic Information System
GRASS	Geographic Resources Analysis Support System
HMS	Hydrologic Modelling System
IFSAR	Interferometric Synthetic Aperture Radar
ILWIS	Integrated Land and Water Information System
JPL	Jet Propulsion Laboratory
LIDAR	Light Detection and Ranging
NASA	National Aeronautics and Space Administration
NED	National Elevation Dataset
NGA	National Geospatial-Intelligence Agency
RMSE	Root Mean Square Error
RRB	Rompin River Basin
SRTM	Shuttle Radar Topography Mission
USGS	United States Geological Survey

CHAPTER 1

INTRODUCTION

1.1 Background

Malaysia is fortunate since it is free from natural disasters such as earthquake, volcano, and typhoon. The most devastating problems faced in this country are only flood and drought. Historically, Pahang is one of the state in Malaysia that has serious problems related to flooding as in many places in the world including the study area in this research, the Rompin River Basin. The Rompin River Basin experiences tropical climate all year-round which consists of wet and dry season. In December 2013, there were massive flash flood in the Rompin District. A total of 3,615 flood victims from 958 families were placed in 10 flood relief centres (Bernama, 2013). Some homes and roads were inundated and closed down in the area. Despite flood disaster, prolong drought was also affecting the area attributed to the El Nino phenomenon, which lasted between 6 to 18 months. According to the Department of Irrigation and Drainage, the water levels in most rivers have dropped drastically, including Sungai Rompin. Therefore, there is a need to delineate the river basins in an integrated way for better water resources management.

With the advancement of technology in the recent years, researchers and water managers have migrated from adopting the traditional method to computerized technology in analysing and extracting topographical dataset (Balasubramani, Saravanabavan, and Kandasamy, 2012). The computerized tool that is widely used is the Geographic Information System (GIS). GIS tool is designed to store, edit, analyse, and visualizes the spatial or geographic information of an area from DEM datasets (Bharata, Darshan, Pavan, and Shanubhog, 2014). Today GIS has served as one of the most powerful technology in hydrology and water resources development. There are several open-source GIS software including ArcGIS, GRASS GIS, OpenJUMP GIS, QGIS and many more that are available for GIS-based watershed delineation. The best-known amongst them is the ArcGIS Hydrology tools which are useful to describe the physical components of a surface by identifying sinks, calculating flow direction and accumulation, stream order, delineating watershed and creating stream network (Alqaysi and Almuslehi, 2016). One of the most important applications of GIS is the delineation of watershed.

The input satellite data used in GIS application is the Digital Elevation Model (DEM). DEM has become popular in the field of hydrology due to its simplicity such as data structure, storage, and calculation. This elevation model provides 3D representation of a terrain surface, which is widely utilized in hydrological analyses including watersheds delineation (Fattah and Yuce, 2015). The data of terrain is stored in a square of grid for elevation values and topographic information such as slope properties, flow direction, flow accumulation, stream network and watershed attributes can be extracted. The key advantages of DEM are its ability to provide more precise measurement and faster than traditional manual delineation method (Mondal and Gupta, 2015).

In this study, ArcGIS is used to extract the river network and physical characteristics. For the validation of the simulated river network, the result obtained will be compared with the digitized river network from Google Earth. Meanwhile, for the physical characteristics, the validation is done by comparing the estimated result with the manual calculation. Finally, the results obtained from the delineated river network can used as the topographic and hydrologic input for the hydrological study in water resource management work.

1.2 Problem Statement

Since decades, flood and drought generally have become the most significant natural disasters in Malaysia, especially the east coast of Peninsula. The Rompin River Basin which is one of the district on the east coast has high potential to be affected by massive flood and drought. In flood and water resources study, topography information is important to identify the low-lying land and high land. Flood risk is generally higher at the low lying residential areas and agriculture lands. Moreover, these lands are also the highly populated areas in which leading to high water supply demands.

For a long river such as the Rompin River, extracting river network and hydrological information can be tedious and time consuming if the traditional method is implemented. Hence, it is essential to utilize the computerized technology available to categorize the topography elevation and delineate the river network in the Rompin River Basin. Furthermore, the lack of hydrological information regarding the Rompin River Basin shall be tackled to ease future research and modelling process.

1.3 Objectives

This study aims to:

- To delineate river networks and watershed for the Rompin River Basin.
- To extract the physical characteristics for developing hydrologic models.

1.4 Scope and Limitation of Study

This study covers only the Rompin River Basin as shown in the Figure 1.1. For the river network result comparison, the river network was digitized by tracing the streamline in Google Earth Pro Application (version 7.3.0.3832). Meanwhile, for the delineated river network, watershed analyses were done via extracting topographic datasets from DEM by using ArcGIS Hydrology tools. Extraction of physical characteristics include topography slope, roughness, sub stream and others. The DEM used in this study is the Shuttle Radar Topography Mission digital elevation model (SRTM 1 Arc-Second Global Elevation Data) with 30 m. This DEM map was selected because it can be downloaded from the United States Geological Survey (USGS) Earth Explorer without charges. Furthermore, it is the highest free version of DEM available online.

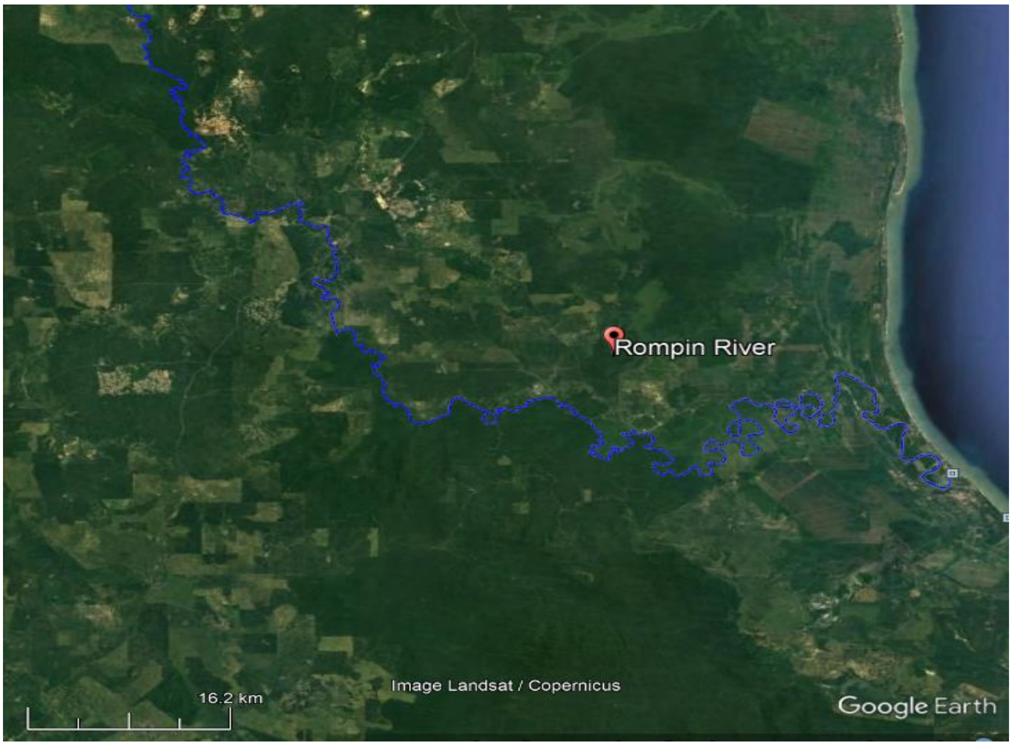


Figure 1.1 The satellite map of Rompin River

1.5 Significance of Study

The main reason this study was conducted is because the topography and hydrological information regarding the Rompin River Basin is still lacking. With the increasing of populations, flood events and agricultural scheme, the water resources management has become a crucial subject in the area. Thus, this study aims to extract and compile the topography and hydrology dataset for the watershed. With the advancement in GIS techniques, ArcGIS application has been proved to be very efficient in providing trustable data of hydrologic features.

Extraction of physical characteristics is prerequisite for hydrologic modelling, water resources planning and the associated flooding models. The simulated river network and physical characteristics are able to fasten the hydrological modelling process by analysing the input parameters priory. In addition, the extracted physical characteristics can be used in estimating flood extent and timing, surface water runoff calculations, and predicting stream discharges.

Therefore, the watershed characteristics obtained from this study are important because the results provide supportive information to any concerned bodies such as the government, community or river authorities. Furthermore, this study can be a significance endeavour in provided the hydrological information for the future researches.

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 waters join another water body, such as a river, lake, reservoir, estuary, wetland, sea, or ocean (Abdul Rahaman, Abdul Ajeez, Aruchamy, and Jegankumar, 2015; Fattah et al., 2015). The term watershed is often used as synonymous with drainage basin, catchment area, and river basin (Bose, Viswanadh, and Giridhar, 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; Sharky, 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 of approximately 3.1 million km^2 (Edwards, Williard, and Schoonover, 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.

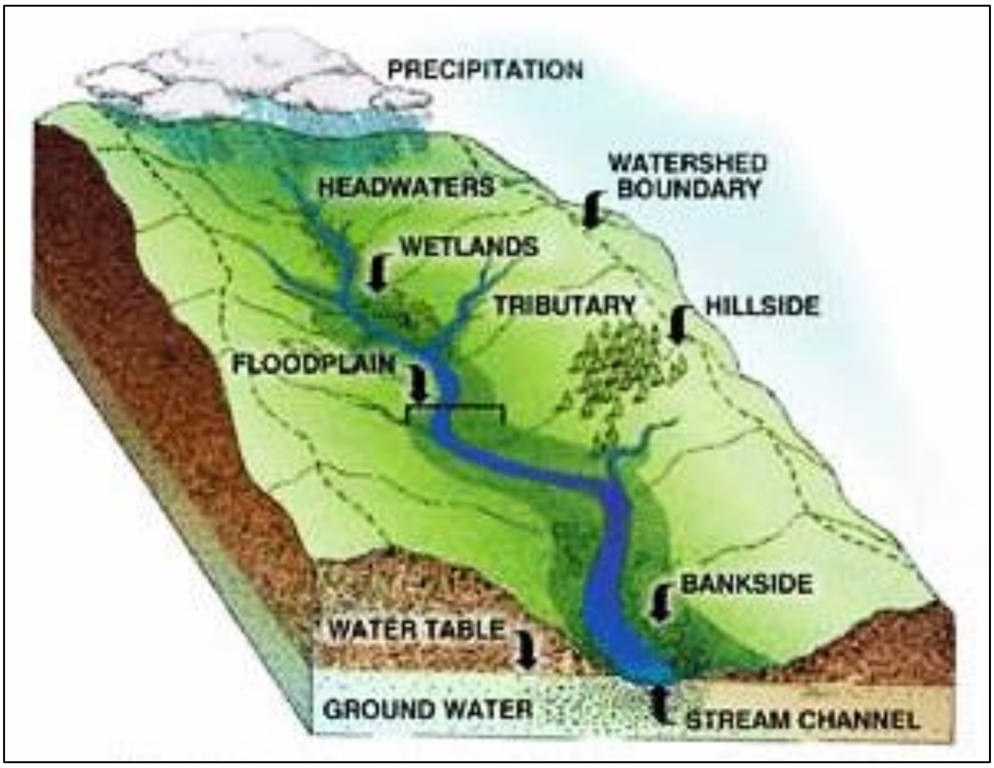


Figure 2.1 Watershed diagram

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, Gironás, Escauriaza, and Rinaldo, 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 (Black, 1997). 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 and 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 humans settled, simple logic demanded that they become part of a community."

Human and livestock are the integral part of a watershed and their activities affect the runoff and water quality within the watershed. From the hydrological point of view, the different phases of hydrological cycle in a watershed are dependent on the various natural features and human activities (Kumar and Sharma, 2013).

2.1.1 Physical Characteristics of the Watershed

It is important to identify the physical characteristics of a watershed to ensure sustainable watershed management and planning. The hydrological process in a watershed is closely related to its physical characteristic such as size, slope, and shape of watershed (Palaka and Sankar, 2015). The physical characteristics of the watershed highly affect its hydrological responses, especially the flow regime during floods and drought. In addition, the watershed characteristics are also the important factors affecting the volume of runoff and hydrograph shape (McCann, 2012).

The watershed outlet defines the watershed boundary and establishes the watershed size (Hayes and Young, 2005). Generally, the watershed size is the most important parameter in estimating the volume and peak runoff rate (Chadha and Neupane, 2011). For large watershed, a greater amount of precipitation can be captured and drained to the outlet. Compared to the small watershed, large watershed requires a longer time for runoff routing to the outlet. Classifications of the watershed based on size are as shown in Table 2.1.

Table 2.1 Classification of watershed size

Category	**Watershed area (hectares)**
Micro watershed	0 – 10
Small watershed	10 – 40
Mini watershed	40 – 200
Sub-watershed	200 – 400
Macro watershed	400 – 1000
River basin	Above 1000

Source: My Agriculture Information Bank (2015).

Watershed slope has a significant effect on the time of concentration and the volume of surface runoff. Watershed slope controls overland flow time and time of concentration of rainfall and therefore affects the resulting peak runoff. The steeper the watershed, the greater the runoff velocity, lesser time required to reach the flow at the outlet, resulting in the formation of peak runoff (Mamat, 2015).

Watershed shape is the most important characteristics in controlling the routing of runoff to the watershed outlet. Also, it has a great influence on the hydrograph shape, especially for small watersheds. The watershed shape is generally expressed by the terms of form factor and compactness coefficient (Balasubramanian, 2017). The watershed can be classified as fan-shaped or fern-shaped (Figure 2.2). For fan-shaped watershed, the size of tributaries is almost the same. Therefore, the peak flood is potentially reach the main stream at the same time, resulting in a greater runoff. For fern-leaf shaped watershed, the length of tributaries is generally different and reach the main stream at the regular intervals.

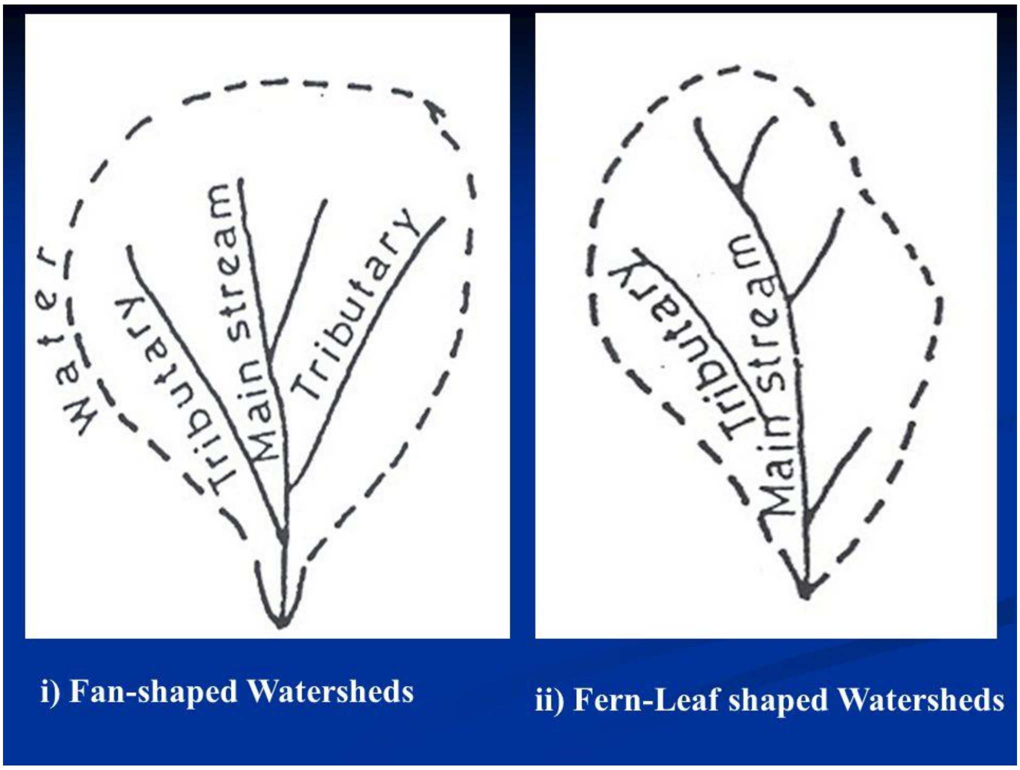


Figure 2.2 Type of watershed shape

Source: Samndi, Augustine, and Mundi (2015).

2.1.2 Watershed Delineation

Watershed delineation is a process of defining a drainage divide based on the topography of the surface in order to determine the stream flow directions. It is also the process of identifying the contributing area of any outlet point on a stream or river network. Watershed delineation involves the process of subdividing the watershed into several sub-watersheds that are relatively homogeneous as shown in Figure 2.3. This homogeneity is generally based on land use, topography and other factors (Alarcon, Nigro, McAnally, O' Hara, Engman, and Toll, 2013).

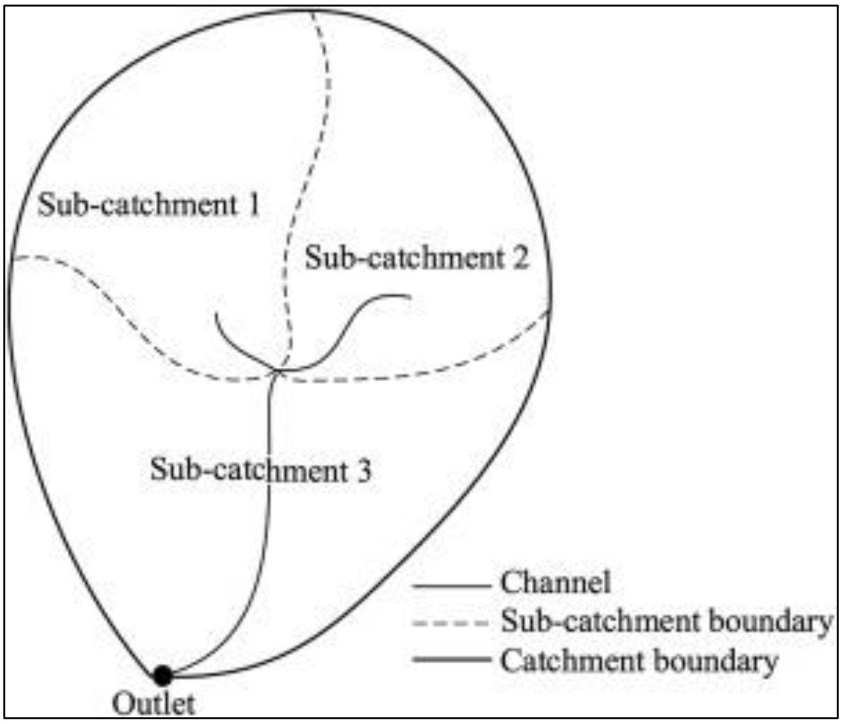


Figure 2.3 Watershed delineation

Source: Zhang, Quan, Zhang, Wang, Wang, and He (2015).

The watershed can either be manually delineated from topographical map or automatically delineated from DEMs using GIS technology (Angillieri and Fernández, 2017). Watershed delineation is essential for extracting the watershed characteristics and drainage network. However, delineating watersheds in the steep terrain of the uplands is usually unambiguous. It is a difficult task for delineating the watershed in the flat areas of the lowlands by any method. However, a reliable watershed delineation can be obtained by combination of field survey, manual and automated delineation methods (Al-Muqdadi and Merkel, 2011).

2.1.2.1 Manual Watershed Delineation

While performing hydrological modelling of a watershed, the landscape survey and extraction of hydrological properties become essential and thus acquire delineation of stream networks and watershed (Anornu, Kabo-bah, and Kortatsi, 2012). In addition, watershed management requires watershed characteristics such as watershed slope, stream network, location of watershed boundary, stream length and geomorphologic parameters for watershed prioritization (Ramu, 2008). Traditionally, these parameters and features were determined from topographic maps or field surveys.

Field survey is acknowledged as the most accurate method to delineate the watersheds, but it is often impractical, especially for the large watersheds. Therefore, manual watershed delineation method based on the topographic maps was considered to be the most effective and accurate method (Figure 2.4). However, stream networks extraction and watershed delineation from topographic maps can be tedious, time-consuming, and expensive (Angillieri et al., 2017; Kumar and Dhiman, 2014). Furthermore, the accuracy of manual delineation is highly affected by the topographic map scale used and the interpretation of the delineator. The manual delineation from the topographic map must be digitized or created in a digital format.

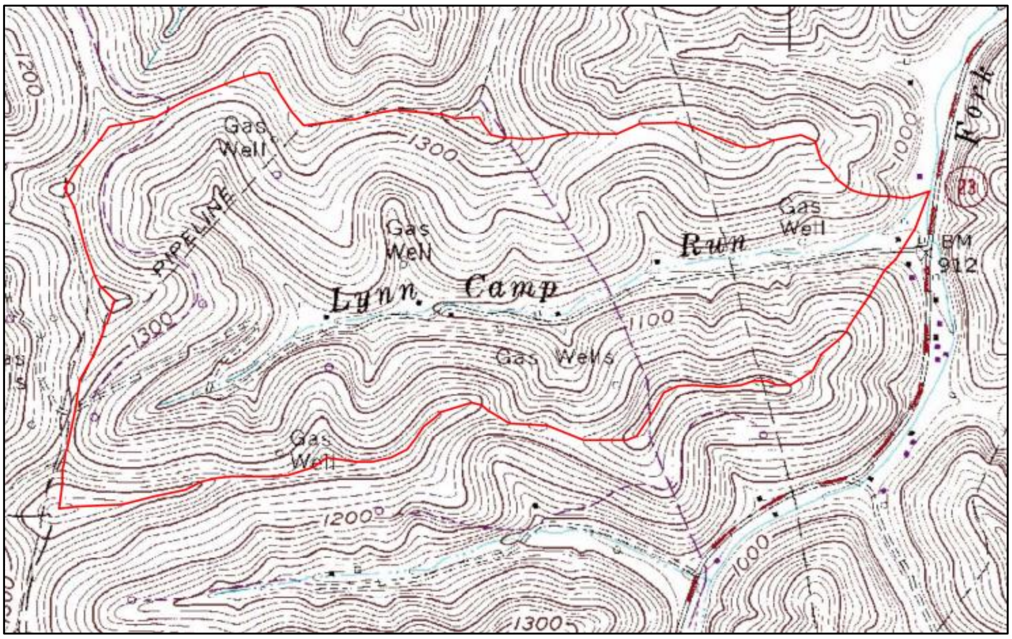


Figure 2.4 Manual watershed delineation

Source: Merwade (2012).

2.1.2.2 Watershed Delineation with Software

With the advancement in GIS technology, automated watershed delineation is preferred compared to the traditional method using topographical map. The implementation of GIS application integrated with DEMs has been proved to be more practical for watershed delineation. There are several GIS packages that are available for automated delineation including ArcGIS, ILWIS, MAP Window, and Grass.

According to Akbari, Yahaya, and Samah (2015), watershed delineation and characterization is one of the most important steps in hydrological modelling. Delineation and analysis of watersheds can be performed in many forms according to the needs of the users and available resources. Using computers, DEM can store geographic data in the form of grid cells electronically. Typically, these grid cells have a resolution of 30 meters or less and elevation intervals of 1 meter. By using a DEM within a Geographical Information System (GIS), digital terrain analysis (DTA) can be perform such as calculating slopes, flow lengths, and delineate watershed boundaries and stream networks as shown in Figure 2.5.

One of the software that can be used to delineate watershed is ArcGIS which provides contextual tools for mapping and spatial reasoning (Lindsay, Rothwell, and Davies, 2008). ArcMap is the main component of ArcGIS suite of geospatial processing programs, and is used primarily to view, edit, create, and analyse geospatial data. ArcMap allows the user to explore data within a data set, symbolize features accordingly, and create maps. This is done through two distinct sections of the program, the table of contents and the data frame.

Meanwhile, Integrated Land and Water Information System (ILWIS) is also a geographic information system (GIS) and remote sensing software for both vector and raster processing. Its features include digitizing, editing, analysis and display of data, and production of quality maps (Shrestha, 2016).

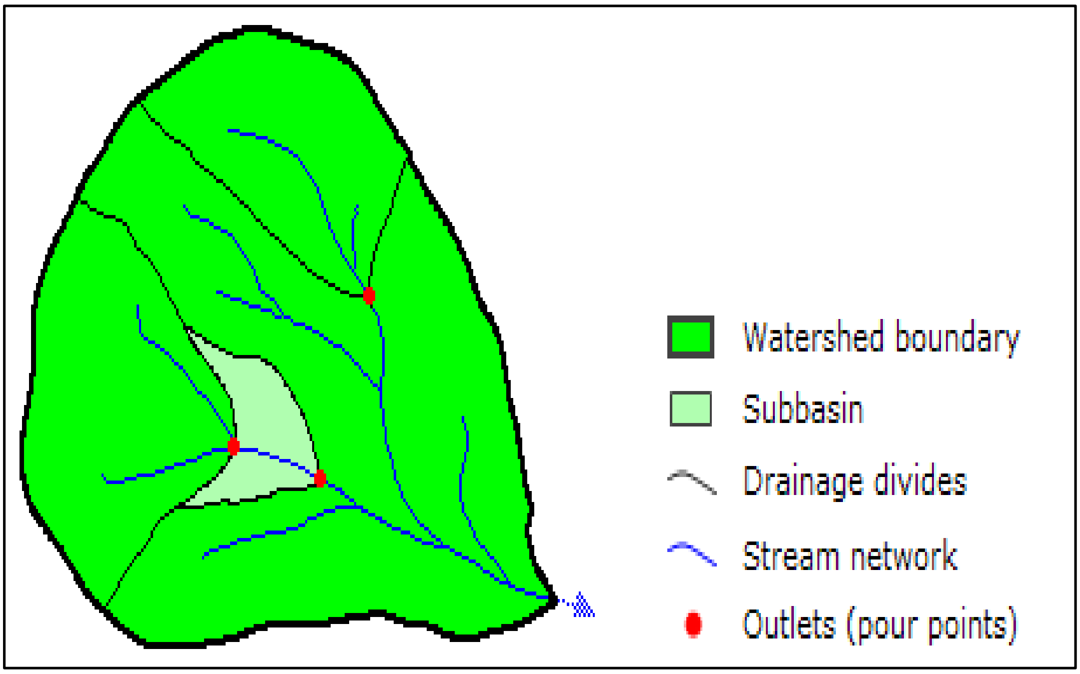


Figure 2.5 Watershed components

Source: Ahmad (2017).

According to Ahmad (2017), the major steps involved in delineating a watershed using ArcGIS are:

i. Geo-registering the scanned topographical map

ii. Creating shape files

iii. Contour digitization

iv. Preparation of DEM

v. Filling of DEM

vi. Flow Direction Raster generation

vii. Flow Accumulation Raster

viii. Determining Pour Points

ix. Watershed Delineation

2.2 Digital Elevation Model (DEM)

DEM is a subset and fundamental component of the Digital Terrain Model (DTM). In practice, these terms (DEM, DSM, and DTM) are often assumed to be synonymous but sometimes they actually refer to different products.

According to Ahmad (2017), DEM refers to bare earth elevation model, unmodified from its original data source (such as lidar, ifsar, or an autocorrelated photogrammetric surface) which is supposedly free of vegetation, buildings, and other non-ground objects as shown in Figure 2.6. Meanwhile, the Digital Surface Model (DSM) is an elevation model that includes the tops of buildings, trees, powerlines, and any other objects. DSM is commonly known as a canopy model and only capture ground where there is nothing else overtop of it. DTM is basically a DEM that has been augmented by elements such as breaklines and observations to correct for artifacts produced by using only the original data. This is often done by using photogrammetrically derived linework introduced into a DEM surface. Incidentally, a DEM is far cheaper to produce than a DTM.

GIS software utilized DEM to produce 3D surface visualization, generating contours, and performing viewshed visibility analysis. A smooth, bare-earth elevation model is particularly useful in fields of study such as hydrology, soils and land use planning or safety. Examples of DEM used in GIS are such as:

i. Hydrologic modelling – Delineation of watersheds, flow accumulation and flow direction.

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

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

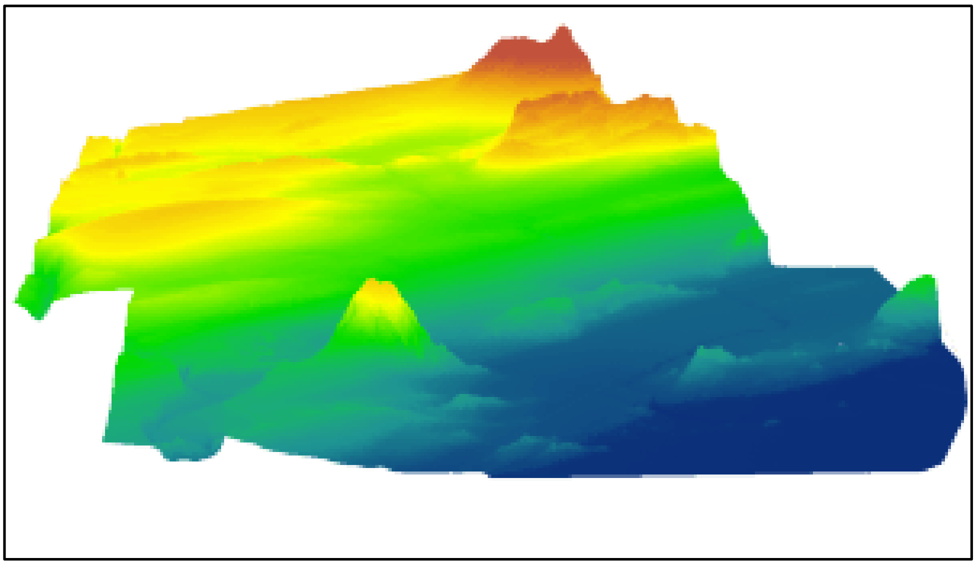


Figure 2.6 Digital Elevation Model (DEM)

Source: Ahmad (2017).

According to Ahmad (2017), some of the remote sensing methods applied to obtain DEM surfaces are:

i. Satellite interferometry with synthetic aperture radar such as Shuttle Radar Topography Mission, uses two radar images from antennas at the same time

ii. Aerial survey photogrammetry uses photographs from at least two different locations to generate stereopairs

iii. LiDAR measures reflected light back to the sensor to obtain a range to the Earth's surface.

2.2.1 Applications of DEM in Hydrology

The availability of more accurate and higher resolution DEMs with broader global coverage, the popularity of DEM utilized in hydrologic modelling is increasing (Hoffmann and Winde, 2010). With a more accurate surface representation, hydrologic characteristics can be derived from the surface model. Hydrologic features produced from DEM include drainage channel networks and channel characteristics, and watershed divides and low lying areas (Dinesh, 2008). These hydrologic features are readily produced from DEM data through a variety of software options.

The DEM derivative features vary depending on the purpose and use of the data. Hydrologic data is often used to predict runoff. Runoff modelling is valuable in predicting the route of water flow, the rate at which the water will flow and the potential for pooling or inundation of the landscape. Flooding, whether inland, in the case of precipitation runoff, or along a coastline, in the case of a tsunami or storm surge, can be modelled with DEM hydrologic data.

2.2.2 Limitations of DEM in Low Terrain

Low terrain presents specific challenges in DEM applications. Hydrographic (surface drainage) delineations in low relief terrain can be complicated and often inadequate due to factors related to lack of sufficient detail in the model representation within those areas. Contour interval or the scale of elevation increments that is too coarse also adequately describe low relief terrain. Resolution, or the cell size of raster DEM datasets, can also produce inaccuracies for DEM applications (Vaze, Teng, and Spencer, 2010).

Most of the land surfaces is considered to low relief terrain. Since contour interpolation is employed, large areas with unknown elevations are estimated between contour intervals. Another challenge that may occur when large vertical measuring intervals are used is instance, a DEM with 1 meter vertical posting intervals likely will not adequately describe topography that undulates on a sub-meter scale. Thus, there is a need to identify the appropriateness of existing individual DEM datasets in low relief terrain. Techniques used to provide a simple horizontal and vertical accuracy may not sufficiently quantify the respective DEM dataset models against the true low relief terrain. Further analysis, such as hydrologic delineations within the GIS, can be used to further test the extent to which DEM datasets can accurately map the terrain (Bera, Singh, Bankar, Salunkhe, and Sharma, 2014).

The methods used to create DEM may also introduce error into the dataset. Remote sensing by nature introduces error into the production of elevation data due to the fact that surface characteristics are measured over distance. Ground surveys may be limited by the accuracy and reliability of equipment used.

Errors associated with differing projections and planimetric offsets also pose a potential source of error in the production of DEM data.

2.3 SRTM Data

SRTM DEM data is produced via the use of interferometric synthetic aperture radar (IFSAR) system. The SRTM data is offered in 3 arc second resolutions for all extents of global coverage and 1 arc second for the U.S. and U.S. Territories (Rexer and Hirt, 2014; Smith and Sandwell, 2003). Previously, SRTM data were made publicly available at a three-arc-second pixel size about 90 m resolution. In the recent years, the newly released data at one-arc-second pixel size about 30 m resolution is made open to public. Figure 2.7 demonstrates the different between SRTM 90 m and 30 m resolution.

SRTM DEM data is referenced horizontally to the WGS84 ellipsoid and vertically to the EGM96 geoid orthometric heights (Elkhrachy, 2016). The product specification is shown in Table 2.2. Previous studies of widely available DEM datasets involve accuracy assessments for ASTER, NED and SRTM datasets. While results of multiple previous studies are consistent with one another, there is a void of studies in areas of low relief terrain. SRTM elevation data are intended for scientific use with a Geographic Information System (GIS) or other special application software.

The level of processing and the resolution of the data vary by SRTM data set as follows:

i. **SRTM Non-Void Filled** elevation data were processed from raw C-band radar signals spaced at intervals of 1 arc-second 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 using a cubic convolution resampling technique for open distribution.

ii. **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.

iii. **SRTM 1 Arc-Second Global** elevation data offer worldwide coverage of void filled data at a resolution of 1 arc-second and provide open distribution of this high-resolution global data set. However, some tiles may still contain voids.

Table 2.2 SRTM Specification

Product Specifications	
Projection	Geographic
Horizontal Datum	WGS84
Vertical Datum	EGM96 (Earth Gravitational Model 1996) ellipsoid
Vertical Units	Meters
Spatial Resolution	1 arc-second for global coverage (~30 meters) 3 arc-seconds for global coverage (~90 meters)
Raster Size	1 degree tiles
C-band Wavelength	5.6 cm

Source: Kolecka and Kozak (2014)

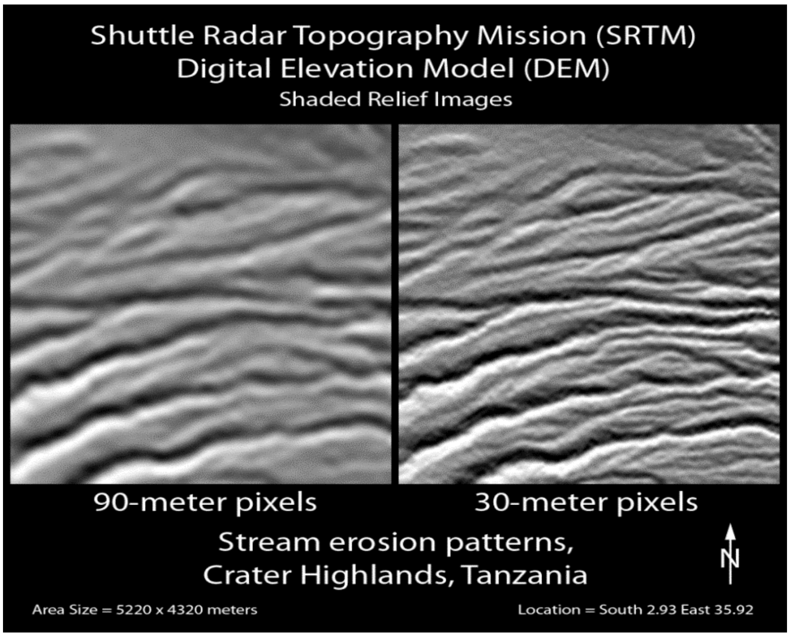


Figure 2.7 Comparison between SRTM 90 m and 30 m pixels

Source: Guth (2010).

2.4 Geographical Information System

A geographic information system (GIS) is a computer based system designed to provide the following functions to handle a variety of spatial and geographic data based on its location (Goodchild, 2009).

i. Data capture and preparation

ii. Data management and storage

iii. Data manipulation and analysis

iv. Data visualization

The main dataset used in GIS are generally geographic and spatial data. Spatial data is defined as the geographic location of features and boundaries that exist on the surface, such as natural or constructed features, oceans, and more. A key advantage of GIS is its ability to integrate different kinds of geographic information, particularly over large areas. These information includes digital maps, aerial photographs, satellite images and global positioning system data (GPS).

GIS is also capable of comparing many different types of information. It includes the landscape information such as the location of streams, hills, and vegetation. It can also include tabular database information, such as population demographics. Data from remote sensing satellites in a variety of spatial, spectral and temporal resolutions are used for various applications of resources survey and management can be imported into GIS flawlessly. GIS is potentially used in a wide range of applications, especially in planning.

2.4.1 Data Representation in GIS

Conventionally, the major types of data representation in GIS are vector and raster as display in Figure 2.8. In vector data, the basic symbols of spatial information are discrete points, lines and polygons (Parmenter, 2008). Vector point is the most basic unit that is represented a single coordinate pair. Vector lines are constructed by connecting each vertex with paths. It is usually representing the linear features such as highways, streams, and pipeline. While polygon is composed of one or more lines that define the boundary of an enclosed area.

Raster data are composed of an array of pixels or grid cells. Each cell has an attribute value as well as location coordinates. Raster datasets are commonly used for representing satellite imagery, scanned maps, DEMs, and numerous other entities. Raster data is also used to represent real-world objects where spatial data is expressed as a matrix of grid cells.

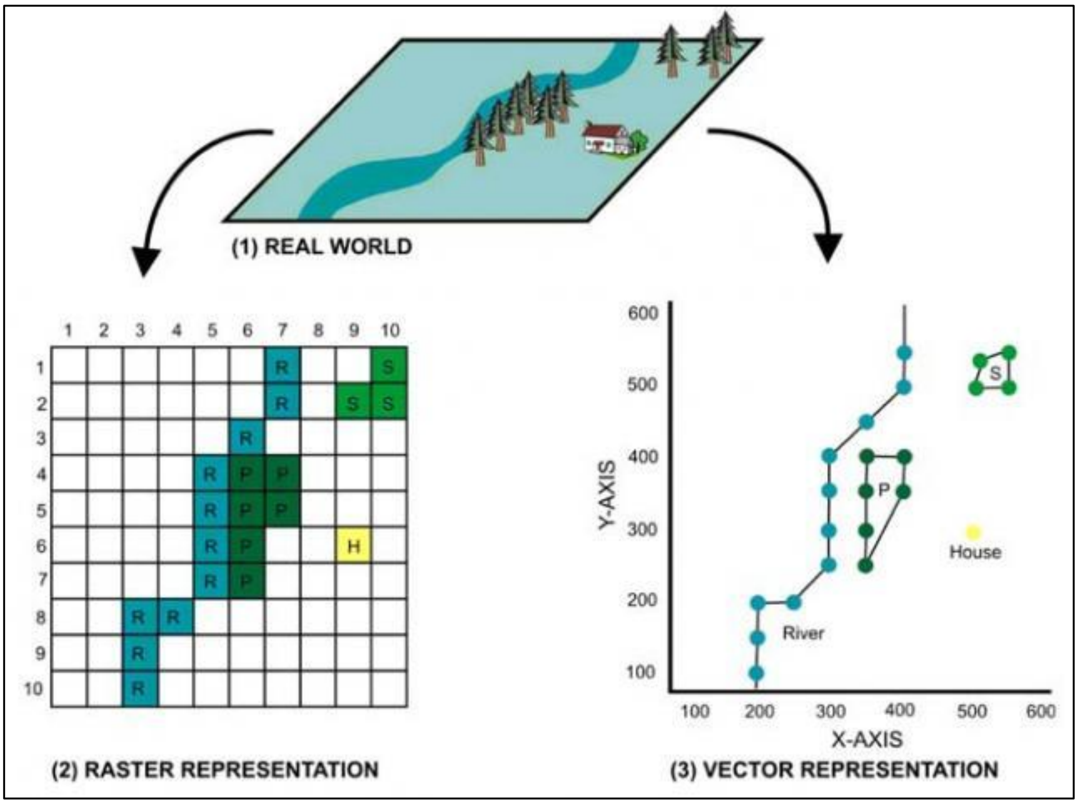


Figure 2.8 Watershed diagram

Source: Bharata et al. (2014).

2.4.2 GIS in Hydrology and Water Resource Management

Nowadays, hydrologists have increasingly recognized the application of GIS to study hydrological processes. Hydrology and Water Resources Engineering as the burgeoning fields require modelling and analysing spatially and temporally varying data. Therefore, GIS could definitely be utilized as an effective and important tool in hydrology and water resources management. In addition, GIS is also very powerful for solving different water resources problems such as water quality, groundwater contamination, river restoration, flood forecasting and management (Khatami and Khazaei, 2014).

GIS is widely used to manage the spatial and geographic data for the hydrologic models development by integrating the system with available DEM. The development of the open source GIS software have evolved over the last several years and provides support for hydrological modelling (Chen, Shams, Carmona-Moreno, and Leone, 2010). Watershed delineation using GIS software can bring advantages in terms of computation, accuracy, and cost effectiveness compared with traditional method (Anornu et al., 2012).

2.5 Previous Case Studies

Historically, watersheds were delineated by implementing the traditional manual delineation method with the aid of topographical maps. With the advancement in GIS technology, automated watershed delineation from DEMs is being preferred compared to traditional method.

Several studies have been conducted to delineate the watershed from DEMs in GIS applications. In Turkey, Alqaysi et al. (2016), used SRTM 1 Arc Second Digital Terrain Elevation Data – Global at 30 m horizontal resolution to delineate the watershed in the Konya city. The study showed that the watersheds can be automatically delineated by using basin function in ArcGIS. Watershed boundary, flow direction, flow accumulation, flow length, and stream ordering had been delineated. This study presented the simple applicability of GIS as a tool of watershed delineation and stream network extraction. (Sinha, Rathore, and Jain, 2015) applied DEM and GIS automated watershed tool to delineate the Narmada Basin. The watershed area and number of sub-basins were obtained. They commended that the results can be effectively used in hydrological modelling, land use planning and watershed studies.

In the study by Daffi and Ahuchaogu (2015), 90 m SRTM DEM is utilized to delineate the Dep River Basin and stream network by using ILWIS 3.7.1 Academic. The delineated watershed boundary and stream network were compared with that of manual method. The study found that there were no significant differences in shape, size and pattern between both the watersheds and stream networks delineated. Result also shows that the ILWIS software can be effectively used to delineate the watershed and stream network and the results can be used with an acceptable accuracy for hydrological processing and analyses.

Forkuor and Maathuis (2012) conducted a study to compare two different types of DEMs (SRTM and ASTER GDEM) with the reference DEM generated from a 1:50,000 topographical map. The study concluded that the SRTM shows a higher vertical accuracy than ASTER GDEM. Nevertheless, the study also indicates that the SRTM has overestimated the elevation while ASTER GDEM underestimated it.

Bharata et al. (2014) compared the 30 m ASTER GDEM and 1:50,000 topographic sheet to delineate the watershed and drainage network for the River Shimsha by using QGIS. The drainage network and morphometric parameters obtained from both methods show no notable variation. Furthermore, the study concluded that the 30 m resolution DEM proved to be sufficient for large watershed delineation. For smaller watersheds studies, it is suggested to use topographic sheet in order to obtain more accurate results.

Li (2014) performed a study to investigate the effect of DEM reconditioning and stream threshold value on the accuracy of stream network and watershed delineation. The stream network and watershed delineation were repeated by using three different stream threshold values. The study showed that the DEM reconditioning can improve the accuracy of simulation. It also proved that lower stream threshold values resulted in a more detailed and accurate stream network and watershed delineation.

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. 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. Based on the previous study conducted for the Malaysia region, the SRTM 1 Arc-Second Global is selected. 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).

In order to investigate the effect of the stream threshold value, repetitive simulations were conducted with different stream threshold values. The extraction of physical characteristics of streams and sub-basins is presented in detail. After the physical characteristics have been extracted, the hydrologic parameters and HEC-HMS model development is discussed. The gage weights and weighted percentage of each sub-basin are computed based on the Thiessen polygons map.

Lastly, the simulated river network was validated against the digitized river network. The reliability and the performance of the simulation were evaluated by performing the Root Mean Square Error (RMSE).

3.2 Flow Chart of Methodology

Figure 3.1 shows the flow chart for the extraction of river network and physical characteristics from DEM for the Rompin River Basin.

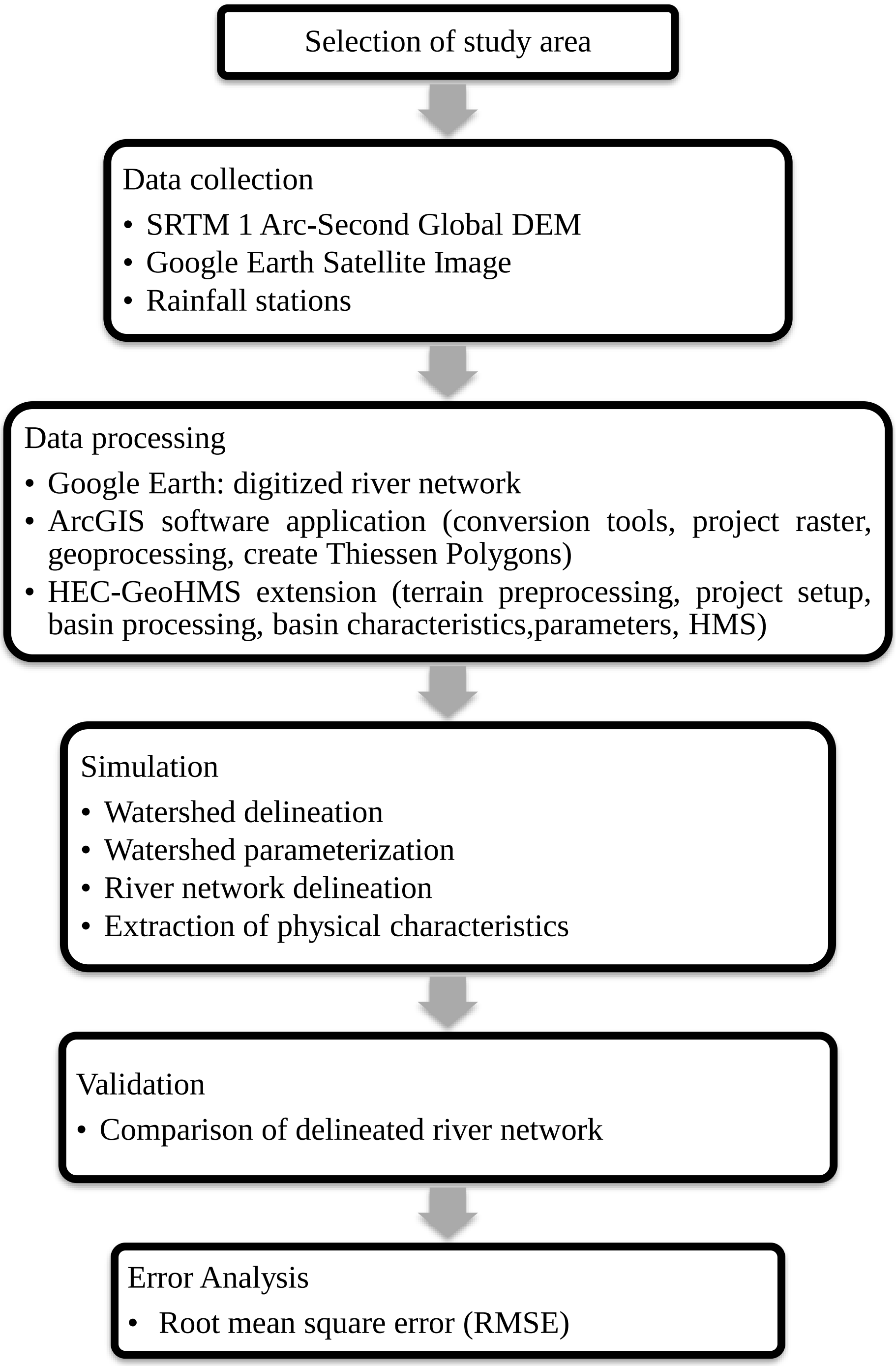


Figure 3.1 Flow chart of methodology

3.3 Study Area

The Rompin River Basin (RRB) 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. RRB 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). RRB is highly influenced by the tropical monsoon (November-February) and the dry season (March-October). The major land uses of the RRB are for agriculture, industrial and domestic activities.

Figure 3.2 The Rompin River Basin

Source: Google Maps (2017).

3.4 Data Collection

In this study, the main dataset required is the DEM for the Rompin River Basin. To effectively avoid the low DEM accuracy problems, the Shuttle Radar Topography Mission digital elevation model (SRTM 1 Arc-Second Global Elevation Data) with 30 m resolution was used as the DEM in this study. The DEM map was downloaded from the United States Geological Survey (USGS) Earth Explorer as presented in Figure 3.3. The type and characteristics of the SRTM selected dataset are described in Table 3.1. Besides the DEM, the satellite base map was captured from the Google Earth Pro Application (version 7.3.0.3832) for the study area to digitize the river network by tracing the streamline (Figure 3.4). Hydrological data such as the locations of rainfall stations were identified from the Department of Irrigation and Drainage (DID). The rainfall stations considered in this study are as listed in Table 3.2.

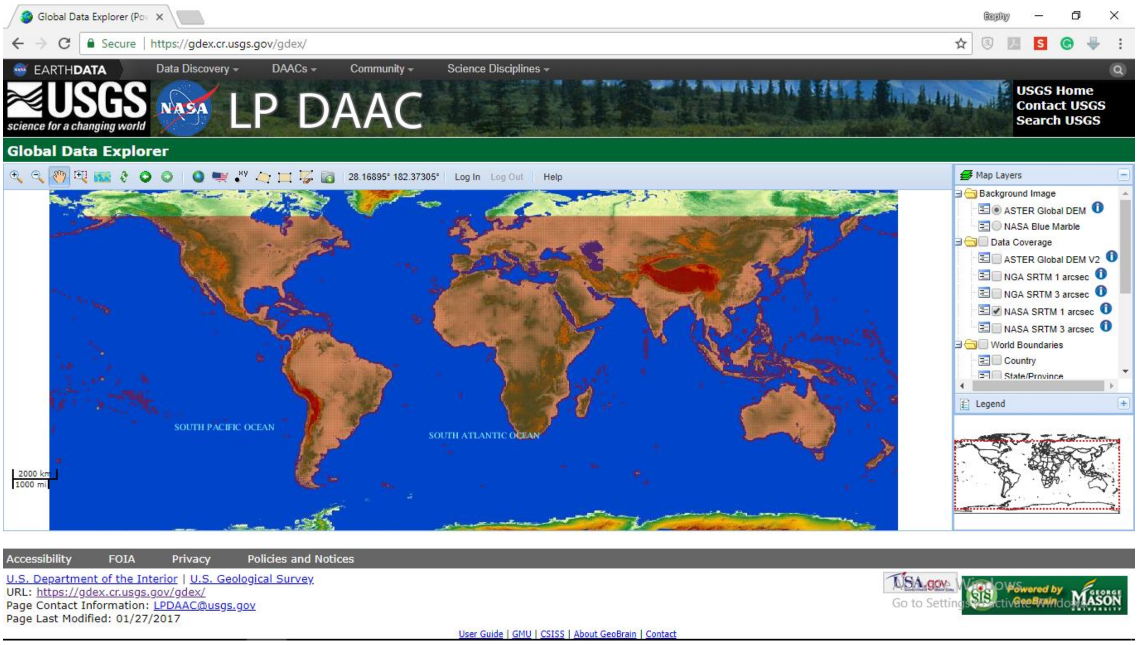


Figure 3.3 DEM map

Table 3.1 Desription of SRTM data

Characteristics	Description
Data source	SRTM Global 1 Arc-Second
Data format	TIFF
Coordinate System	Geographic latitude and longitude
Datum	WGS 1984
Spatial Extent	Global
Pixel Size	30 m

Figure 3.4 Google Earth satellite image and traced streamline

Table 3.2 Rainfall stations in the Rompin River Basin

Station no.	Station Name	Latitude	Longitude
2828173	Kg. Gambir	02° 51' 00"	102° 51' 20"
2829001	Ulu Sg.Chanis	02° 48' 45"	102° 56' 15"
2831179	Kg. Kedaik	02° 53' 20"	103° 11' 10"
2834001	Stn. Pertanian Rompin-Endau	02° 48' 45"	103° 27' 00"
3028001	Sg. Kepasing	03° 01' 15"	102° 49' 55"
3030178	Pecah Batu Bkt. Raidan	03° 03' 55"	103° 04' 50"

3.5 Data Pre-processing

The digitized river network was converted from KML (Google Earth) to shapefile (GIS) format. Coordinate system of the SRTM DEM and digitized river network layer were projected from WGS 1984 into the same coordinate system – Kertau RSO Malaya (Meters). Kertau RSO Malaya (Meters) was selected because it is suitable to be used in the Peninsular Malaysia. The projected SRTM DEM is set as the raw DEM whereas the projected river shapefile is the reference streamlines 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. Figure 3.5 displays the projected SRTM DEM and river network in Google Earth.

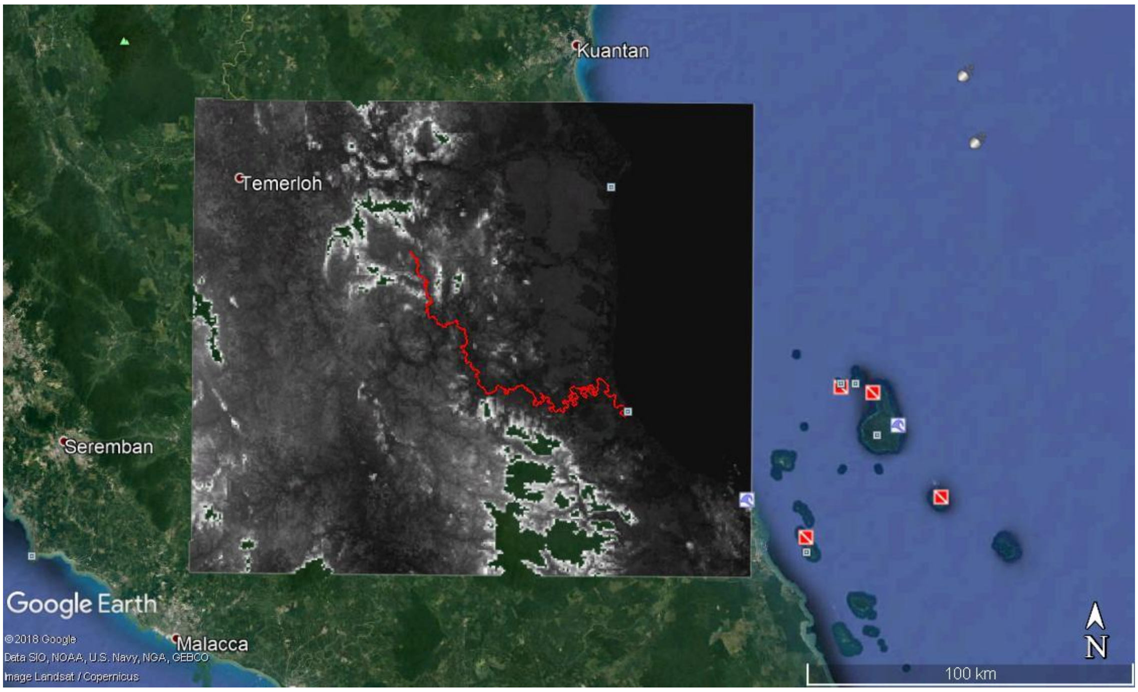


Figure 3.5 Projected SRTM DEM and river network in Google Earth

3.6 Watershed and River Network Delineation

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 accessed through the terrain pre-processing component in HEC-GeoHMS extension. Figure 3.6 shows the procedures adopted to delineate watershed and river network in RRB. First, the raw SRTM DEM was reconditioned in reference to the digitized river network to adjust the alignment of the simulated river network for higher accuracy. The depressions from the reconditioning outcome were identified in the raw DEM as shown in Figure 3.7 (the scattered points). 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 values to compare the extend of the delineated river network. The complete steps involved is described in Appendix A.

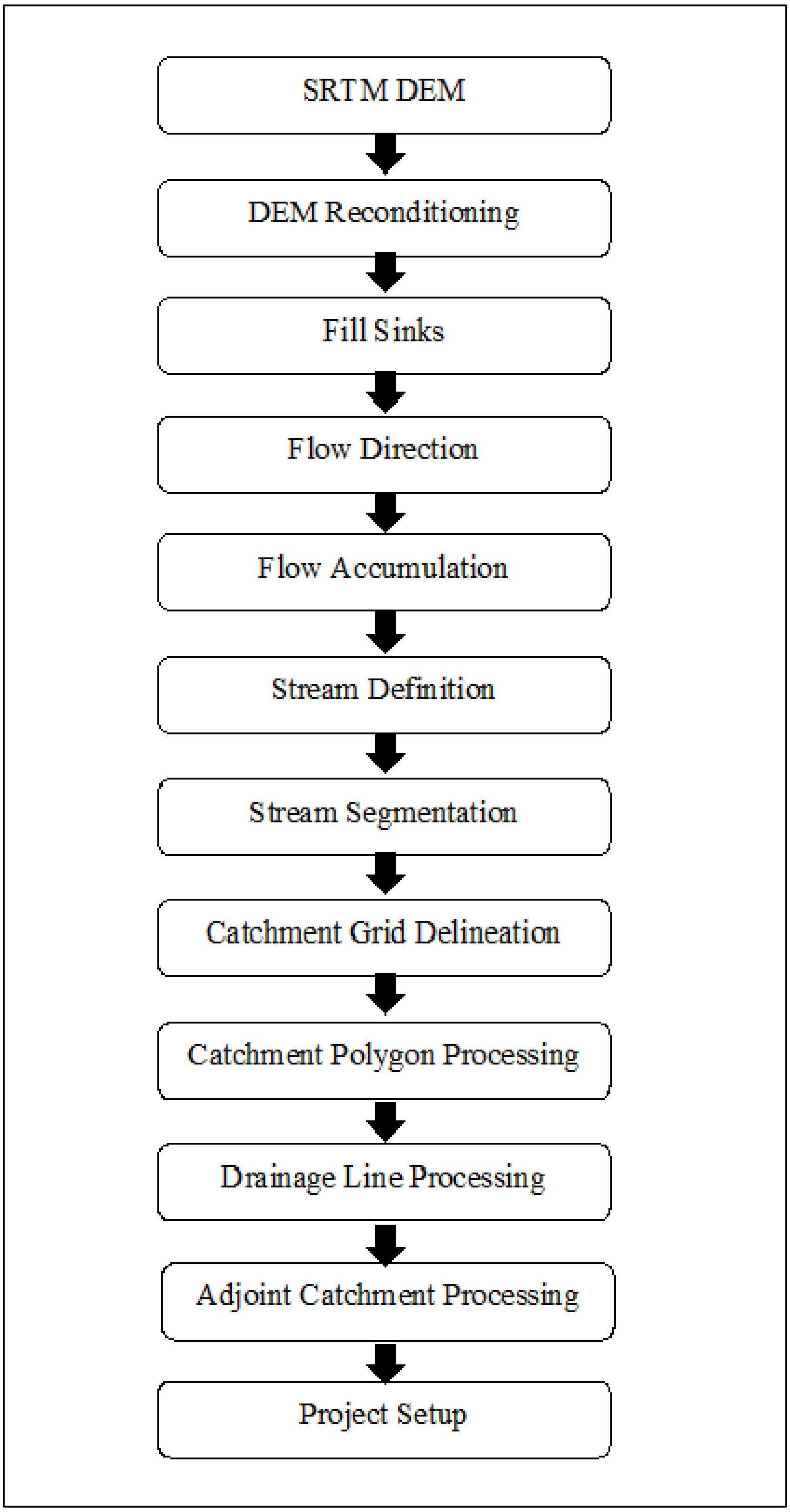


Figure 3.6 Procedures of watershed and river network delineation

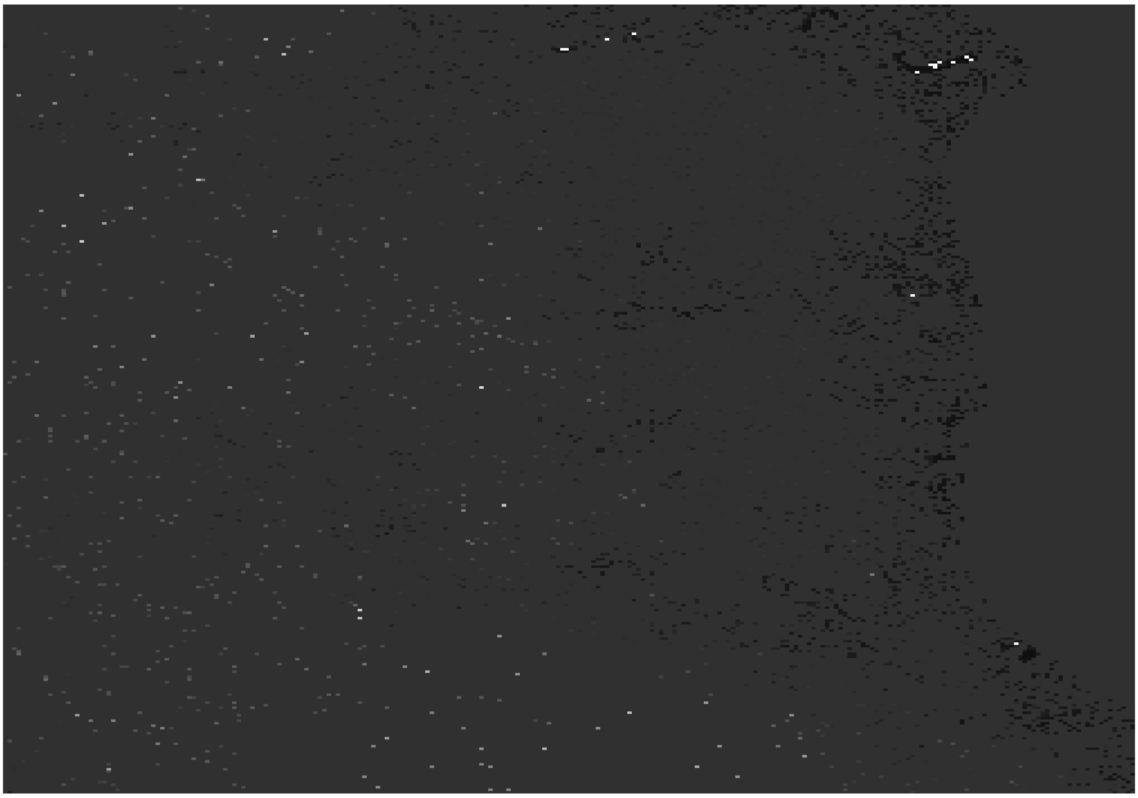


Figure 3.7 Depressions in raw DEM

3.7 Extraction of Physical Characteristics

The physical characteristics can be extracted through the basin characteristics menu in the HEC-GeoHMS extension. Figure 3.8 shows the procedures of the physical characteristics extraction. Both streams and sub-basins characteristics were extracted and stored in the layer’s attribute tables as summarized in Table 3.3.

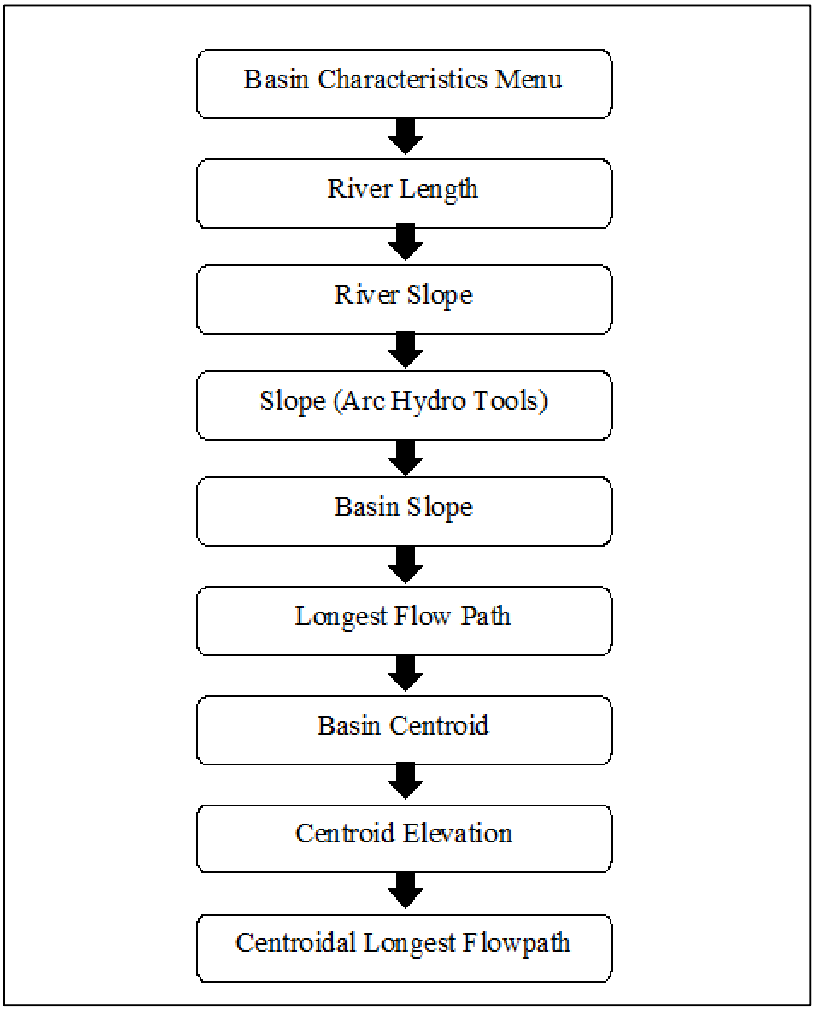


Figure 3.8 Procedures of the physical characteristics extraction

Table 3.3 Physical Characteristics of streams and sub-basins

Data layer	**Physical Characteristics**	**Attribute table heading**
Stream	Length Upstream elevation Downstream elevation Slope	RivLen ElevUP ElevDS Slp
Sub-basin	Perimeter Area Slope	Shape_Length Shape_Area BasinSlope
Centroid	Centroid location Centroid elevation	N/A Elevation
Longest Flow Path	Longest flow path location Longest flow length Upstream elevation Downstream elevation Slope between the endpoints	N/A LongestFL ElevUP ElevDS Slp
Centroidal Longest Flow path	Centroidal longest flow path location Centroidal length	N/A CentroidalFL

3.8 Hydrologic Parameters and HEC-HMS Modelling Development

The watershed and stream parameterization can be completed through the hydrologic parameter menu in HEC-GeoHMS extension. In this study, the HMS processes selected were Soil Conservation Service Curve Number (SCS-CN) for the loss method, Clark Unit Hydrograph for the transform method, monthly constant for the baseflow, and lag time for the channel routing. Figure 3.9 shows the procedures of hydrologic parameterization and HMS model development.

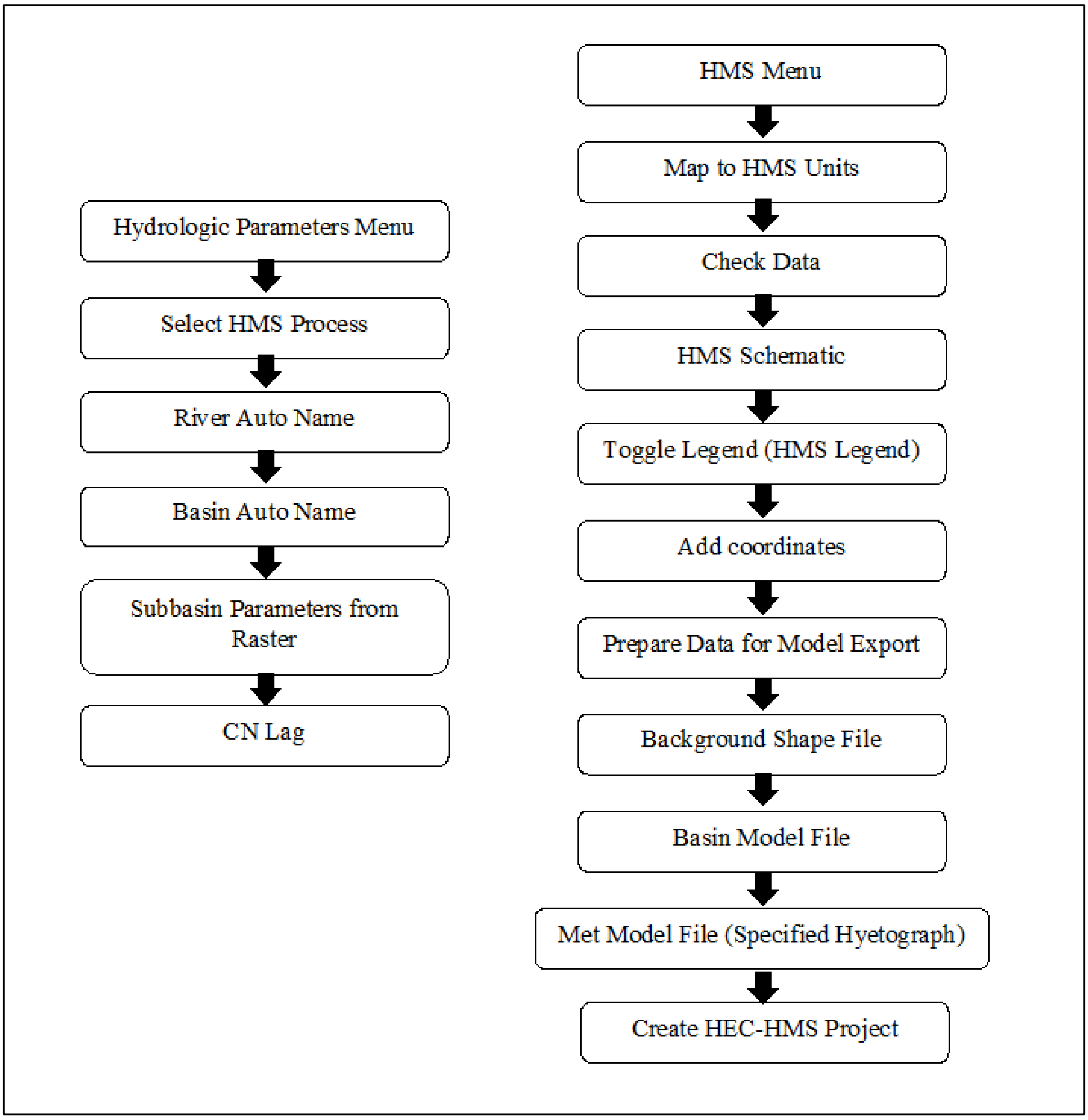


Figure 3.9 Procedures of the hydrologic parameterization (left) and HMS model development (right)

3.9 Rainfall Distribution in RRB

In this study, the amount rainfall depths over the sub-basins were distributed using the Thiessen polygons. The territorial boundaries were generated from the Thiessen polygons in the Rompin River Basin. In HEC-HMS, the distribution method adopted was the gauge weights or weighted percentage for each sub-basin.

3.10 Model Performance Analysis

For the performance analysis, the Root Mean Square Error (RMSE) is preferable in this study to measure of the percentage of error for the delineated river network. RMSE is also used as an indicator of accuracy in the DEM for forecasting errors of different models (Chai and Draxler, 2014). Each individual difference between the predicted values and the actual observed values is called residuals. RMSE can be calculated as:

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(Oi-Si)^2}{n}} \qquad 3.1$$

where O_i is observed coordinate and S_i is simulated coordinate.

The RMSE values can be used to distinguish simulation performance in validation period as well as to compare the individual simulation performance to that of other simulated model. Lower RMSE value indicate desirable closeness of the predicted model to the observed data.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Watershed Delineation

The watershed of the Rompin River has been successfully delineated using ArcGIS application with the integration of HEC-GeoHMS extension. Result of the final delineated watershed map is shown in Figure 4.1. The delineated watershed perimeter and area are 702 km and 4,208 km^2, respectively. According to the report of Department of Irrigation and Drainage (DID), the Rompin River Basin covers an area of 3,939 km^2. Thus, the SRTM and DID watershed area were compared and the result shows that there was an overestimation of the watershed area by using SRTM in which the watershed area is larger than DID watershed with about 269 km^2 (about 6.83 %).

The comparison between DID and SRTM result clearly indicates that there is no significant variation in the watershed area. Thus, the 30 m resolution SRTM is sufficient to provide an acceptable result for the entire Rompin River Basin. Previous study stated that a DEM resolution between 100 and 300 m is generally suitable for large watersheds whereas a high-resolution DEM is required to produce a better simulation result for the small watershed area which is less than 100 km^2 (Wu, Shi, Chen, Shen, and Wang, 2017). However, a high-resolution DEM is recommended to be used for the extensive studies on the smaller sub-basins. Based on the default stream threshold value, various stream orders of the watershed were identified. The result shows that the highest stream order is estimated to be three along with few first-order and second-order streams. The general characteristics of the SRTM based watershed are summarized in Table 4.1.

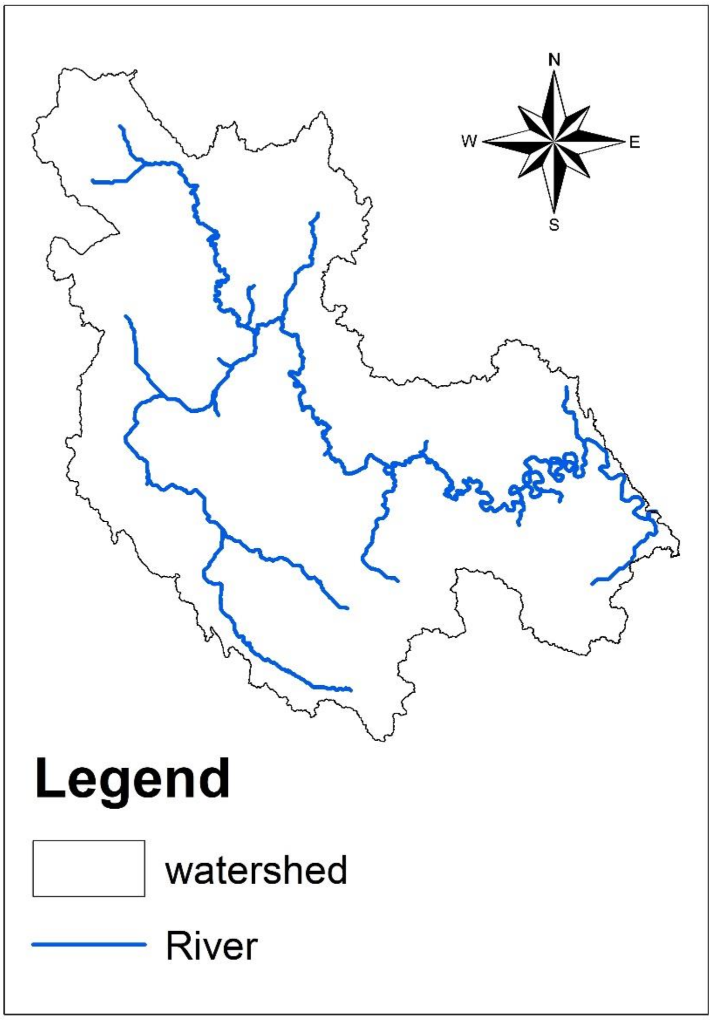


Figure 4.1 Delineated watershed map

Table 4.1 General characteristics of the SRTM based watershed

Watershed area	4,208 km^2
Perimeter of watershed	702 km
Minimum elevation	0 m
Maximum elevation	988 m
Highest order stream	3rd

4.2 Distribution of Sub-basins

Demarcations of sub-basin boundaries are presented in Figure 4.2. The result shows the capability of 30 m resolution SRTM DEM used to produce a smooth and continuous demarcation of sub-basins in RRB. In this study, a total of 40 sub-basins was delineated automatically with each sub-basin encompasses the total area of about 4,208 km^2 and the basin perimeter of 3092.441 km. There were 40 streams generated in the basins and the total length of streams in various orders were 504.688 km. However, few studies have shown that the DEM resolution highly affects the accuracy of sub-basins area, and the number of streams and sub-basins (Reddy and Reddy, 2015). This means the accuracy of sub-basins areas increases with finer DEM resolution. Oppositely, the number of sub-basins and streams decreased as the coarser DEM resolution is used. Therefore, it is suggested to delineate the watershed with finer DEMs resolution in order to obtain a more precise result. The results of the basic parameters for the Rompin River Basin are summarized in Table 4.2.

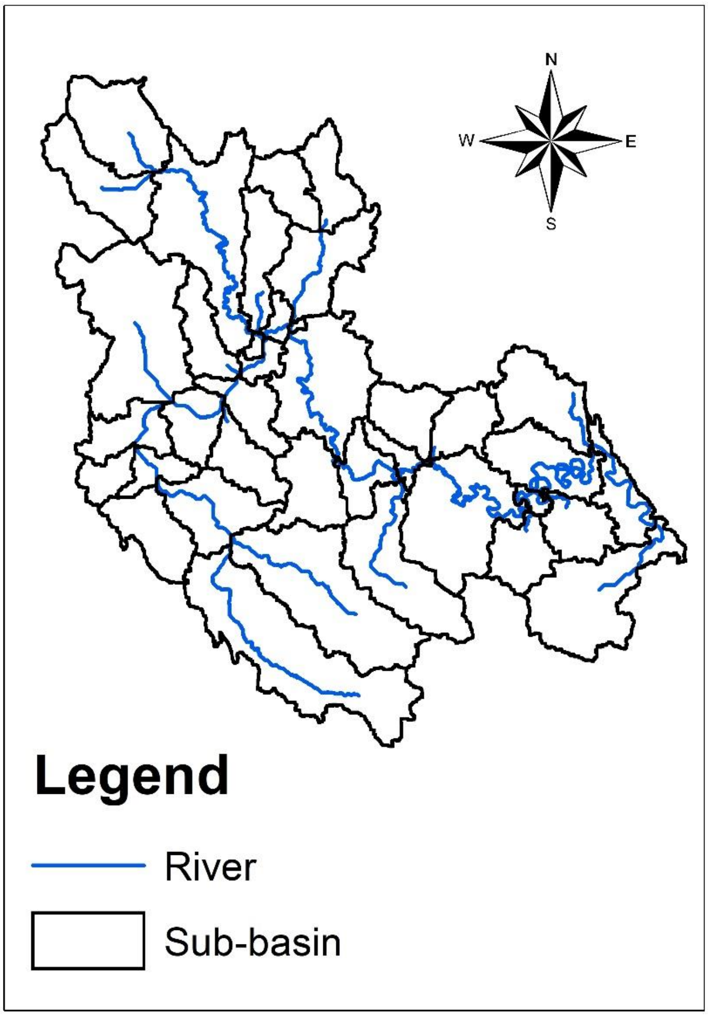


Figure 4.2 Demarcations of sub-basin boundaries

Table 4.2 Result of the basic parameters for the Rompin River Basin

Sub-basin no.	**Sub-basins Name**	**Basin Perimeter (km)**	**Basin Area (km^2)**	**River Length (km)**
1	W380	78.162	146.099	8.053
2	W390	155.769	269.361	51.554
3	W400	88.641	124.611	9.450
4	W410	70.272	74.414	1.995
5	W420	58.251	69.393	0.283
6	W430	98.319	127.834	16.813
7	W440	81.675	91.531	7.131
8	W450	149.789	308.044	13.577
9	W460	31.067	19.437	5.973
10	W470	18.123	7.464	2.687
11	W480	42.348	25.177	7.701
12	W500	73.045	75.767	2.380
13	W510	73.662	70.052	4.286
14	W520	54.060	69.882	10.313
15	W530	70.456	75.021	4.024
16	W550	102.325	128.011	10.276
17	W560	64.909	71.999	2.190
18	W570	80.936	104.152	0.789
19	W580	61.149	78.409	0.368
20	W590	94.743	120.043	51.085
21	W600	1.233	0.022	0.062
22	W610	67.128	65.960	17.267
23	W620	56.464	29.432	9.054
24	W630	74.278	97.381	1.657
25	W640	111.571	184.645	22.894
26	W650	94.867	74.880	24.501
27	W660	113.667	228.007	43.802
28	W670	85.620	116.130	17.348
29	W680	30.020	13.184	11.508
30	W690	73.477	78.022	4.923
31	W700	66.635	76.978	4.454
32	W710	4.561	0.254	1.035
33	W720	135.119	203.110	16.961
34	W730	182.336	333.711	41.027
35	W740	135.797	283.838	25.029
36	W760	77.915	72.828	9.699
37	W780	54.491	41.079	6.603
38	W820	46.046	41.325	0.087
39	W860	120.325	206.902	34.351
40	W870	13.191	3.306	1.499
Total		3092.441	4207.694	504.688

4.3 Spatial Distribution of Elevation and Slope

In this study, the topographic depressions were identified in the raw SRTM DEM. Previous studies have pointed out that it is important to remove all depressions in the DEM processing for hydrological analysis so that the simulation result will not be affected (Fernandez, Adamowski, and Petroselli, 2016). The spatial elevation distribution in the raw SRTM data was found to have a range of -16 to 988 m. The negative elevation value is caused by underestimation of the elevations. With the sink filling tools, the non-depression DEM was developed with the spatial elevation distribution range of 0 – 988 m as presented in Figure 4.3. From the figure, it can be clearly seen that the areas with higher elevations are located along the south and northwest ridge of the watershed whereas the areas with lower elevation are located in the east of the watershed, all along the watersheds' outlets. From the result, the basin slopes obtained were within the range of 2.057 % - 22.149 % for the entire watershed.

Many researchers revealed that river slope is one of the topographical parameters that significantly affected by the resolution and quality of DEMs (Forkuor et al., 2012). In this study, there were 12 negative river slopes were extracted from the SRTM DEM. This slopes error is possibly caused by the vertical accuracy of DEMs used. For satellite based DEMs, the ground surface may be obscured by frequent cloud cover and dense tree cover in forest area (Ravibabu and Jain, 2008). Thus, the vertical accuracy of SRTM-30 m may not be sufficient to extract the accurate river slopes for the Rompin River Basin. Further improvement can be achieved by conducting the field surveys to capture the river cross-section. The spatial distribution of basin and river slopes are summarized in Table 4.3.

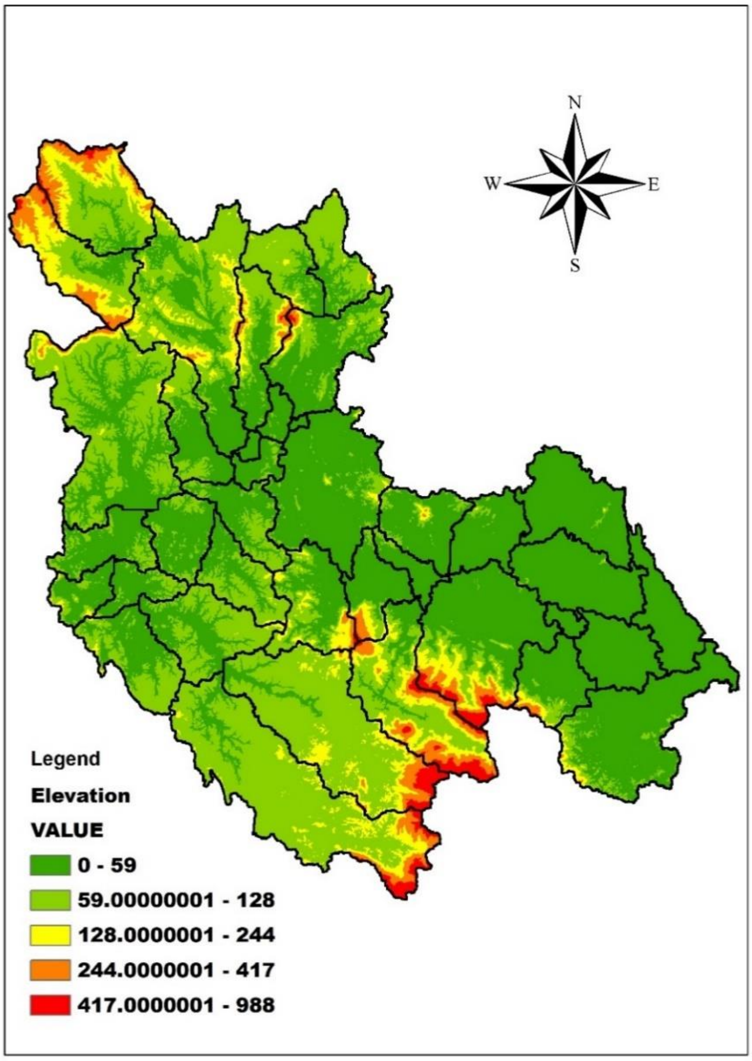


Figure 4.3 Spatial distribution of elevations

Table 4.3 Spatial distribution of basin and river slopes

Sub-basin no.	Sub-basins Name	Basin slope (%)	River slope (%)	Upstream elevation (m)	Downstream elevation (m)
1	W380	20.187	0.025	55	53
2	W390	15.763	0.062	53	21
3	W400	19.327	0.021	55	53
4	W410	11.979	-0.100	36	38
5	W420	13.285	-1.059	35	38
6	W430	13.837	0.167	38	10
7	W440	17.596	0.042	24	21
8	W450	10.947	0.103	39	25
9	W460	12.534	0.234	24	10
10	W470	6.627	-0.112	21	24
11	W480	10.107	0.065	29	24

12	W500	10.289	-0.420	19	29
13	W510	10.442	0.023	30	29
14	W520	8.777	-0.049	25	30
15	W530	9.871	-0.099	26	30
16	W550	6.277	0.156	28	12
17	W560	6.267	0.183	16	12
18	W570	16.194	0.507	25	21
19	W580	10.555	0.272	12	11
20	W590	6.092	0.002	13	12
21	W600	5.460	-1.622	11	12
22	W610	11.969	-0.006	21	22
23	W620	7.487	0.122	22	11
24	W630	9.054	0.000	36	36
25	W640	22.149	0.114	48	22
26	W650	5.560	0.045	12	1
27	W660	13.365	0.005	12	10
28	W670	8.445	0.006	37	36
29	W680	4.796	-0.026	10	13
30	W690	4.531	-0.061	10	13
31	W700	13.360	0.090	14	10
32	W710	2.507	-0.870	1	10
33	W720	9.586	0.030	6	1
34	W730	13.660	0.134	92	37
35	W740	14.016	0.176	81	37
36	W760	8.355	0.021	27	25
37	W780	8.104	0.136	36	27
38	W820	9.842	3.441	30	27
39	W860	9.827	0.020	28	21
40	W870	8.665	-1.201	10	28

4.4 Delineated Longest Flow Path

The longest flow path of the watershed was extracted with HEC-GeoHMS tools. Figure 4.4 displays the longest flow path map. From the result, the average slopes obtained were within the range of 0.019 % - 3.268 % while the total longest flow length is 943.335 km. Watershed's lag time and time of concentration are closely related to the length and slope of the longest flow path. The defined longest flow path and the average slope of each sub-basin can be used in various time of concentration estimation methods such as Kirpich and SCS lag equation. Thus, the delineated longest flow path and its slope can be effectively used as the general inputs for hydrological modelling such as rainfall-runoff models. The result of the longest flow path delineation is shown below in Table 4.4.

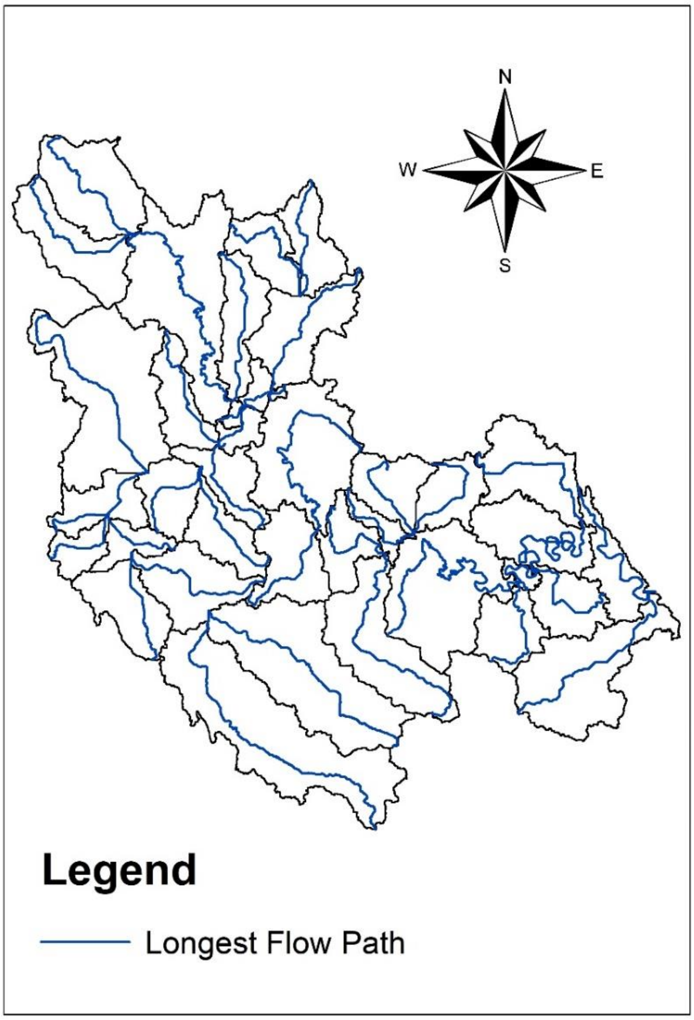


Figure 4.4 Longest flow path map

Table 4.4 Result of the longest flow path delineation

Sub-basin no.	Sub-basins Name	Average slope (%)	Longest flow path length (km)	Upstream elevation (m)	Downstream elevation (m)
1	W380	1.845	24.717	514	58
2	W390	0.416	54.551	251	24
3	W400	1.893	25.256	531	53
4	W410	1.529	19.424	335	38
5	W420	0.407	21.620	126	38
6	W430	0.422	26.293	121	10
7	W440	0.690	25.817	196	18
8	W450	0.938	35.627	359	25
9	W460	1.118	7.335	92	10
10	W470	0.543	5.339	50	21
11	W480	0.161	9.295	39	24
12	W500	1.236	21.440	293	28
13	W510	0.723	18.108	159	28
14	W520	0.387	15.231	90	31

15	W530	0.395	20.747	112	30
16	W550	0.087	26.513	35	12
17	W560	0.607	18.633	124	11
18	W570	0.384	18.777	93	21
19	W580	0.940	15.955	166	16
20	W590	0.019	51.921	22	12
21	W600	2.249	0.400	21	12
22	W610	0.235	20.003	69	22
23	W620	0.438	17.802	89	11
24	W630	0.706	17.572	160	36
25	W640	1.946	38.849	781	25
26	W650	0.114	29.017	34	1
27	W660	1.098	59.544	664	10
28	W670	0.663	25.938	208	36
29	W680	0.111	13.480	28	13
30	W690	0.085	18.843	35	19
31	W700	3.268	19.766	658	12
32	W710	0.859	1.746	15	0
33	W720	0.823	31.952	264	1
34	W730	1.799	52.850	988	37
35	W740	1.642	39.526	686	37
36	W760	1.148	19.870	253	25
37	W780	0.532	12.601	95	28
38	W820	1.370	14.093	220	27
39	W860	0.466	42.663	220	21
40	W870	0.474	4.220	48	28
Total			943.335		

4.5 Delineated Centroids and Centroidal Longest Flow Path

The centroids of each sub-basin were identified and defined using default center of gravity tool. Figure 4.5 shows the centroid locations of each sub-basin. For the centroidal flow path, it is delineated for each centroid with the input of longest flow path. The total centroidal flow length obtained was about 468.802 km. Figure 4.6 displays the centroidal flow path map. The result of the centroid elevations and the centroidal flow path are presented in Table 4.5.

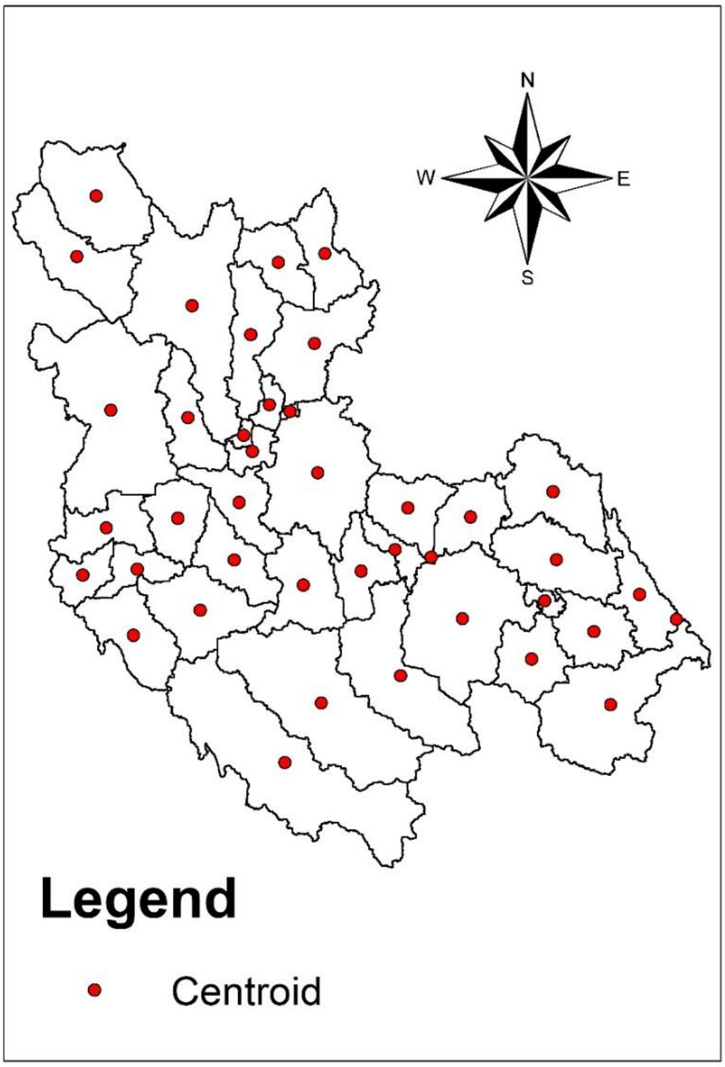


Figure 4.5 Centroid locations of each sub-basin

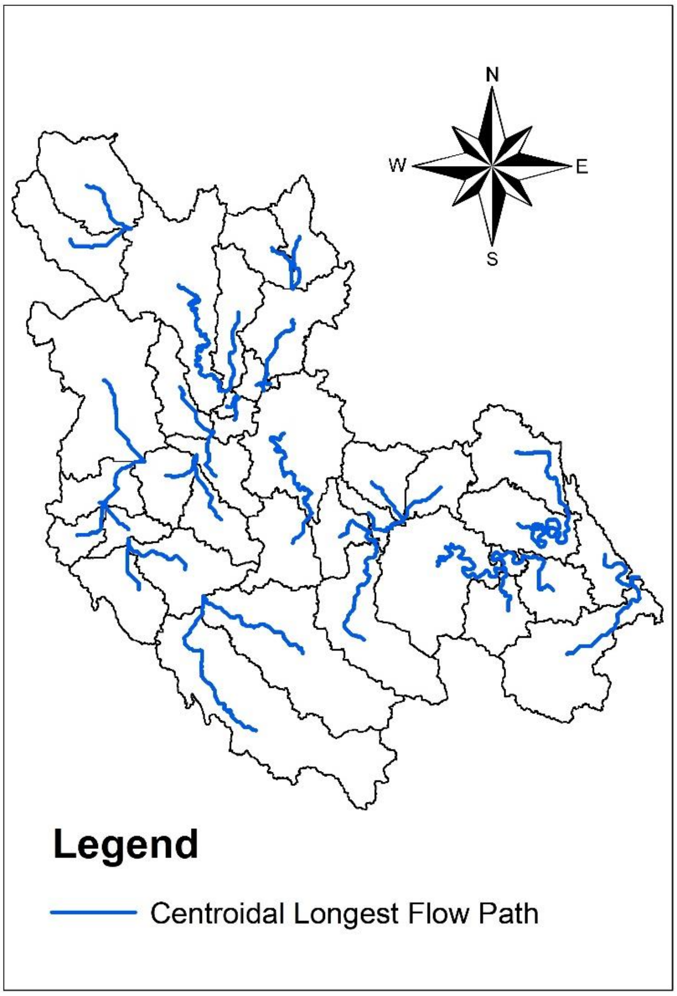


Figure 4.6 Centroidal longest flow path map

Table 4.5 Result of the centroid elevations and the centroidal flow path

Sub-basin no.	Sub-basins Name	Centroid elevation (m)	Centroidal longest flow length (km)
1	W380	62	10.289
2	W390	54	33.400
3	W400	57	10.290
4	W410	64	8.665
5	W420	72	7.794
6	W430	34	11.954
7	W440	53	12.957
8	W450	36	13.918
9	W460	36	1.274
10	W470	26	2.909
11	W480	33	4.093
12	W500	36	9.119
13	W510	71	7.723
14	W520	42	6.565
15	W530	59	11.249
16	W550	21	15.047

17	W560	23	7.853
18	W570	38	4.837
19	W580	77	7.542
20	W590	12	35.150
21	W600	19	0.200
22	W610	30	9.672
23	W620	14	8.810
24	W630	48	7.881
25	W640	191	20.224
26	W650	12	10.567
27	W660	43	28.933
28	W670	32	12.004
29	W680	4	10.783
30	W690	18	10.675
31	W700	21	8.574
32	W710	1	1.072
33	W720	22	18.256
34	W730	94	27.871
35	W740	92	19.772
36	W760	38	10.487
37	W780	29	4.948
38	W820	50	7.874
39	W860	45	25.233
40	W870	13	2.341
Total			468.802

4.6 Input Files for HEC-HMS

The watershed and stream parameterization have been successfully generated through the HEC-GeoHMS extension tools. Results obtained from the HEC-GeoHMS feature were used as the input data for HEC-HMS. The HMS schematic network was created in GIS and the setup is presented in Figure 4.7. In the schematic network, the hydrologic elements such as sub-basin, junction, and reach were assigned in the model. There are a total of the 40 sub-basins, 21 junctions and 20 reaches delineated in the schematic diagram.

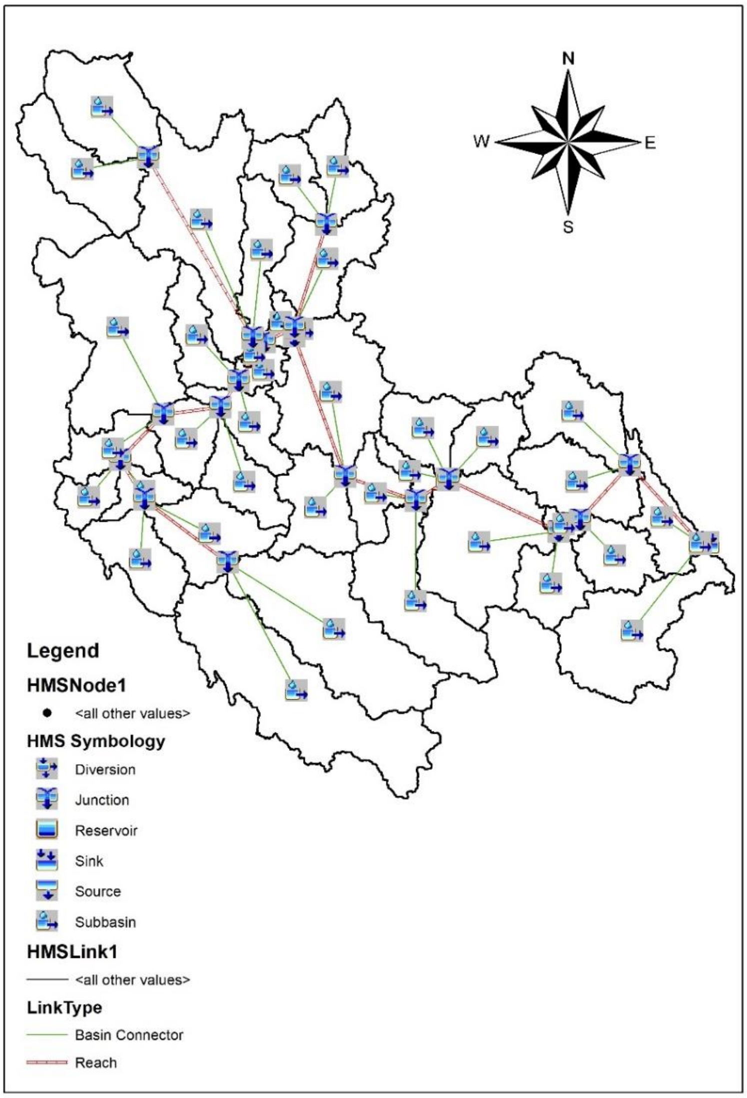


Figure 4.7 Schematic diagram for the setup of HEC-HMS

4.7 Determination of Gauge Weights

The Thiessen polygons map was successfully generated as shown in Figure 4.8. The individual gauge weights obtained for each sub-basin representing the rainfall distributions in reference to the rainfall gauging data. The gauge weight percentage can be used as the input data for hydrological modelling. The gauge weights and the corresponding percentage of each sub-basin are shown in Table 4.6.

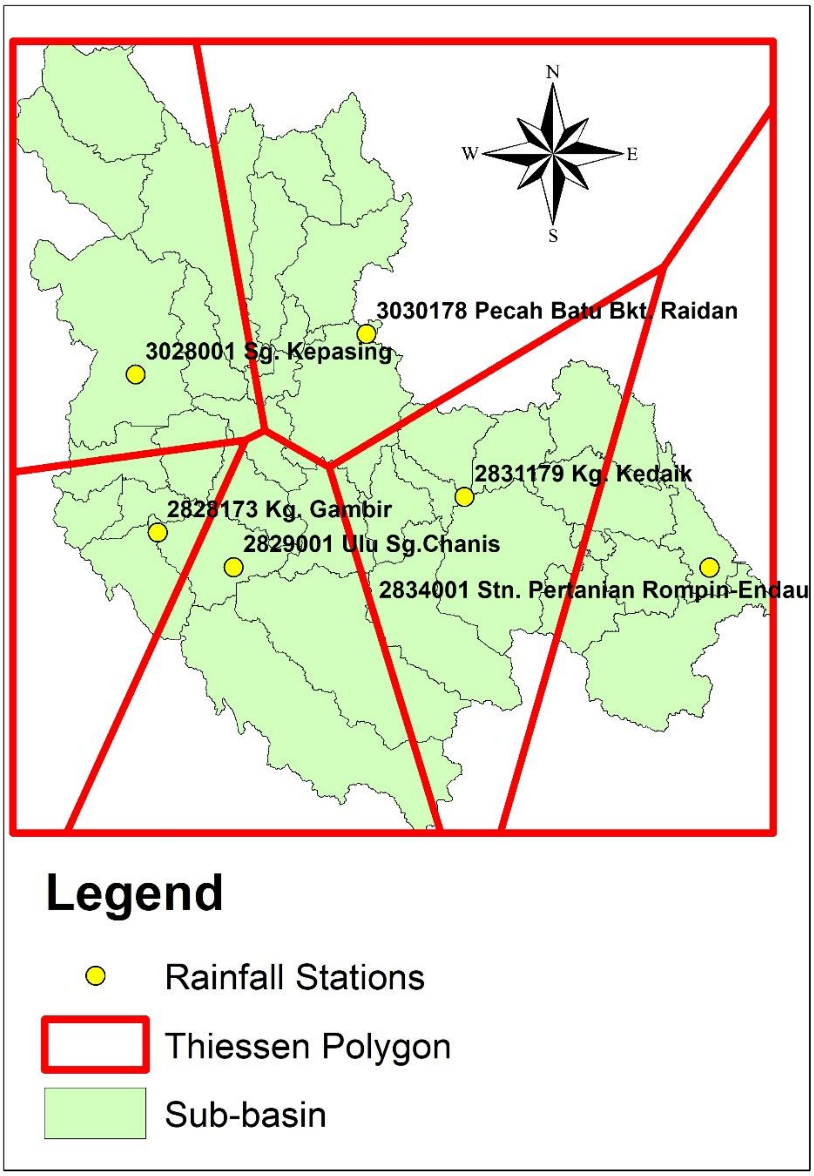


Figure 4.8 Thiessen polysons map

Table 4.6 Gauge weights and weighted percentage of each sub-basin

Rainfall stations	Sub-basins Name	Gauge weights (km^2)	Sub-basin Area (km^2)	Weighted Percentage (%)
2828173 Kg. Gambir	W510	0.529	70.052	1
	W520	37.766	69.882	54
	W530	11.815	75.021	16
	W630	79.782	97.381	82
	W670	32.242	116.130	28
	W760	44.625	72.828	61
	W780	41.079	41.079	100
	W820	41.325	41.325	100
2829001 Ulu Sg.Chanis	W860	7.113	206.902	3
	W510	29.276	70.052	42
	W530	61.749	75.021	82

	W570	75.361	104.152	72
	W630	17.599	97.381	18
	W640	1.824	184.645	1
	W670	83.888	116.130	72
	W730	307.600	333.711	92
	W740	225.260	283.838	79
2831179 Kg. Kedaik	W860	22.954	206.902	11
	W550	83.229	128.011	65
	W560	71.999	71.999	100
	W570	27.954	104.152	27
	W580	73.629	78.409	94
	W590	53.037	120.043	44
	W600	0.022	0.022	100
	W610	65.960	65.960	100
	W620	29.432	29.432	100
	W640	182.822	184.645	99
	W660	226.190	228.007	99
	W680	4.087	13.184	31
	W700	23.084	76.978	30
	W730	26.112	333.711	8
	W740	58.578	283.838	21
2834001 Stn. Pertanian Rompin-Endau	W550	44.782	128.011	35
	W590	67.006	120.043	56
	W650	74.880	74.880	100
	W660	1.817	228.007	1
	W680	9.097	13.184	69
	W690	78.022	78.022	100
	W700	53.894	76.978	70
	W710	0.254	0.254	100
	W720	203.110	203.110	100
3028001 Sg. Kepasing	W380	146.099	146.099	100
	W390	189.724	269.361	70
	W400	124.611	124.611	100
	W450	308.044	308.044	100
	W470	0.421	7.464	6
	W480	4.700	25.177	19
	W500	75.767	75.767	100
	W510	26.236	70.052	37
	W520	32.116	69.882	46
	W530	1.458	75.021	2
	W760	28.203	72.828	39
3030178 Pecah Batu Bkt. Raidan	W390	79.637	269.361	30
	W410	74.414	74.414	100
	W420	69.393	69.393	100
	W430	127.834	127.834	100
	W440	91.531	91.531	100
	W460	19.437	19.437	100
	W470	7.043	7.464	94
	W480	20.477	25.177	81
	W860	176.835	206.902	85
	W510	14.010	70.052	20
	W570	0.836	104.152	1
	W580	4.779	78.409	6
	W870	3.306	3.306	100

4.8 Threshold Simulations

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 4.9 and 4.10. The simulations were evaluated by comparing their stream length, number of streams, catchment area, and number of catchment. Summary of the simulated stream networks and watershed are presented in Table 4.7.

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. The finding in this study can be 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 result is proved to be reasonable and the consideration of stream threshold values could be further applied to the future work.

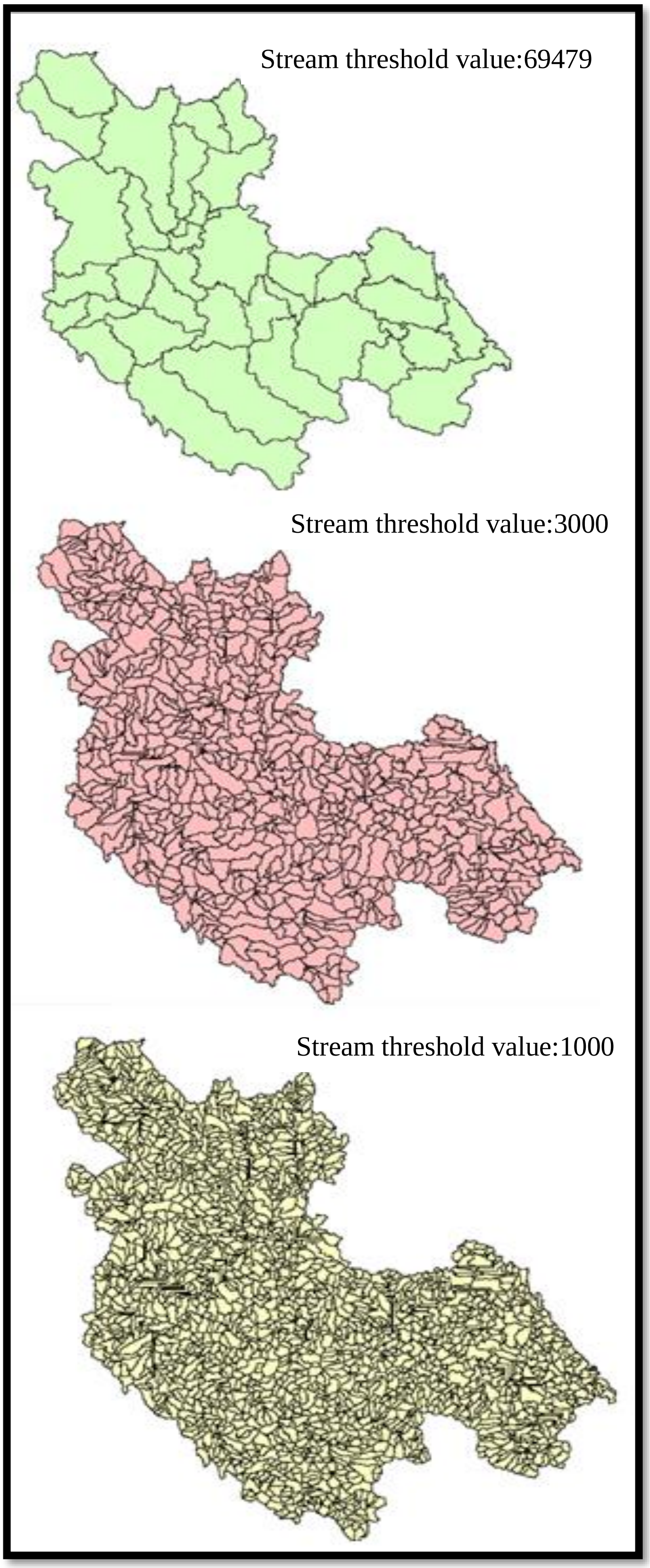
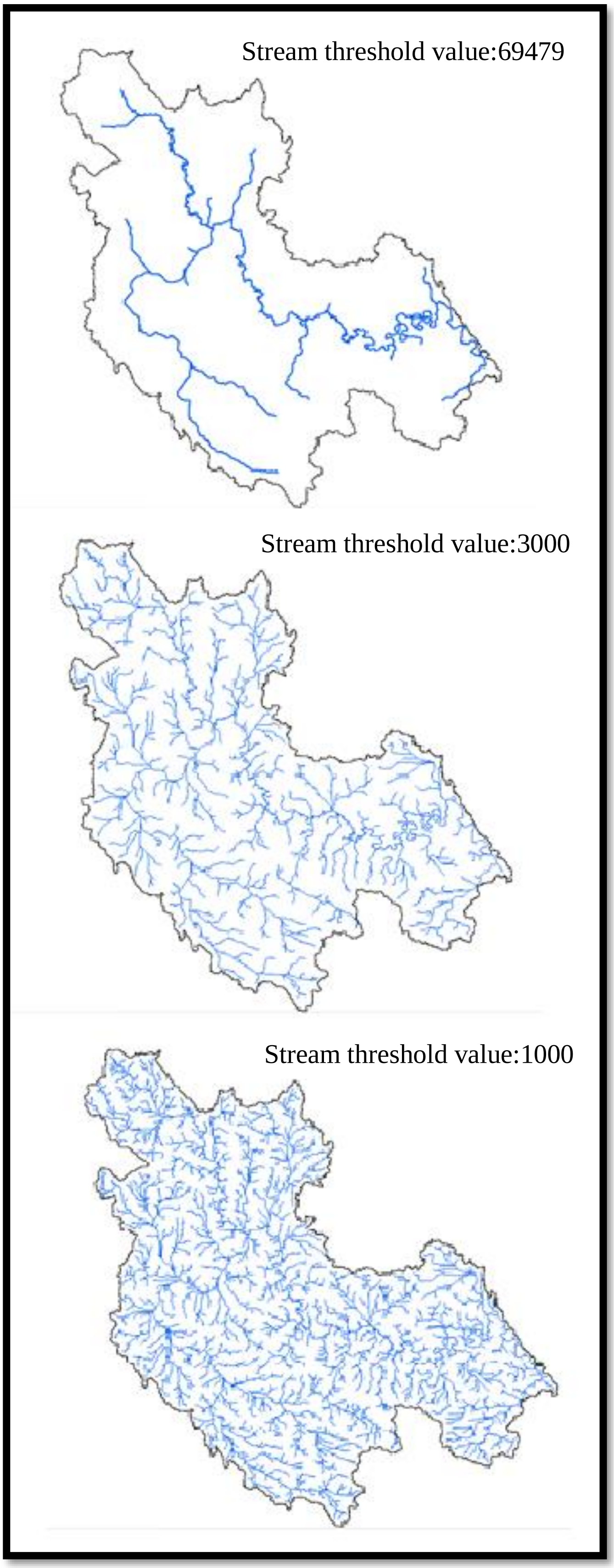


Figure 4.9 Comparison of the watershed delineation in three simulations



Stream threshold value:69479

Stream threshold value:3000

Stream threshold value:1000

Figure 4.10 Simulated stream networks under different stream threshold values

Table 4.7 Summary of the simulated stream networks and watershed

Stream threshold value	Stream length (km)	Number of streams	Catchment area (km^2)	Number of catchments
Default (69479)	504.688	40	4207.6937	40
3000	2026.748	840	4207.6880	840
1000	3431.864	2492	4207.6890	2492

4.9 Validation of River Network

For the validation of the simulated river network, the result obtained was compared to the digitized river network from Google Earth. The simulated and digitized river networks are presented in Figure 4.11. From the comparison, a total of 25 points were placed on both SRTM and digitized river network by using AutoCAD (Figure 4.12). The digitized river network is subjected as a reference to compare the accuracy with that of SRTM based. The accuracy or error analysis was done by measuring the differences of the distances between the digitized and the SRTM based river network and the results are tabulated in Table 4.8.

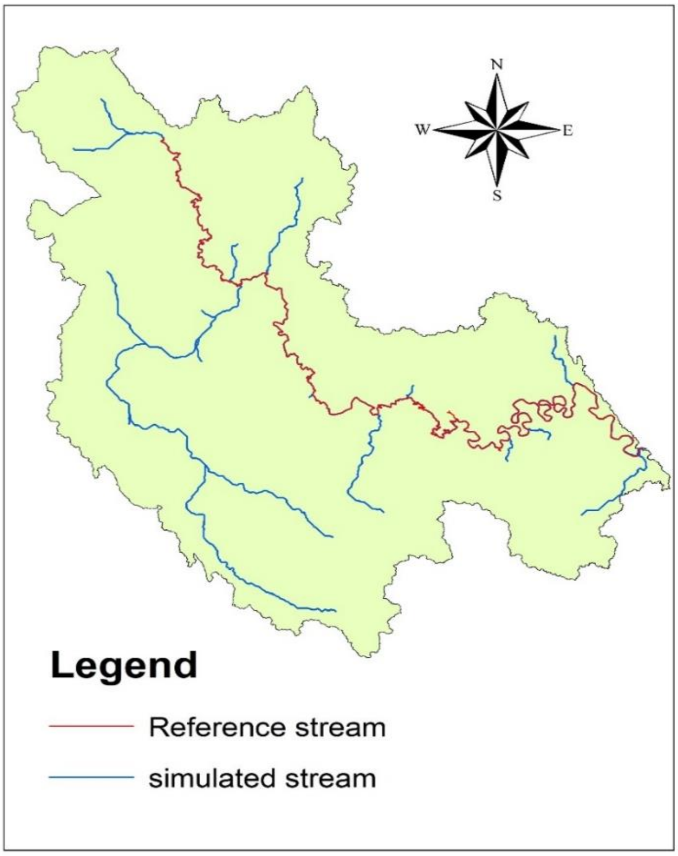


Figure 4.11 Simulated and digitized river networks

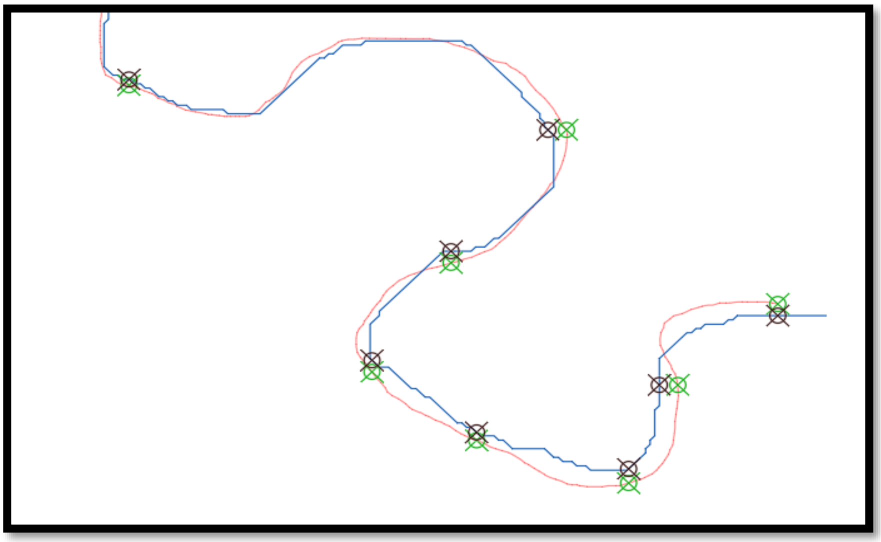


Figure 4.12 Points marked on both digitized and simulated river networks

Table 4.8 Coordinates distance between the points

Points	Digitized		SRTM		
	x-coordinate	y-coordinate	x-coordinate	y-coordinate	Distance between coordinates (m)
1	609988.1659	311730.5392	609988.1659	311647.0193	83.5199
2	609316.9557	311149.3294	609192.9340	311149.3294	124.0217
3	608986.6608	310445.2138	608986.6608	310546.9415	101.7277
4	607966.2164	310751.9367	607966.2164	310808.7399	56.8032
5	607263.6370	311243.2473	607263.6370	311326.3942	83.1469
6	607794.3467	312025.8549	607794.3467	312109.332	83.4771
7	608569.4409	312980.4480	608445.1014	312980.448	124.3395
8	605632.3558	313300.9412	605632.3558	313342.166	41.2248
9	605100.2573	316756.6634	605100.2573	316708.135	48.5283
10	602750.3142	320367.1719	602750.3142	320400.1406	32.9687
11	600454.3450	318436.0569	600439.8126	318436.0569	14.5324
12	599071.3918	319137.7035	599113.2984	319137.7035	41.9066
13	596385.1945	316898.1822	596385.1945	316886.5637	11.6185
14	593388.9262	317179.0805	593388.9262	317163.9514	15.1291
15	590150.7724	314061.5437	590150.7724	314081.8664	20.3227
16	587091.9748	312154.6507	587091.9748	312170.9737	16.3230
17	580646.0496	313970.1602	580646.0496	313989.4039	19.2437
18	576769.3999	319363.7232	576769.3999	319352.2317	11.4915
19	568617.2171	317431.4403	568617.2171	317441.339	9.8987
20	563011.0873	323989.4261	563023.3009	323989.4261	12.2136
21	559642.2500	331081.1504	559642.2500	331064.1547	16.9957
22	555472.1927	337797.9278	555472.1927	337813.9208	15.9930
23	548430.6185	343145.9278	548445.0389	343145.9278	14.4204
24	547015.8182	351820.7247	547015.8182	351837.4075	16.6828
25	543596.6843	359845.1136	543596.6843	359798.6679	46.4457
				Average =	42.5190

Performance of the river networks simulation in ArcGIS was evaluated by using Root Mean Square Error (RMSE) for assessment of the river networks accuracy. The RMSE value obtained was about 0.0556 km which is closer to 0 indicating a good fit between the simulated and digitized river network. The overall simulation performance of the Rompin River is highly acceptable and useful for prediction.

4.10 Summary

In overall, it shows that the delineated watershed area of RRB using SRTM-30 m has relatively small difference with the one from the DID. The physical characteristics extracted from the SRTM DEM is acceptable except for the river slopes. Result of the stream threshold value 1000 shows that a lower stream threshold resulted in more detailed stream networks 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 simulated and digitized river network shows a low RMSE value of 0.0556 km, indicating that the river is well simulated by the SRTM-30 m. In conclusion, SRTM-30 m is considered acceptable for the river networks simulation in the Rompin River Basin.

CHAPTER 5

CONCLUSION

5.1 Introduction

The present study demonstrates the application of Geographical Information System (GIS) technique in delineating watershed and river networks based on Digital Elevation Model as well as the integration of HEC-GeoHMS extension. In this study, the watershed and river network have been successfully delineated from 30 m resolution SRTM DEM. Repetitive simulations for different stream threshold values have been performed in the Rompin River Basin, with the aim to identify and evaluate the effect of the stream threshold values on the simulated river networks and watershed. The simulated river network has been validated by using 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 achieved accordingly.

The watershed and river network were successfully delineated by using ArcGIS application with the integration of HEC-GeoHMS extension. Based on the results, the watershed perimeter and area delineated from SRTM were 702 km and 4,208 km^2, respectively. A total of 40 sub-basins and streams were delineated. These results can be effectively used in hydrological modelling and watershed studies on the Rompin River Basin.

The physical characteristics of streams and sub-basins were also successfully extracted and estimated through the basin characteristics in Hec-GeoHMS extension. For streams, the physical characteristics include river length, river slope, upstream and downstream elevation, longest flow path length, and centroidal longest flow path length. While the sub-basins characteristics were basin slope, area, perimeter, and elevation.

For the validation of the simulated river network, the result obtained has been compared with the digitized river network from Google Earth. The simulated river network compared favourably with the digitized river network, resulting in a low RMSE value of 0.0556 km. The result indicated that the simulated river network is a good representation of the digitized river network. Thus, the simulated 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 SRTM DEM of 30 m resolution is sufficient to delineate the river network and watershed. The physical characteristics of the watershed extracted show acceptable results except for river slope. For the extensive studies in sub-basins, it is suggested to use the traditional manual delineation method in order to obtain more detailed and accurate results. In contrast, DEM with 30 m resolution has been proved to be sufficient to provide desired results.

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 the future enhancement of this simulation:

i) With the stream definition function in HEC-GeoHMS extension, this simulation used the default stream threshold value which is 69479. The default stream threshold value was much higher compared to the values of 1000 and 3000. Thus, only main river channel and few tributaries were extracted in this simulation. Therefore, further stream network simulation with different stream threshold values is needed to improve the accuracy of the stream network extraction and watershed delineation.

ii) Researchers have found that the DEM quality and resolution can profoundly affect the accuracy of delineated watersheds and extracted physical characteristics. It has been proven that higher resolution DEMs produced a more detailed and accurate result than coarser resolution DEMs. Thus, this simulation can be improved by taking into consideration the high-resolution DEMs sources such as the Light Detection And Ranging (LIDAR) or Interferometric Synthetic Aperture Radar (IFSAR). Therefore, it is recommended that if the higher resolution DEM is available, it should be used instead of the coarse resolution SRTM DEM.

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APPENDIX A
HEC-HMS MODEL DEVELOPMENT

HEC-GeoHMS or Arc Hydro Preprocessing

A. Terrain Preprocessing

1) DEM Manipulation ⟶ DEM Reconditioning
2) Fill sinks
3) Flow Direction
4) Flow Accumulation
5) Stream Definition
6) Stream segmentation
7) Catchment Grid Delineation
8) Catchment polygon processing
9) Drainage line processing
10) Adjoint catchment processing

Development of GeoHMS Model Layout

1) Run GeoHMS "Project Setup ⟶ Start New Project" function.
    a. Defined project name (e.g. "RRB" – for Rompin River Basin)
    b. Specify description (e.g. "Rompin River Basin")
    c. Select "Original Stream Definition" as extraction method
    d. Select "Outside MainView Geodatabase" as project data location
2) This will generate a new directory where to store the new project.
3) Zoom in to the outlet of the dataset (most downstream DEM cell).

4) Click on “Add Project Points” GeoHMS tool (📌).

5) Click on the most downstream cell of the DEM.

   a. Specify point name and description (can keep defaults)

6) Run GeoHMS “Project Setup → Generate Project” function.

   a. Verify that all input layers are pointing to the right data. In particular, the “Raw DEM”.

   b. Specify output layers (can keep defaults)

7) When the watershed is delineated, say “Yes” to create the project for the area shown.

Characterizing and Parameterizing GeoHMS Model

A. Run GeoHMS “Characteristics” Function

   1) Select “River Length”.

   2) Select “River slope”.

   3) Before running the “Basin Slope” function, run the “Slope” function from “Arc Hydro Tools” → “Terrain Preprocessing” → “Slope”.

   4) Run “Basin slope”.

   5) Select “Longest Flow Path”

   6) Select “Basin Centroid”

   7) Select “Centroid Elevation”

   8) Select “Centroidal Longest Flowpath”

B. Run GeoHMS “Parameter” Function

   1) Select “Select HMS Processes” function

        a. Specify the Loss Method, Transform Method, Baseflow Type, and Route Method.

    2) Select “River Auto Name”

    3) Select “Basin Auto Name”

    4) Select “Subbasin Parameters from Raster”

    5) Select “CN Lag Method”

Finalizing GeoHMS Model Development

1) Open attribute Table of Centroidal Longest Flowpath layer ⟶ Add field (Name: CentriodalFL_HMS”; Type: Float) ⟶ Field calculator (Make the values = CentroidalFL)

2) Select “Map to HMS Units” to compute the parameters in HMS units.

    a. When prompted, select unit type (“SI”) and click OK.

3) Select “Check Data”

4) Select “HMS Schematic”

5) Select “Toggle Legend” ⟶ “HMS Legend”

6) Select “Add Coordinates”

7) Select “Prepare Data for Model Export”

8) Select “Background Shape File”

9) Select “Basin Model File”

10) Run “Met Model File -> Specified Hyetograph”

11) Run “Create HEC-HMS Project”