COMPARISON OF WATERSHED BOUNDARIES DELINEATION FOR KUANTAN RIVER BASIN

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ABSTRAK

Kawasan tadahan air juga dikenali sebagai lembangan sungai yang meliputi setiap bahagian tanah di bumi kerana air sentiasa bergerak dari hulu ke titik hiliran. Selain itu, model tadahan air adalah satu langkah penting dalam penyediaan data untuk pemodelan. Kajian ini adalah untuk menggambarkan sempadan kawasan tadahan air menggunakan 3 Model Kenaikan Digital (DEMs) yang berbeza dan menilai ketepatan sempadan kawasan tadahan air untuk Lembangan Sungai Kuantan. Perisian yang digunakan untuk menggambarkan sempadan kawasan tadahan air adalah Sistem Maklumat Geografi (GIS), ArcGIS versi 10.2. Data yang diperoleh daripada 3 Dems berbeza, *Shuttle Radar Topography Mission* (SRTM) yang terdiri dari dua resolusi iaitu 1 *arc second* (30 m) resolusi dan 3 *arc second* (90 m) resolusi dan *Advanced Spaceborne Thermal Emission and Reflection Radiometer* (ASTER) dengan (30 m) resolusi. Seterusnya analisis dilakukan dengan menggunakan Jarak Euclidean dalam ArcGIS untuk mendapatkan perbezaan jarak antara sempadan DEMs dan sempadan manual (JPS). Hasilnya akan dibandingkan dengan Lembangan Sungai Kuantan yang diambil dari Jabatan Pengairan dan Saliran (JPS). Daripada analisis, SRTM-30 m data mempunyai beberapa kelebihan seperti menyediakan data asas yang penting untuk analisis topografi dalam pelbagai bidang. Bukan itu sahaja, ia mempunyai resolusi dataset topografi tertinggi pernah dihasilkan untuk permukaan tanah Bumi. Bagi SRTM-90 m, ia mempunyai berbeza sedikit dari SRTM-30 m kerana berbeza dalam resolusi. Sementara itu, data ASTER mempunyai resolusi spatial yang lebih tinggi dan liputan yang lebih luas daripada SRTM-30 m tetapi mempunyai kecenderungan negatif terhadap tanah rata. Oleh itu, ketepatan sempadan kawasan tadahan air yang diperoleh daripada 3 sumber yang berbeza bergantung kepada ketepatan DEM akan membincangkan dalam kertas ini.

ABSTRACT

Watershed also known as river basin is a part that covered every piece of land on the Earth because of water always moves off land to downstream point where it collects in a water body. Additionally, watershed modelling is an important step in preparation of data for modelling. This study is to delineate watershed boundaries using 3 different Digital Elevation Models (DEMs) and evaluate the accuracy of watershed boundaries derived from 3 difference sources for Kuantan River Basin. The software that was used to delineate watershed boundaries is Geographical Information System (GIS), ArcGIS version 10.2. The data was derived from 3 different DEMs, Shuttle Radar Topography Mission (SRTM) which consist two resolutions that is 1 arc-second (30-m) resolution and 3 arc-second (90-m) resolution and Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) with (30-m) resolution. Next the analysis is done by using Euclidean Distance in ArcGIS to obtain the differences in distance between DEMs boundaries and manual boundaries (DID). The result will be compared with the Kuantan River Basin that retrieved from Department of Irrigation and Drainage (DID). From the analysis, SRTM-30 m data have several advantages such as provide important fundamental data for topographic analysis in many fields. Not only that, it has the highest resolution topographic dataset ever produced for the Earth’s land surface. As for SRTM-90 m, it has a slight different from SRTM-30 m due to the different in resolution. Meanwhile, ASTER data has higher spatial resolution and wider coverage than the SRTM-30 m but have negative bias toward flat region. Thus, the accuracy of watershed boundaries derived from 3 different sources depends on the accuracy of the Digital Elevation Model (DEM) will be discuss in this paper.

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m	meter
km	kilometer

LIST OF ABBREVIATIONS

ACWI	Advisory Committee on Water Information
ALOS	Advanced Land Observing Satellite
ASTER	Advanced Space Borne Thermal Emission and Radiometer
AVNIR-2	Advanced Visible and Near Infrared Radiometer type
AWiFS	Advanced Wide Field Sensor
CERES	Clouds and the Earth's Radiant Energy System
DEM	Digital Elevation Model
DID	Department of Irrigation and Drainage Malaysia
DSM	Digtial Surface Model
DTA	Digital Terrain Model
DTM	Digital Terrain Model
FGDC	Federal Geographic Data Committee
FOV	Field Of View
GDEM	Global Digital Elevation Map
GIS	Geographical Information System
GNl	General Public License
IFOV	Instantaneous Field of View
InSAR	interferometric synthetic aperture radar
IRS	Indian Remote Sensing
JAXA	Japan Aerospace Exploration Agency
JERS-1	Japanese Earth Resources Satellite-1
JPL	Jet Propulsion Laboratory
KRB	Kuantan River Basin
LiDAR	Light Detection and Ranging
LISS	Linear Imaging Self-Scanning Sensor
LP DAAC	Land Processes Distributed Active Archive Center
MISR	Multiangle Imaging Spectroradiometer
MODIS	Moderate Resolution Imaging Spectroradiometer
MOPITT	Measurements of Pollution in the Trophosphere
MPK	Majlis Perbandaran Kuantan
NASA	National Aeronautics and Space Administration
NED	National Elevation Dataset
NGA	National Geospatial-Intelligence Agency
NIR	near infrared imagery

NRCS	Natural Resources Conservation Service
NRSA	National Remote Sensing Centre
PALSAR	Phase Array type L-band Synthetic Aperture Radar
PAN	panchromatic
PRISM	Panchromatic Remote Sensing Instrument for Stereo Mapping
SAR	Synthetic Aperture Radar
ScanSAR	Scan Synthetic Aperture Radar
SPOT	Satellite Pour l'Observation de la Terre
SRTM	Shuttle Radar Topographic Mission
SWIR	shortwave infrared
TIR	thermal infrared
TM	Thematic Mapper
US	United State
USDA	United State Department of Agriculture
VNIR	visible and near infrared
WiFS	Wide Field Sensor

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Malaysia is a country that receives abundant rainfall during the year. Most of the rivers are due to the high ground in the middle. Moreover, most rivers in peninsular Malaysia emanating from the Banjaran Titiwangsa and flows into the South China Sea and the Strait of Malacca. Meanwhile, in Sabah and Sarawak, the rivers originating from mountain ranges in the hinterland then flow into the South China Sea. Rivers in Malaysia are short, the flow is heavy on the upstream and meander along downstream.

Malaysia consists of a variety of terrain, namely the highlands, plains, basins, and seaside. Watershed also known as river basin is a part that covered every piece of land on the Earth because water always moves off land to downstream point where it collects in a water body. Over the time watershed changes, some changes happen rapidly and some of it will take thousand or million years to change. Thus, it is crucial to know the exact measurement of watershed from time to time.

One of the important components of the project is watershed modelling. It is an important step in preparation of data for modelling which delineate accurate watershed boundaries for the study of watersheds corresponding with the objective to evaluate the accuracy of watershed boundaries derived from three different sources (Pryde et al., 2007).

Additional to objective, this study is searching the most accurate Digital Elevation Model (DEM) generic term for Digital Surface Model (DSM) which only representing height information without any further definition about the surface. In this case it is use for delineation of watershed boundaries. One of the DSM selected is Shuttle Radar Topography Mission (SRTM) and The Advanced Spaceborne Thermal

Emission and Reflection Radiometer (ASTER). Only then, the result will be compared with data that retrieved from Department of Irrigation and Drainage (DID).

Thus, Kuantan region in Pahang, Malaysia, as shown in (Figure 1.1) has been selected as the study area for this study.

Figure 1.1 Kuantan Region
Source: jps@komuniti (2011)

1.2 Problem Statement

SRTM and ASTER are digital elevation models (DEMs) with open access to public. These DEMs have provided basic information on heights of the Earth's surface and features upon it. Moreover, the existence of different uncertainties like horizontal shift, elevation offset, horizontal resolution, voids, artifacts and so on cause users faced with many ambiguous problem when using these open access DEMs.

Another problem that comes across is that, there is no map of showing their accuracy in individual areas like tropical countries same as Malaysia with dense forests and vegetation cover and no comprehensive study for preparing specific framework to showing different accuracy in specific land covers zones.

Malaysia is a well-known country that rich with it tropical rainforest, which is covered by dense forest in most regions. This condition is one of the problematic factors in using active remote sensor instruments in surveying ground data from the earth, because DEM have difficulties on penetrating vegetation canopy to the ground.

Thus, in this study the accuracy of SRTM and ASTER with DID data as ground truth data by using statistical approach.

1.3 Objectives

The objectives of this study:-

i. to delineate watershed boundaries using 3 different Digital Elevation Models (DEMs).

ii. to evaluate the accuracy of watershed boundaries derived from 3 difference sources for Kuantan River Basin.

1.4 Scope of Study

The scopes of study are selected:-

i. Area of watersheds boundary for Kuantan river basin are selected in this study.

ii. The data was derived from 3 different DEMs:

- ASTER
- SRTM-30 m
- SRTM-90 m

iii. Software that was used is Geographical Information System (GIS), ArcGIS version 10.2.

1.5 Significance of Study

The significance from this study is that it will help local authorities or agencies such as Department of Irrigation and Drainage (DID) and Majlis Perbandaran Kuantan (MPK) in order to prepare flood map especially for Kuantan River Basin. Not only that, from this study also, hydrology and hydraulics studies can be enhances especially in Kuantan River Basin. Finally, the outcome from this study can be used as guideline to determine the relevance of a particular DEM datasets in varied relief terrain.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Literature review is actually a discussed of a simple summary from published information such as article, journal, books and other reading material sources which covered specific subject area and also can be within certain period of time. For this study, it covered hydrology part that is watershed boundaries delineation for Kuantan River basin one of the catchment that situated in Kuantan, Pahang.

This chapter briefly describe the review on watershed, digital elevation model (DEM) and remotely sensed data. In this literature review, it comprises three sections: the first section is about the introduction of watershed, watershed boundaries and watershed delineation. The second section describes about each type of digital elevation model (DEM) and their advantages and disadvantages. Lastly, the third section shows the software that will be used for this study.

Thus, from this study, it is initials to study and review what existing scholarship knows about a particular topic for example digital elevation model. It is always based on secondary sources. As such, it is a prelude to further research, a digest of scholarly opinion. Finally, literature review should focus only on the relevant academic literature: popular or non-academic sources may be brought in occasionally to illustrate a point, but the central interest is always on the data collected or the theories put together by recognised experts in the field.

2.2 Watershed

Watershed also known as drainage basin is an entire river system on Earth. From the definitions, watershed is an area of land that catches rain and snow and other precipitation then funnels it to a lake or stream or wetland as shown in Figure 2.1. For example, runoff water from a large watershed in the midcontinent United States drains into Gulf of Mexico through the Mississippi River system. This Amazon River watershed is absolutely huge, that can drain over a third of the entire South American ascetic (Entry, Encyclopedic, 1996-2016) which proof that watershed can cover a wide range of areas.

In fact, they are topographic areas within which apparent surface water runoff drains to a specific point on a stream or to a waterbody such as a lake. There are an infinite number of points from which topographic watersheds can be delineated, although regarding streams, confluences are normally used. Large watersheds are commonly termed basins (e.g., the Colorado River Basin or the Susquehanna River Basin). The hierarchical classification of hydrologic units as mapped by the U.S. Geological Survey (Seaber et al., 1987) is made up of watersheds or segments of watersheds often with areas in between. However, at each level of classification, the majority of these hydrologic units are not true topographic watersheds.

One of the reasons watersheds are important to scientists is that they affect the quality and amount of flow through a stream or river at a given point. For example, as the Mississippi River empties into the Gulf of Mexico, it is carrying water from its entire watershed, the second-largest in the world.

It includes about 40 percent of the area of the continental United States and provides water for millions of people. (Entry, Encyclopedic, 1996-2016).

Watersheds are more than just drainage areas in and around our communities. They are necessary to support habitat for plants and animals, and they provide drinking water for people and wildlife. Lastly, they also provide the opportunity for recreation and enjoyment of nature.

Although, these water bodies supply our drinking water, for agriculture purposes and manufacturing and even offer the opportunities for recreation, unfortunately, Watersheds confront a range of degradation challenges related with mankind's activities, such as pollution, deforestation and changes in sediment generation that can interfere with the health of the watershed.

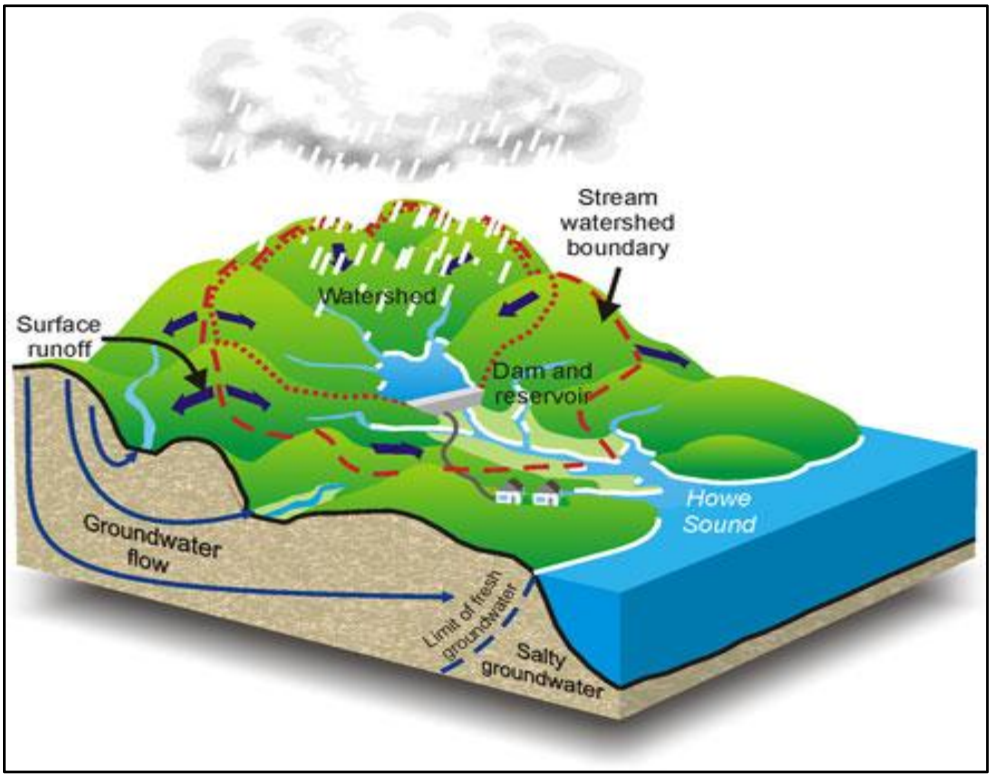

Figure 2.1 Watershed Boundary
Source: North and South Rivers Association (n.d.)

2.2.1 Watershed Boundaries

According to the USDA, Watershed boundaries define the aerial extent of surface water drainage to a point. The intent of defining hydrologic units (HU) for the Watershed Boundary Dataset is to establish a base-line drainage boundary framework, accounting for all land and surface areas. The selection and delineation of hydrologic boundaries are determined solely upon science-based hydrologic principles, not favouring any administrative or special projects nor particular program or agency. At a minimum, they are being delineated and georeferenced to the USGS 1:24,000 scale topographic base map meeting National Map Accuracy Standards (NMAS). A hydrologic unit has a single flow outlet except in coastal or lakefront areas. As stated by the Federal Standard for Delineation of Hydrologic Unit Boundaries, A hydrologic unit is a drainage area delineated to nest in a multi-level, hierarchical drainage system. Its boundaries are defined by hydrographic and topographic criteria that delineate an area of land upstream from a specific point on a river, stream or similar surface waters. A hydrologic unit can accept surface water directly from upstream drainage areas, and indirectly from associated surface areas such as remnant, non-contributing, and diversions to form a drainage area with single or multiple outlet points. Hydrologic units are only synonymous with classic watersheds when their boundaries include all the source area contributing surface water to a single defined outlet point.

The Watershed Boundary Dataset is being developed under the leadership of the Subcommittee on Spatial Water Data offsite link image, which is part of the Advisory Committee on Water Information offsite link image (ACWI) and the Federal Geographic Data Committee offsite link image (FGDC). The USDA Natural Resources Conservation Service (NRCS), along with many other federal agencies and national associations, have representatives on the Subcommittee on Spatial Water Data.

As watershed boundary geographic information systems (GIS) coverage are completed, statewide and national data layers will be made available via the Geospatial Data Gateway to everyone, including federal, state, local government agencies, researchers, private companies, utilities, environmental groups, and concerned citizens. The database will assist in planning and describing water use and related land use activities.

2.2.2 Watershed Delineation

Watershed delineation is a step or a way on creating a boundary that represents the contributing area for a particular control point or outlet and it is used to define boundaries of the study area and to divide the study area into sub areas as shown in Figure 2.2. Delineation of watersheds within a large drainage basin and their prioritization is required for proper planning and management of natural resources for sustainable crop production.

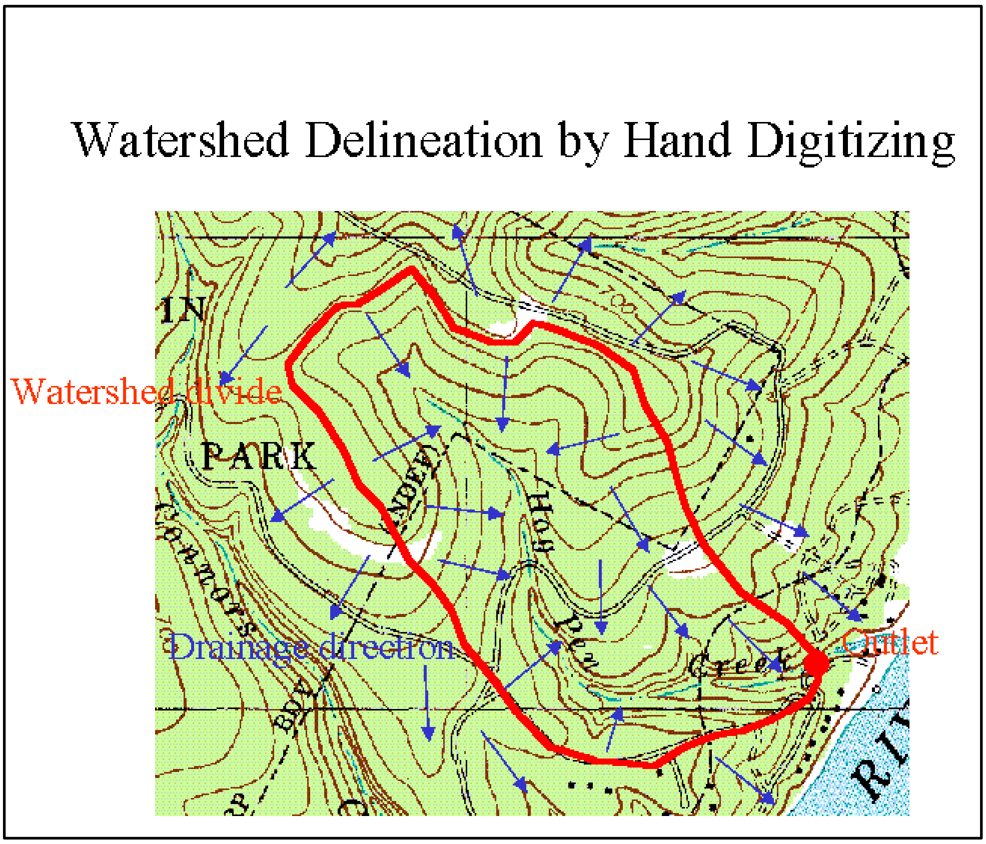

Figure 2.2 The delineation of watershed by hand digitizing

Source: Maidment (1999)

From (Ammann & Stone, 1991) there are two way on measuring watershed areas widely available methods for measuring the area of a watershed: Dot Grid Method, and Planimeter. These methods can also be used to measure the area of the wetland itself as required by The New Hampshire Methods.

The dot grid method is a simple technique which does not require any expensive equipment. In this method the user places a sheet of acetate or mylar, which has a series of dots about the size of the period at the end of this sentence printed on it, over the map area to be measured. The user counts the dots which fall within the area to be measured and multiplies by a factor to determine the area. A hand held, mechanical counting device is available to speed up this procedure.

The second of these methods involves using a planimeter, which is a small device having a hinged mechanical arm. One end of the arm is fixed to a weighted base while the other end has an attached magnifying lens with a cross hair or other pointer. The user spreads the map with the delineated area on a flat surface. After placing the base of the planimeter in a convenient location the user traces around the area to be measured with the pointer. A dial or other readout registers the area being measured.

Planimeters cost from several hundred dollars (almost 400 ringgit Malaysia) up to a thousand dollars or more depending on the degree sophistication. For the purposes of The New Hampshire Method, a basic model would be sufficient. Dot counting grids are more affordable, and are in the 10 to 20 dollar range(Ammann & Stone, 1991). Both planimeters and dot grids are available from engineering and forestry supply companies. Users of either of these methods should refer to the instructions packaged with the equipment they purchase.

2.2.2.1 Watershed Delineation by hand-drawn

Watershed is the area of land that drains down slope to the lowest point of the terrain. The water moves by gravity means in a network of drainage pathways that may be underground or on the surface into a specified body of water, river or stream. Although there are many ways for water to enter a stream, much will enter as run-off from the land. This land is what forms the stream's watershed. However, in some regions, the water drains to a central depression such as a lake or marsh with no surface-water exist.

Traditionally, delineation of watershed boundaries is done manually using topographic map that shows stream channels, contour plots. The watershed boundaries will follow major ridge-lines around the channels and meet at the bottom where the water flows out of the watershed, commonly referred to as the mouth of the stream or river. In contour plots, droplets of water flows out usually travel along lines normal to the contour lines down the hills. As the ground retains water for longer periods, more water will penetrate into ground and reduced amount will reach the downstream mouth of the area.

According to Abed, (2013), watershed can be as large as several hundreds of square kilometres. As the streams get smaller toward the upstream direction, watershed can be as small as few square meters. A common term in this regard is the basin and sub basin. Each smaller division belongs to a single stream or a collection of streams in the specified area.

In Malaysia, the Department of Survey and Mapping Malaysia produce the topographic map as example of topographic maps is shown in Figure 2.3. The large scale map is produced in full colour showing cultural feature, area classification, vegetation, hydrography, relief and annotation.

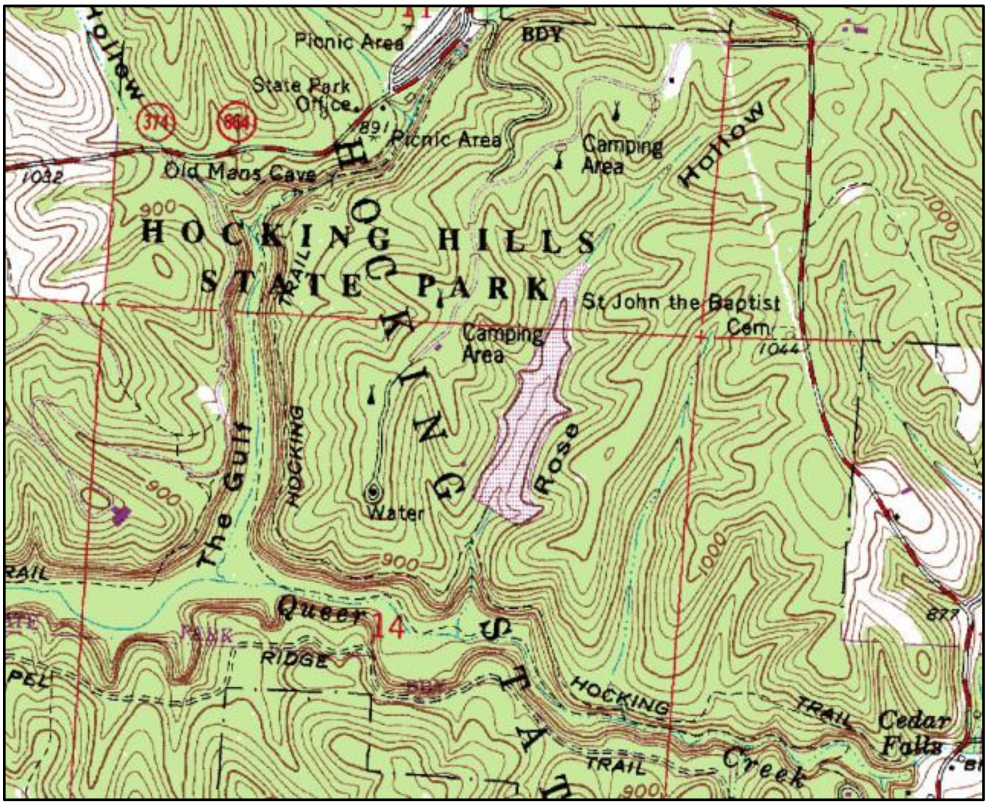

Figure 2.3 Topo Maps from LibreMaps
Source: TrekOhio.com (2017)

2.2.2.2 Watershed Delineation with Software

One of the most useful applications of Geographical Information System (GIS) is the delineation of watershed boundaries. A watershed boundary is the line divides two basins mountain peaks, while in flat and urban it is invisible. According to Akbari at el (2015), watershed delineation and parametrization is primary and basic step in hydrologic modelling and it can significantly the results of hydrological simulations which shown in Figure 2.4. Additionally, it is now done using digital elevation model

(DEM) and automated processor which embedded or linked with GIS software. Beside GIS, there is several GIS package that available for based watershed boundary delineation including ArcGIS, IL WIS, MAP Window, Grass and many more available for GIS.

According to Akbari at el (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, geographic data can now be stored electronically. Digital Elevation Models (DEM's) store topographic data in the form of grid cells. 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 so you can explore data and share location-based insights. ArcGIS creates deeper understanding, allowing to quickly seeing where things are happening and how information is connected. ArcMap is the main component of Esri's ArcGIS suite of geospatial processing programs, and is used primarily to view, edit, create, and analyze geospatial data (ESRI, n.d.). 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.

In ArcGIS consists of ArcMap which can create and manipulate data sets to include a variety of information. For example, the maps produced in ArcMap generally include features such as north arrows, scale bars, titles, legends, neat lines, etc. The software package includes a style-set of these features. As well as the ability to upload numerous other reference styles to apply to any mapping function.

The ArcGIS suite is available at four license levels: Basic, Standard, or Advanced (formerly ArcView, ArcEditor, or ArcInfo), and Pro. Each step up in the license provides the user with more extensions that allow a variety of querying to be performed on a data set. Pro is the highest level of licensing, and allows the user to use such extensions as 3D Analyst, Spatial Analyst, and the Geostatistical Analyst as well as a numerous new functionalities at each new release.

Meanwhile, according to Wikipedia (2017), 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. ILWIS was initially developed and distributed by ITC Enschede (International Institute for Geo-Information Science and Earth Observation) in the Netherlands for use by its researchers and students. Since 1 July 2007, it has been released as free software under the terms of the GNL General Public License (Wikipedia, 2017). Having been used by many students, teachers and researchers for more than two decades, ILWIS is one of the most user-friendly integrated vector and raster software programmes available. ILWIS has some very powerful raster analysis modules, a high-precision and flexible vector and point digitizing module, a variety of very practical tools, as well as a great variety of user guides and training modules all available for downloading. The current version is ILWIS 3.8.1. Similar to the GRASS GIS in many respects, ILWIS is currently available natively only on Microsoft Windows. However, a Linux Wine manual has been released.

ILWIS uses GIS techniques that integrate image processing capabilities, a tabular database and conventional GIS characteristics. The major features include:

i. Integrated raster and vector design
ii. On-screen digitizing
iii. Comprehensive set of image processing and remote sensing tools like extensive set of filters, resampling, aggregation, classifications. Etc.
iv. 3D visualization with interactive zooming, rotation and panning. "Height" information can be added from multiple types of sources and isn't limited to DEM information.
v. Hydrologic Flow Operations
vi. DEM operations including ISO line generation.
vii. Variable Threshold Computation, to help preparing a threshold map for drainage network extraction

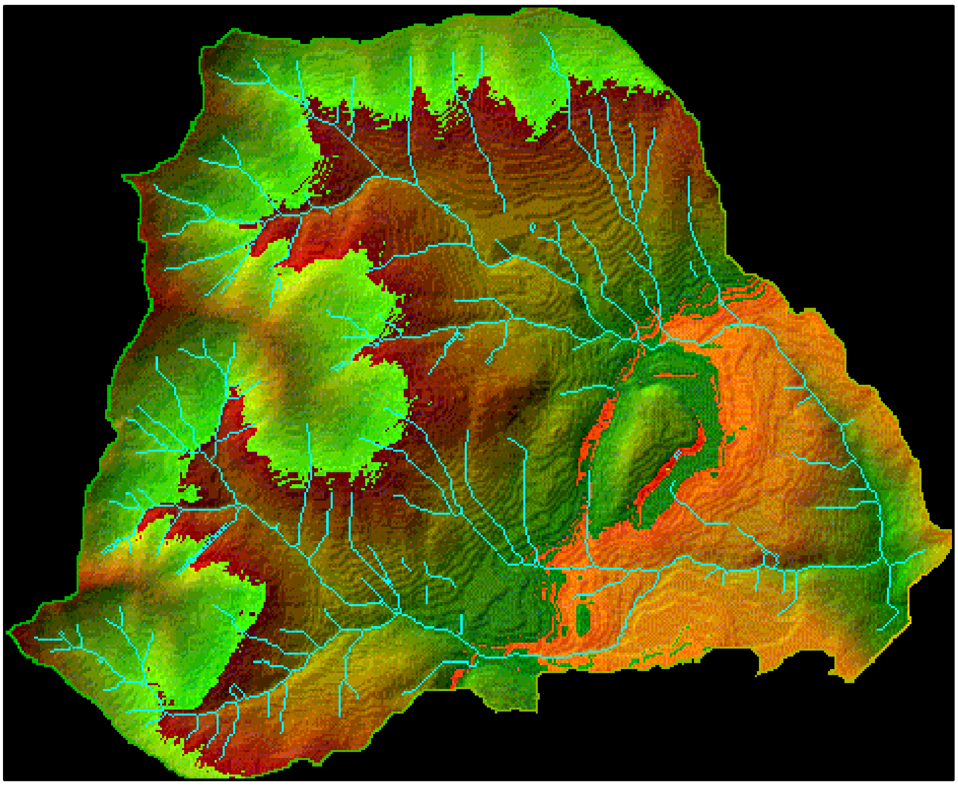

Figure 2.4 Hillshaded view of John's Creek watershed with DEM derived stream network.

Source: John’s Creek (1999)

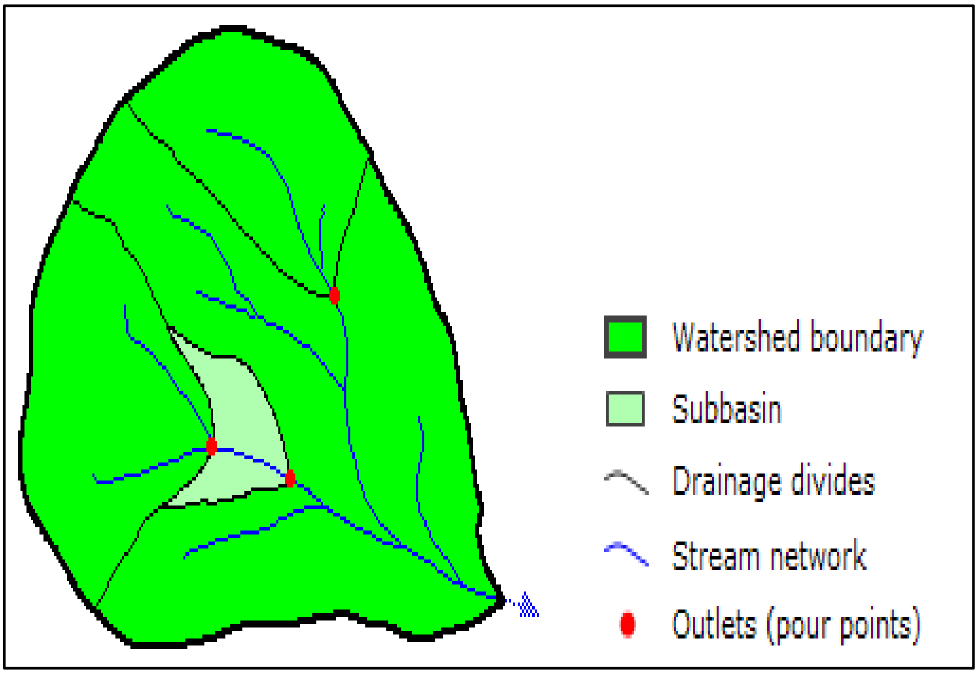

Figure 2.5 Watershed components

Source: Eldho (2012)

According to Eldho (n.d) the major steps involved in delineating a watershed using ArcGIS are:

i. Geo-registering the scanned topo sheets
ii. Creating shapefiles
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

2.3 Geographical Information System

A geographic information system (GIS) is a computer system for capturing, storing, checking, and displaying data related to positions on Earth's surface. GIS can show many different kinds of data on one map. This enables people to more easily see, analyze, and understand patterns and relationships.

With GIS technology, people can compare the locations of different things in order to discover how they relate to each other. For example, using GIS, the same map could include sites that produce pollution, such as gas stations, and sites that are sensitive to pollution, such as wetlands. Such a map would help people determine which wetlands are most at risk.

GIS can use any information that includes location. The location can be expressed in many different ways, such as latitude and longitude, address, or ZIP code (National Gographic, n.d.). Many different types of information can be compared and contrasted using GIS. The system can include data about people, such as population, income, or education level. It can include information about the land, such as the location of streams, different kinds of vegetation, and different kinds of soil. It can include information about the sites of factories, farms, and schools, or storm drains, roads, and electric power lines.

2.3.1 An Introduction to GIS Applications in Hydrology

Water professionals need to be able to manage surface and groundwater resources over the scale of an entire watershed. Within any given watershed, there may be thousands of groundwater monitoring wells, numerous stream reaches with gages, as well as snow measurements and weather stations. The effects of land cover, vegetation, soil type, topography, geology, water quality, and other factors must be considered in order to make sound management decisions. The data are available from a variety of public agencies, but often in different coordinate systems, at different scales, and from different time periods.

By using a geographic information system (GIS) a holistic view of the watershed is form from synthesizing all these data. Put simply, a GIS is a system of computer software, hardware, and data, combined with qualified people to assist with manipulation, analysis, and presentation of information that is tied to a spatial location. A GIS can be thought of as a "smart map" that has features that are associated with information typically derived from a database, which is simply a table of information(Jordan, 2004). The critical element is the association of information with a location on the map. For example, a monitoring well shown as a point on a map might also have well construction information such as depth, screened interval, and lithological logs associated with it, along with a time series of water levels. Therein lays the beauty of the GIS: the GIS user can access and manipulate information associated with geographic features and look for spatial and temporal patterns and relationships.

A key advantage of GIS is its ability to integrate, manage, and analyse large volumes of data, particularly over very large areas. GIS enables data to be integrated and viewed on the scale of an entire watershed, allowing a holistic approach to water resources management. These same integration capabilities also make GIS useful for local-scale analyses, where many diverse types of data must be considered.

2.3.2 Applications of Remote Sensing and GIS in Hydrology

Remote Sensing and GIS technologies are well-established tools and are routinely used in applied hydrology, forestry, land use dynamics analyses, etc. Abilities of remote sensing technology in hydrology are to measure spatial, spectral, and temporal information and provide data on the state of the earth's surface. It provides observation of changes in hydrological states, which vary over both time and space that can be used to monitor hydrological conditions and changes. Sensors used for hydrological applications cover a broad range of electromagnetic spectrum. Both active sensors that send a pulse and measure the return pulse (like radar, microwave etc.) and passive sensors that measure emissions or reflectance from natural sources (like Sun, thermal energy of the body) are used (Geographic Information System (GIS), 2001). Sensors can provide data on reflective, thermal and dielectric properties of earth's surface.

Remote sensing techniques indirectly measure hydrological variables, so the electromagnetic variables measured by remote sensing have to be related to hydrological variables empirically or with transfer functions.

Remote sensing applications in hydrology that are being used today are mainly in:

i. Precipitation estimation
ii. Runoff computations
iii. Snow hydrology applications
iv. Evapotranspiration over land surface
v. Evaluation of soil moisture content
vi. Water quality modelling
vii. Groundwater identification and estimation
viii. Hydrological modelling

GIS can play fundamental role in the application of spatially distributed data to hydrological models. In conventional applications, results either from remote sensing or from GIS analyses serve as input into hydrological models. Land use and snow cover are the most commonly used input variables for hydrological models. The integration of GIS, database management systems and hydrological models speed up the use of remote sensed data in hydrological applications.

2.4 Digital Elevation Model (DEM)

DEM is a subset of DTM and the most fundamental component of DTM. In practice, these terms (DEM, DSM, and DTM) are often assumed to be synonymous and indeed this is often the case. But sometimes they actually refer to different products. That is, there may be slight differences between these terms.

According to StackExchange (2011), a DEM is a '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. Whereas, a DSM is an elevation model that includes the tops of buildings, trees, powerlines, and any other objects (StackExchange, 2011). Commonly this is seen as a canopy model and only 'sees' ground where there is nothing else overtop of it. DTM is effectively a DEM that has been augmented by elements such as breaklines and observations other than the original data 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 a DTM.

A Digital Elevation Model (DEM) is a specialized 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. GIS software can use digital elevation models for 3D surface visualization, generating contours, and performing viewshed visibility analysis.

From the GisGeography (2017), a digital elevation model is a regularly-spaced bare-earth raster grid referenced to a common vertical datum. The non-ground points such as bridges and roads will be filter out, and will only left with a smooth digital elevation model. The built (powerlines, buildings and towers) and natural (trees and other types of vegetation) are not extruding in a DEM as shown in Figure 2.6.

When removing void vegetation and man-made features from elevation data, DEM is obtaining. A smooth, bare-earth elevation model is particularly useful in fields of study such as hydrology, soils and land use planning/safety. Here are examples how a DEM can be used in GIS:

Hydrologic modeling – A DEM is used to delineate watersheds, calculate flow accumulation and find out flow direction.

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

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

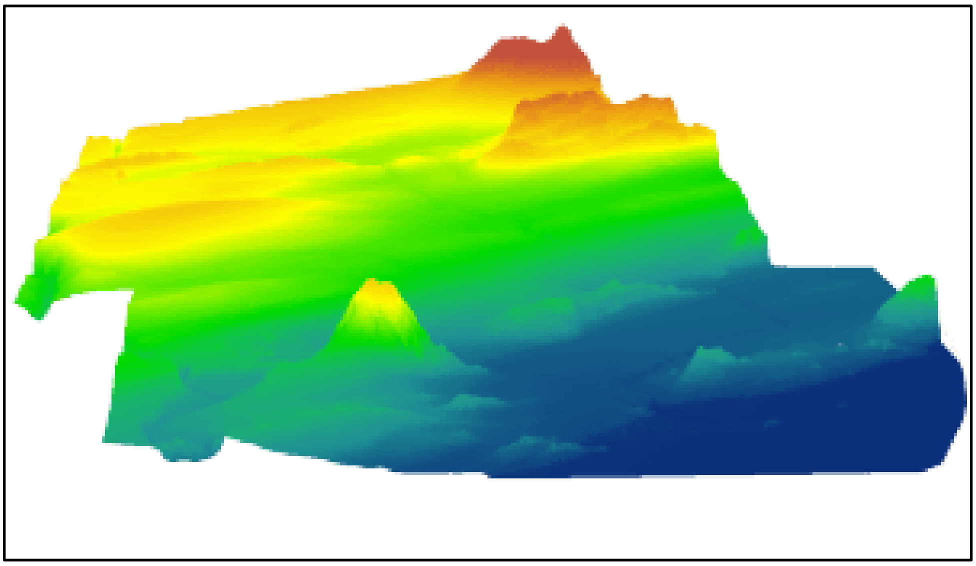

Figure 2.6 Digital Elevation Model (DEM)
Source: GisGeograpy (2017)

From (GISGeography, 2017), there are some of the remote sensing methods for obtaining 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.

2.4.1 Applications of Digital Elevation Models (DEMs) in Hydrology

The value of the DEM in hydrologic applications is growing (Maidment, 2002). With an accurate representation of a surface, hydrologic characteristics can be derived from that surface. Hydrologic features produced from DEMs include drainage channel networks and channel characteristics, watershed divides and low lying areas (Dinesh, 6 2008). These hydrologic features are readily produced from DEM data through a variety of software options.

The value of these DEM derivative features varies depending upon 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.

DEM data is a component in the planning and construction of nearly all types of physical structure development. Characteristics such as slope, aspect and hydrology are integral components in planning structural development. Specific incidents of where DEM data may be useful are determining aspect, such as when aligning a wind farm development with prevailing winds, calculating slopes, when planning the construction of a roadway, or in hydrology, when performing a flood risk assessment for a building site.

With the availability of more accurate and higher resolution DEMs with broader global coverage, the utility of DEMs in hydrologic modelling is increasing (Hoffman and Winde, 2010).In addition to the SRTM flight data, the National Aeronautics and Space Administration (NASA) presently have DEM data for both the moon and Mars. Moon DEM data was derived from APOLLO and Lunar Orbiter Imagery. Mars DEM imagery was derived from the systems on board of the Mars Global Surveyor satellite (NASA, 2010).

Whether a DEM provides an adequate representation of surface elevation varies depending upon the user’s objective and needs. Both resolution and accuracy determine whether or not the dataset is sufficient. Accuracy in relation to a DEM is a measure of how closely the modelled value approaches the true surface value. Accuracy is measured along both horizontal and vertical axes.

2.4.2 Limitations of Digital Elevation Models in Areas of Low Terrain

Low relief terrain presents specific challenges in DEM applications. Hydrographic (surface drainage) delineations in low relief terrain can be complicated due to factors related to model representation within those areas. Digital elevation model representation in areas of low topographic relief is often inadequate (Garbrecht and Martz, 1996). Lack of sufficient detail may result in lack of accuracy in low relief terrain. Contour interval or the scale of elevation increments may be too coarse to adequately describe low relief terrain. Resolution, or the cell size of raster DEM datasets, can also produce inaccuracies for DEM applications.

A large portion of the earth's land surface is considered to be low relief terrain. As contour interpolation is employed, large areas with unknown elevations are estimated between contour intervals. Another challenge may occur when large vertical measuring intervals are used. For instance, a DEM with 1 meter vertical posting intervals likely will not adequately describe topography that undulates on a sub-meter scale. There is a need to identify the appropriateness of existing individual DEM datasets in low relief terrain. Information resulting from such an analysis could prove profitable for associated 8 management applications. Techniques used to provide a simple horizontal and vertical accuracy may not sufficiently quantify how accurately a respective DEM dataset models the true low relief terrain. Further analysis, such as hydrologic delineations within a GIS, can be used to further test the extent to which DEM datasets accurately map terrain (Stanton, 1999).

The methods used to create DEM datasets may also introduce error into a dataset. Remote sensing by nature may introduce 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 in elevation models are likely to have a more pronounced impact on delineations in low relief terrain due to being exaggerated where slope values are relatively small or are spaced far apart. The occurrence of pits can be greatly influenced by these factors and can present challenges to the process of hydrographic delineations. DEM pits, cells or groups of cells completely surrounded by cells of higher value, occur both as natural features of terrain and as spurious artifacts of DEM production (Tribe, 1992). The fact that natural pits, "sinks," are often endemic to low relief basins requires that differentiation between real or artificial pits be performed.

Differentiation between real and spurious pits can be performed by first identifying where pits exist within a DEM. The next step involves determining authenticity through either "ground-truthing" or remote sensing. Ground-truthing might involve the survey of elevation or the presence and spatial extent of playas to determine the veracity and extent of pits (Messina et al, 2005). Remote sensing of pits might involve the use of imagery to determine the authenticity and spatial extent of pits through the classification 9 of land cover. Specifically, the remote sensing of pits might be accomplished through the determination of the spectral signatures of the vegetation or soil types associated with playas (Strand et al., 2007).

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

2.5 Remotely Sensed Data-Earth Resources Satellite Data

Several satellite in this category share the same characteristics of capturing radiation in the visible light and near infrared imagery (NIR) spectrum at a medium spatial resolution and a return period of 20 days. There are six of the lead sensors:-

i. Shuttle Radar Topography Mission (SRTM)
ii. Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER)
iii. LANDSAT Data
iv. Moderate Resolution Imaging Spectroradiometer (MODIS)
v. Indian Remote Sensing (IRS)
vi. Advanced Land Observing Satellite (ALOS)

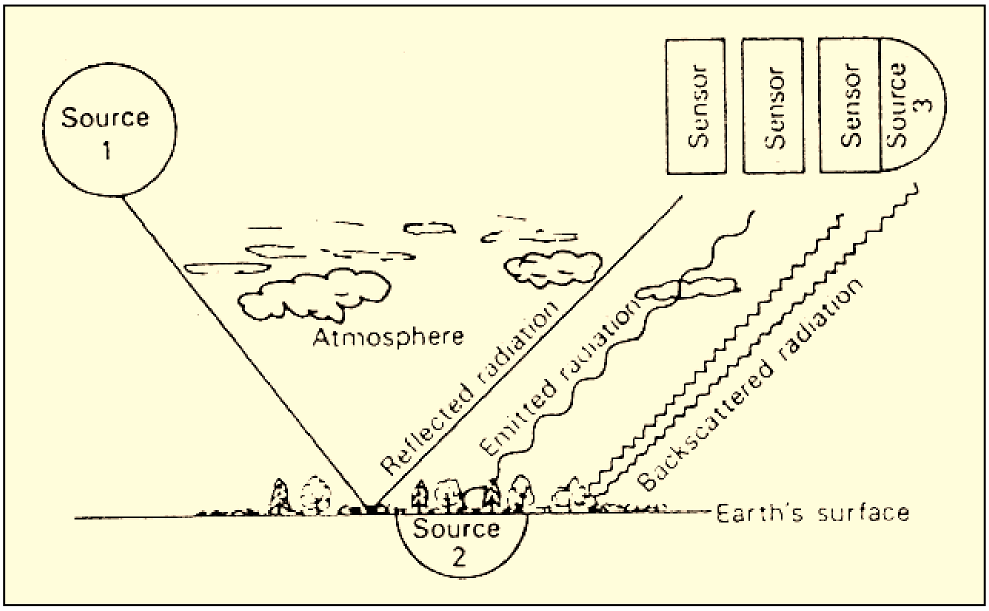

Figure 2.7 The Key Features of the Remote Sensing Data Collection Process
Source: Curran (1985)

2.5.1 SRTM Data

SRTM DEM data is produced via the use of interferometric synthetic aperture radar (InSAR) system. The SRTM mission was obtained on the space shuttle Endeavour in February 2000. 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 (Laboratory Jet Propulsion). For most of the world, SRTM data were originally made publicly available at a three-arc-second pixel size (1/1,200 of a degree of latitude and longitude), which is about 90 meters (295 feet). The newly released data are at one-arc-second pixel size, which is about 30 meters (98 feet). The actual resolution of the SRTM DEM varies somewhat but is larger than 50 meters, and is commonly 75 meters or less. In short, the term "resolution" refers to the size of the smallest feature observable in the data. Thus, 90-meter pixels were too large to display the full resolution of the SRTM DEM, but the full resolution is now revealed by the much smaller 30-meter pixels as shown in Figure 2.8.

SRTM DEM data is referenced horizontally to the WGS84 ellipsoid and vertically to the EGM96 geoid orthometric heights (Hoffman and Walter, 2006). The product specification is shown in Table 2.1. 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 will vary by SRTM data set:-

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

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 (30 meters) and provide open distribution of this high-resolution global data set. Some tiles may still contain voids. Users should check the coverage map in EarthExplorer to verify if their area of interest is available. Please note that tiles above 50° north and below 50° south latitude are sampled at a resolution of 2 arc-second by 1 arc-second.

Table 2.1 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: USGS (2015)

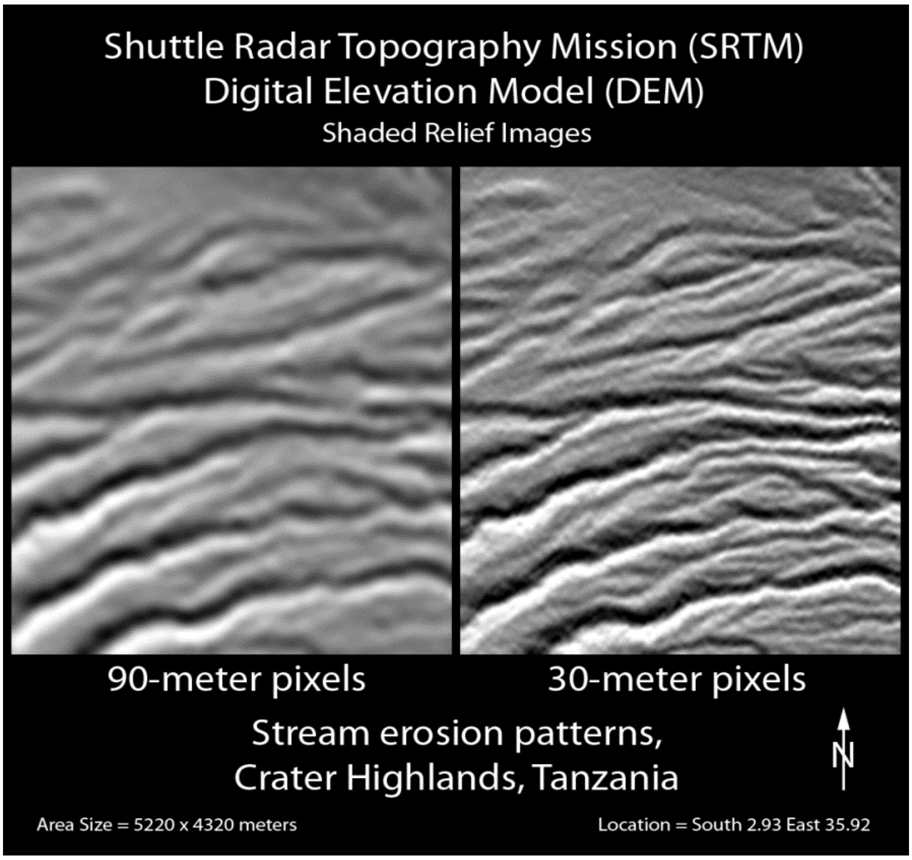

Figure 2.8 SRTM 90 m and 30 m pixels

Source: NASA/JPL (n.d.)

2.5.2 ASTER Data

The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) data come from flagship satellite come from Terra spacecraft launched on 18 December 1999. The Terra spacecraft model is shown in Figure 2.9. Terra space craft has a polar orbit, 705 km in altitude and to ensure data continuity, Terra space craft has orbital path that follows closely of Landsat 7. Not long after that, Terra was later complemented by another satellite name, Aqua launched on 4 May 2002. The payload of the Terra satellite includes five state-of-the-art sensors each designed for a specific domain of applications. These sensors are called ASTER, MODIS, Clouds and the Earth’s Radiant Energy System (CERES), Multiangle Imaging Spectroradiometer (MISR), and Measurements of Pollution in the Trophosphere (MOPITT). Through these sensors, the diverse data collected. In addition , these sensors are excellent in studying the Earth’s radiation balance, including the effect of heavier cloud cover and land use changes, glacier volume, properties of the mid to upper atmosphere, and the effects of volcanic activity on the atmosphere (JPL,2004).

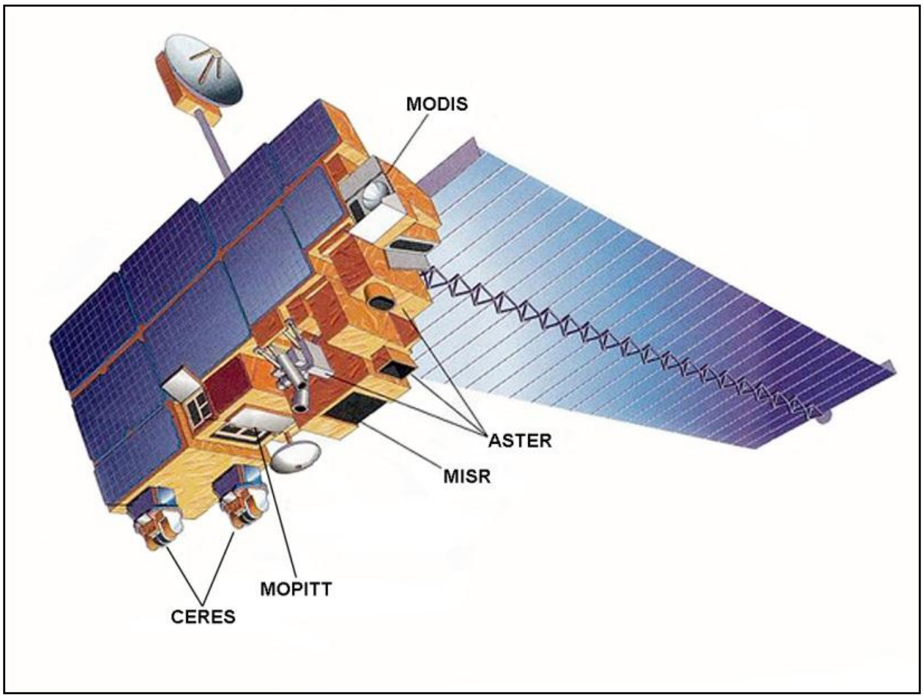

Figure 2.9 Terra Spacecraft
Source: NASA (2015)

Table 2.2 Summary of Sensors Aboard The Terra Spacecraft

Sensor	General Characteristics	Primary Application
ASTER	Three scanners	land surface, land cover mapping (including vegetation conditions), hazard monitoring, geology and hydrology
MODIS	36-channel imaging spectrometer	Monitoring large-scale changes in the biosphere (e.g, global carbon cycle)
CERES	Two broadband scanners	Assessing clouds' roles in radiative fluxes from the surface to the top of the atmosphere
MISR	Four-channel CCD arrays	Differentiation of different types of clouds, aerosol particles, and surfaces
MOPITT	Three NIR scanners	studying distribution, transport, sources, and sinks of carbon monoxide and methane in the troposphere

Source: Gao (2009)

Among the five sensors, ASTER is designed to study Earth resources. Along the 14 spectral bands from the visible light to the TIR (thermal infrared) wavelengths are tools to collect ASTER data. Interestingly, the ASTER sensing system is made up of three subsystem (telescope) covering the visible and near infrared (VNIR), shortwave infrared (SWIR) and thermal infrared (TIR) respectively. The VNIR bands have a spatial resolution of 15-m finer than the SPOT multispectral bands. Meanwhile, the SWIR bands have a 30-m resolution whereas, the TIR subsystem operates with resolution of 90-m. ASTER is on demand instrument which are not routinely recorded unless a special request is received. ASTER data is rather affordable compare from other sensor. Plus, if the user has excess to the broadband the data delivery via Internet is rather quick and efficient and it is similar to Landsat TM data as ASTER server as the continuation of TM data.

Table 2.3 Characteristics of ASTER Spectral Bands

Characteristics	VNIR	SWIR	TIR
Ground resolution at nadir (m)	15	30	90
swath width (km)	60	60	60
Data rate (Mbps)	62	23	4.2
Cross-track pointing (^{0})	±24	±8.55	±8.55
Cross-track pointing (km)	±318	±116	±116
Quantization (bits)	8	8	12

Source: Gao (2009)

2.5.3 LANDSAT Data

According to the author Gao (2009), on 23 June 1972, the first landed satellite has launched by the National Aeronautics and Space Administration (NASA) accompanied remote sensing into the space era. In Figure 2.10 shows latest Landsat Data Continuity Mission of Landsat-8. This, Landsat images has evolved towards higher spatial and finer spectral resolution for a long term monitoring application that collect an astounding quantity of data that are crucial. Form Table 2.4 and Table 2.5 show the orbital characteristics of Landsat from Landsat 1 to 7. Additionally, this satellite is essential in studying changes on Earth, in land cover and the environment making this Landsat one of the suitable data collection for this research study. Interestingly, this Landsat satellite is the first unmanned which design specifically to acquire medium resolution, multispectral data about the Earth on a systematic and repetitive basis.

Figure 2.10 Landsat Data Continuity Mission, Landsat-8
Source: NASA (2015)

Table 2.4 Orbital Characteristic of Landsats 1, 2, and 3

Height	915km (880-940)
Inclination	99º
Period	103 min
Revolution	14 per day
Speed	6.47 km/s
Distance between successive tracks at the equator	2760 km
Distance between orbits	159.38 km
Repeat cycle	18 days
Overlap at the equator	14%
Time of equatorial crossing	9:42 a.m.
Total IFOV	11.56º
Orbit type	Circular, sun-synchronous

Source: Gao (2009)

Table 2.5 Orbital Characteristics of Landsat 4, 5 and 7

Altitude	705 km
Period	98.9 min
Total FOV	14.92^{0}
Inclination	98.2^{0}
Repeat Cycle	16 days (233 revolutions)
Orbit Type	sun-synchronous polar
Equatorial crossing time	10:00 a.m.

Source:Gao (2009)

2.5.4 MODIS Data

From Terra and Aqua satellites, there also another key sensor aboard that is Moderate Resolution Imaging Spectro-radiometer (MODIS) instrument. MODIS data has swath dimension of 2330 x 10 km that enable to scan using cross-track scanning as shown in Table 2.6. This is because of the combination of total Field Of View (FOV) of $\pm 55^{o}$ with satellite altitude. MODIS has the advantages on covering the entire Earth for 1 to 2 days. The MODIS multispectral radiometer captures solar radiation over the wavelength in 36 spectral bands at three spatial resolutions ranging from 250 m to 1000 mm. MODIS bands used to differentiate according to their spatial resolution. According to the Goa (2009), band 1-7 have the applicable on differentiate land from cloud and study of the boundaries and the properties of aerosol, instead for band 8-16 has the benefit on study the ocean, especially on colour and phytoplankton. Meanwhile, the remaining bands are suited in determine the atmosphere element such as cloud and ozone. Thus, MODIS data not only applicable on the study of the Earth surface, but also all about the oceanography biology and atmosphere.

Table 2.6 Characteristic of MODIS Data

Swath dimension	2330 x 10 km (at nadir)
Spatial resolution	250 m (bands 1-2) 500 m (bands 3-7) 1000 m (bands 8-36)
Spectral resolutions	36 bands covering 0.4-14.4 μm
Quantization	12 bits
Revisit period	1-2 days
Equatorial crossing	10:30 a.m. descending node (Terra) or 1:30 p.m. ascending node (Aqua)
Data rates	10.6 Mbps (peak daytime); 6.1 Mbps (orbital average)
Applications	Land/cloud/aerosols Ocean color/ phytoplankton/ biogeochemistry atmospheric water vapour, surface/ cloud temperature/ cloud properties/ ozone

Source: NASA (2008)

2.5.5 IRS Data

India National Space program is the third major player in remotely sensing the Earth's surface for resources mapping. Since the last 1980, the IRS program has witness the launch of a series of satellites with a repeat cycle of 22 days. IRS has 3 types of satellite that is IRS-1A and IRS-1B. IRS-1A was launched on 17 March 1988 and followed by IRS-1B on 29 August 1991 into an orbit of 905km with an inclination of 99^o. This satellite has set of orbital parameters such as near polar and sun-synchronous orbit.

An IRS satellite which is also called Linear Imaging Self-Scanning Sensor (LISS) has the sensor aboard named Different. There contain a series of LISS sensors. LISS-1 has a spatial resolution of 72m and a swath width of 146km. Whereas LIS-II has two separate imaging sensors, LISS-IIA and LISS-IIB at a spatial resolution of 36.25 m each as shown in Table 2.7. Jointly, they provide a composite swath width of 146. 98

km. This first generation of sensors contains four spectral bands, three visible and one NIR (Gao, 2009).

IRS-1C and IRS-1D represent the second generation of IRS series are launched on 28 December 1995 and 28 September 1997 respectively (Gao, 2009). There were design with an enhanced resolution and capability. That is IRS-1C has a near polar, sun-synchronous orbit at an altitude of 817 km at the local north to south equatorial crossing time of 10.30 a.m. According to NRSA (1995), the satellite completes about 14 revolutions around the Earth per day and has repeat cycle 24 days consist 3 sensor one panchromatic (PAN) camera, one LISS-III sensor, and one Wide Field Sensor (WiFS).

On 17 October 2003, IRS has expanded to include Resourcesat-1 followed the ground track of the IRS-1C satellite. Not only that, its payload namely LISS-III, LISS-IV and Advanced (AWiFS) similar to that IRS-C and D satellites. Moreover, LISS-III is identical to the previous satellites but for LISS-IV has sensor that operates in two modes, which multispectral and monospectral. For multispectral mode, all three visible and near infrared (VNIR) spectral band covers a swath with width of 23 km within a total swath of 70 km. Whereas for the monospectral also known panchromatic mode, has a single band at spatial resolution of 5.8 m a full of swath of 70 km. While for AWiFS operates in four spectral bands. This AWiFS is specifically designed for agricultural applications and Earth resources and both image have a nadir resolution of 56 m with a 5-day repeat cycle.

Unfortunately, from the above characteristics, the first generation of IRS has limited application outside the India. This is because of the absence of ground station to receive the data of IRS. Not only that, there are no established data vendors that selling the IRS data (Gao, 2009). Instead, over the year, the second generation of IRS has undergo a huge improvement in term of quality, stereo viewing capability added and the shortened of the repeat period.

Table 2.7 Orbital Characteristic of IRS Satellites

Parameter/Satellite	**IRS-1A AND 1B**	**IRS-1C,-1D**	**Resourcesat-1**
Height (km)	905	817	817
Inclination	99^0	98.6^0	98.59^0
Period (min)	103	101.35	101.35
Revolution	14 per day	About 14 per day	14 per day
Orbit type	Sun synchronous, near polar	Sun synchronous	Sun synchronous
Repeat cycle (days)	22	5-24	5-25
Time of equatorial crossing	9:40 a.m.	10:30 a.m.	10:30 a.m.
Sensor aboard	LISS-I,LISS-IIA,LISS-IIB	LISS-III,PAN,WiFS	LISS-III,LISS-IV,AWiFS

Source:Gao (2009)

2.5.6 ALOS Data

Advanced Land Observing Satellite (ALOS) was launched on 24 January 2006 has the orbit type of sun synchronous which design for precise land observation over the optical and microwave portion of the spectrum. Its payload comprises three sensors, the Panchromatic Remote Sensing Instrument for Stereo Mapping (PRISM), the Advanced Visible and Near Infrared Radiometer type 2 (AVNIR-2), and the Phase Array type L-band Synthetic Aperture Radar (PALSAR). In PRISM sensor, there consist of 3 independent optical systems for forward, nadir, and backward observations in the long-track direction.

Panchromatic images are acquired along the satellite track with a base to height ration of 1.0 in this forward-nadir-backward stereo mode a swath width of 35 km on the ground is covered at spatial resolution of 2.5 m (Gao, 2009). This width rises to 70 km in the nadir in only viewing mode. Through pointing the telescope side away, the normal repeat cycle of 46 days can be reduced up to 2 days. Besides that, stereoscopic PRISM data can be used to construct highly accurate and to produce topographic maps of the world at a scale less than 1:25000.

AVNIR-2 is visible and not only that it has NIR imaging radiometer of four multi spectral bands at a spatial resolution of 10m at nadir. In this position the swath width 70 km is scanned along the track. For quickly monitoring natural disasters, such as earthquakes, fires, volcanic eruptions and oil spills.

Next, PALSAR is an L-band (1.27GHz) sensor designed to succeed the Synthetic Aperture Radar (SAR) sensor aboard the Japanese Earth Resources Satellite-1 (JERS-1) satellite with improved functionality (JAXA, n.d.). This sensor is able to operate in either high resolution mode or the ScanSAR mode and on Table 2.8 shows the ScanSAR sensor characteristics.

Table 2.8 Major Characteristics of ALOS Imagery

			PALSAR	
Sensor	**PRISM**	**AVNIR-2**	**High Resolution**	**ScanSAR**
Spatial resolution (m)	2.5	10	10	100
Swath width (km)	35-70	70	70	250-350
Point angle (^{0})	+/-24	+/-44	10-51	10-51
Number of looks	3	Flexible	2	8
Polarization			HH, VV, HH & HV, VV & VH	HH,VV
Data transmission rate (Mbps)	960	160	240	240

Source:Gao (2009)

CHAPTER 3

METHODOLOGY

3.1 Introduction

Research methodology is very important part that must be done to complete the study. Research is known as the systematic investigation and study material that done by researcher to create facts and provided new conclusions about it. Usually, research was done to find a solution of the problem that exists in our life. Based on Rajasekar et al. (2013), research is important both scientific and non-scientific fields where scientists must carry out research on problem occurred in order to find their causes, solutions and explanation.

In this chapter, there are three different sources of data that will be used to delineate watershed boundaries for the analysis. One watershed boundary will be manually digitized by using topographic map from Department of Irrigation and Drainage Malaysia (DID). Besides that, watershed boundaries will also be derived from three DEMs, ASTER and SRTM-30m and SRTM-90m. To add on, the ArcGIS software was utilized to analyse the difference between DEMs and DID.

In addition, the data collection will be analysed to compare visually the three watershed boundaries. Method that was used is Euclidean Distance tools in ArcGIS. This tool was used to measure the straight-line from each cell to the closet source. Thus, to obtain the differences in distance between DEMs boundaries and DID. Finally, the accurate data source can be determined.

3.2 Flow Chart of Methodology

Figure 3.1 shows the flow chart of the methodology for this study that is Comparison of Watershed Boundaries Delineation for Kuantan River Basin, from the zero to the end:

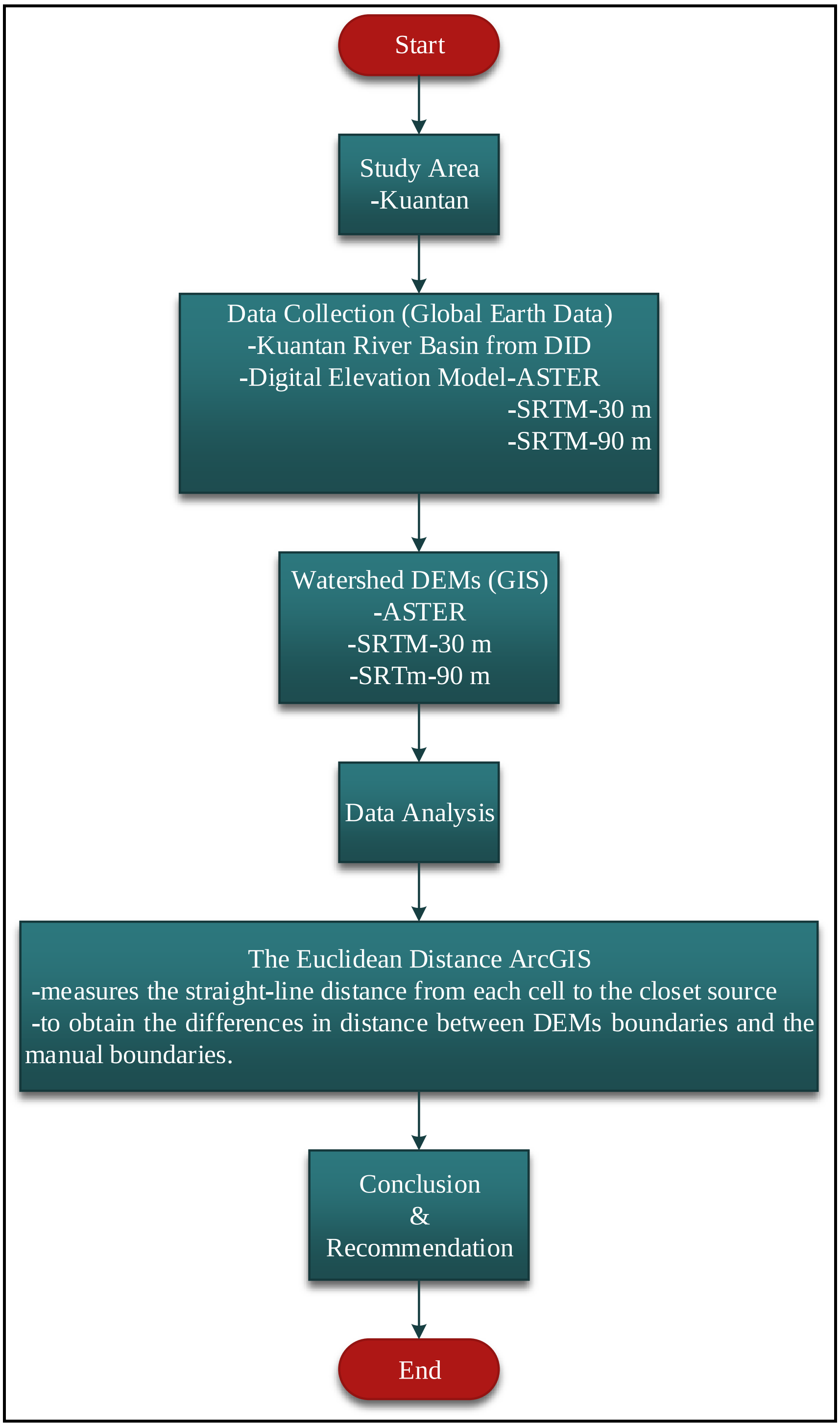

Figure 3.1 Flow Chart of Methodology

3.3 Study Area

Kuantan is the administrative center and the capital of the State of Pahang with a total area of 2,453 km² and an estimated number of population of over 500,000 people. Additionally, Kuantan is an emerging city in the east coast region and is connected via:

i. East Coast Highway (LPT)

ii. Highway Kuantan - Pekan

iii. Highway Kuantan - Kemaman

There are several basins in Kuantan region which are Balok River basin, Cherating River basin, Chendur River basin, Nyuir River basin, Beserah River basin, Penur River basin and Kuantan River basin as shown in Figure 3.2. For this study, Kuantan River basin (Figure 3.3) will be selected as the study area.

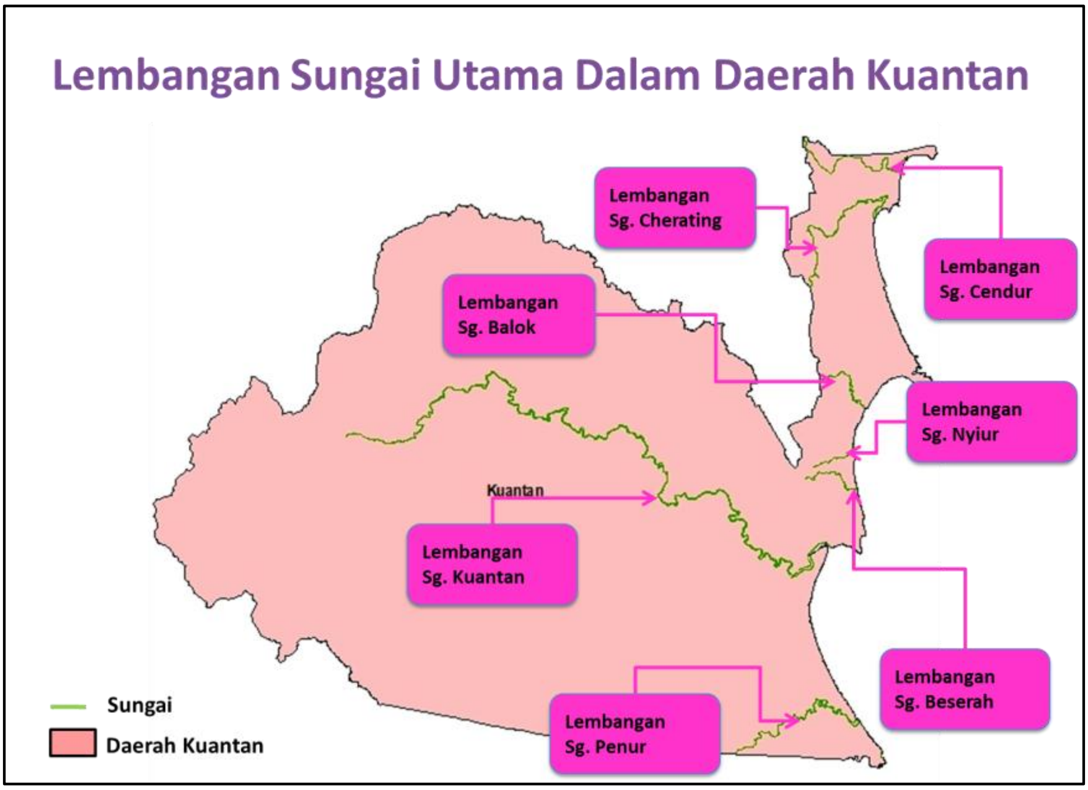

Figure 3.2 The main river basins in the area of Kuantan
Source: jps@komuniti (2011)

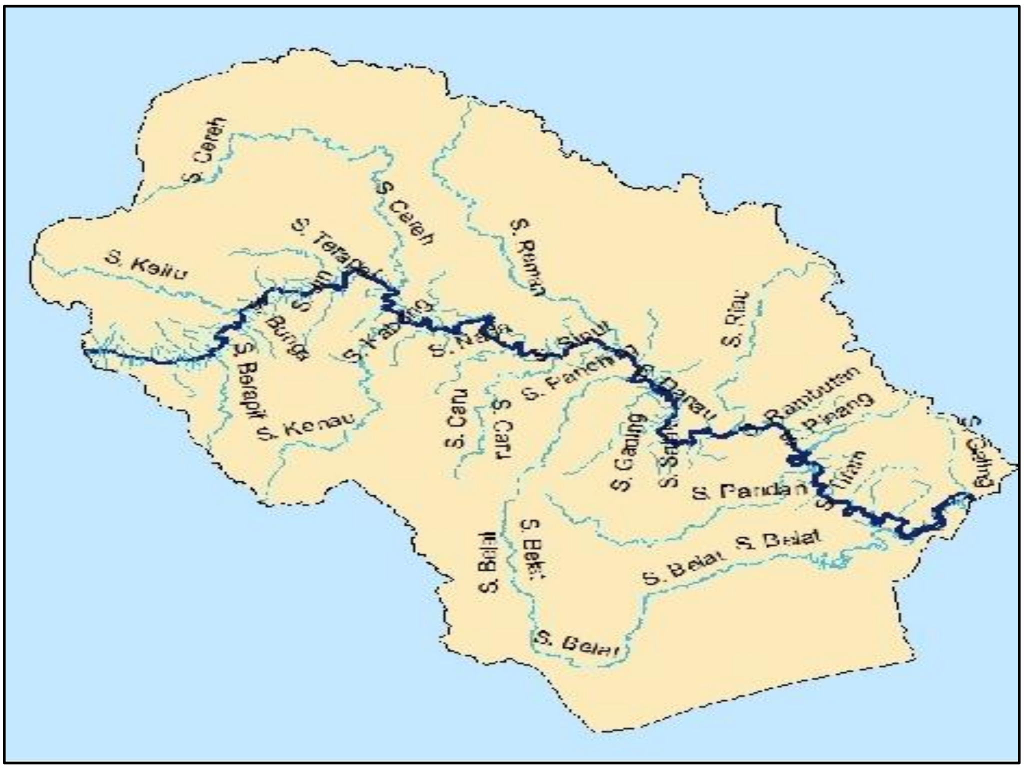

Figure 3.3 Kuantan River Basin
Source: DID (n.d)

Besides that, in Kuantan River Basin (Figure 3.3), there are tributaries that connected to Kuantan River. Almost 20 tributary connected to Kuantan River. Such as Galing River, Belat River, Pandan River and etc.

3.4 Data Collection

For data collection, two Digital Elevation Models (DEMs) were selected that are Shuttle Radar Topography Mission (SRTM) and Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) will be chosen among the six lead sensors. This is because the SRTM and ASTER elevation data can be achieved from LP DAAC Global Data Explorer as shown in Figure 3.4 (https://gdex.cr.usgs.gov/gdex/), which is open access and free to public user. There are also others website that can retrieved these DEMs such as Earth Explorer, NASA Reverb, and J-spacesystems ASTER GDEM Page.

Moreover, these two DEMs also provide high resolution. Resolution here refers to the size of the smallest feature observable in the data. SRTM offers two resolutions that are 3 arc-second resolution for all extents of global coverage and 1 arc-second for the U.S. and U.S. Territories. Meanwhile, for ASTER, it only offers one resolution in geographic decimal coordinates (latitude and longitude) and posted on 1-arc-second equivalent to 30m.

Furthermore,these two DEMs are designed to stduy Earth resources which have collecting data on nearly 80 percent of Earth's land. Not only that, they have gathered high-resolution images of landforms and topography affected by major weather events on Earth, including tsunamis, earthquakes and floods.

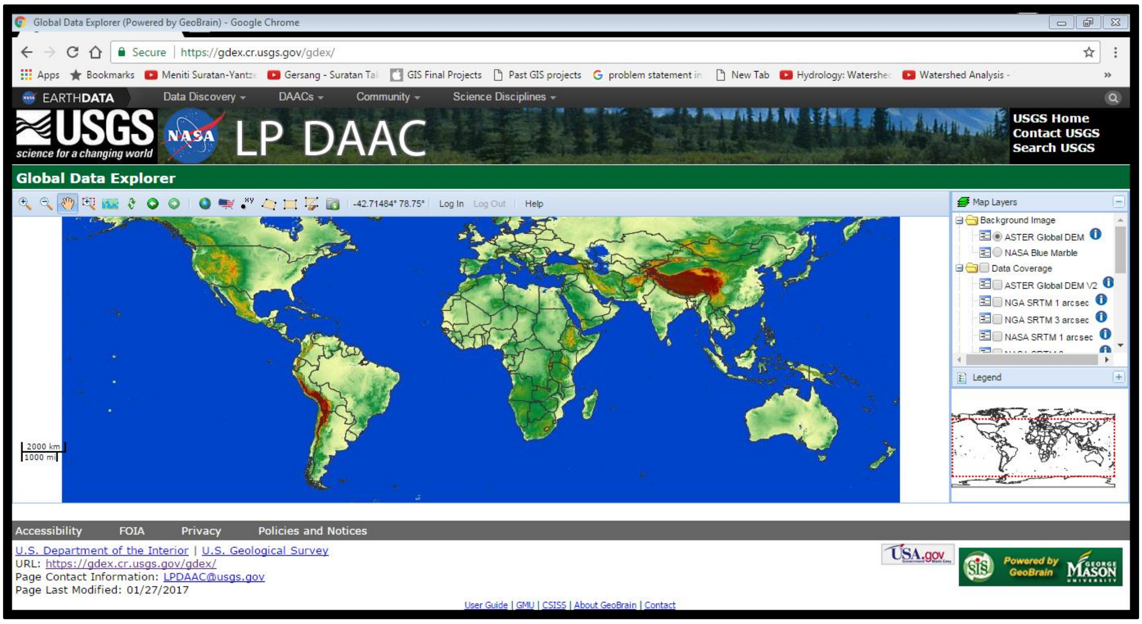

Figure 3.4 Digital Elevation Models Map

Source: LP DAAC (n.d.)

3.5 Data Analysis

Geographic information systems (GIS) have become a useful and important tool in hydrology in the scientific study and management of water resources. Climate change and greater demands on water resources require a more knowledgeable disposition of arguably one of our most vital resources.

A watershed is a spatial area, and the occurrence of water throughout its space varies by time. In the hydrologic budget are inputs such as precipitation, surface flows in, and groundwater flows in. All of these quantities, including storage, can be measured or estimated, and their characteristics can be graphically displayed in GIS.

Thus, GIS software is applied in this research to digitize the watershed boundaries and analyse the differences in distance in DEMs and DID.

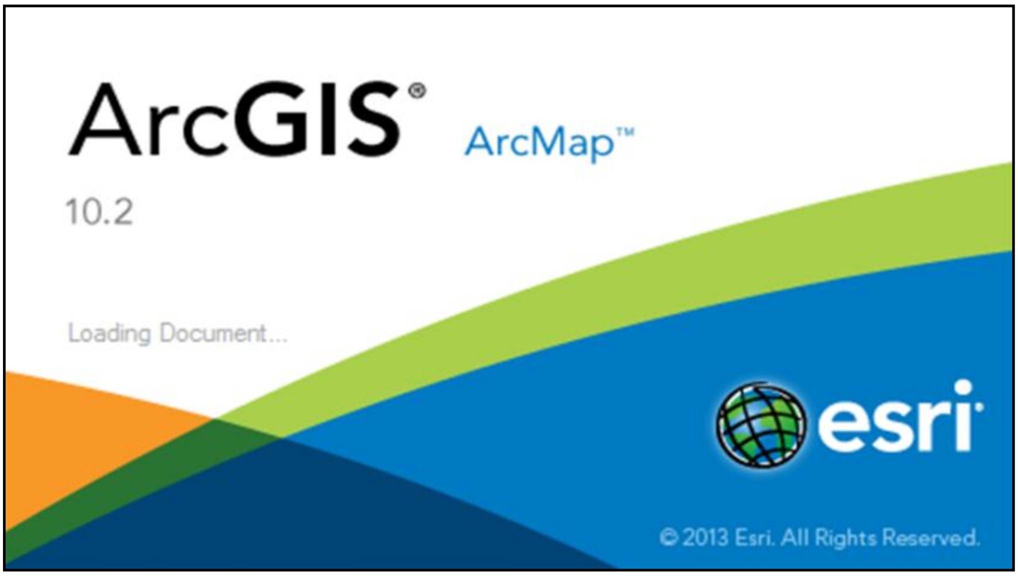

Figure 3.5 ArcGIS software
Source: ESRI

3.5.1 Watershed Delineation Process

Watershed delineation has been developed using Geographical Information System (ArcMap 10.2). The GIS technique for watershed delineation consists of the following steps below as shown in Table 3.1. By using Spatial Analyst Tools, the watershed boundaries were vectorized for further analysis and comparison.

Table 3.1 Tools used to delineate watershed

Tools	Purpose
spatial analyst tools	
fill	fills sinks in a surface raster to remove small imperfections in the data
flow direction	creates a raster of flow direction from each cell to its steepest downslope neighbour
flow accumulation	creates a raster of accumulated flow into each cell. A weight factor can optionally be applied.
conditional	performs a conditional if/else evaluation on each of the input cells of an input raster.
basin	creates a raster delineating all drainage basins
arc-catalog shapefile(point)	creates a point in form of shapefile to mark the oulet point
snap pour point	snaps pour points to the cell of highest flow accumulation within a specified distance
watershed	determines the contributing area above a set of cells in a raster
conversion tools	
raster to polygon	converts a raster dataset to polygon features

3.5.2 Euclidean Distance Tools

Watershed derived from 3 difference sources is compared visually with DID. From Pryde et al (2007) said the Euclidean Distance Tools was used to measure the straight line distance from each cell to the closet sources. Thus, to obtain the differences in distance between DEMs boundaries and DID. For analysis, a total of 5 point for every 4 segment (north, east, south and west) is taken on each DEMs and DID to calculate the differences of the nearest distance between them. From this difference in distance, the descriptive statistic were generated from excel to define the accuracy between DEMs.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

In order to complete this study, result and finding an outcome for this study and the reason for the particular result in form of text, figure graphics and chart will be stated and analysed. Inherent in GIS data is information on the attributes of features as well as their locations. This information is used to create maps that can be visually analysed. Next, statistical analysis will extract additional information from GIS data that might not be obvious by simply looking at a map. Statistical analysis reveals the characteristics of a set of features as a whole.

This chapter comprises the analysis, presentation and interpretation of the findings resulting from this study. The analysis and interpretation of data is carried out in one phase which will be through statistical analysis from Euclidean distance tools in ArcGIS and with the help of Microsoft Excel software. The Euclidean Distance ArcGIS helps to measures the straight-line distance from each cell to the closet source and to obtain the differences in distance between DEMs boundaries and DID boundaries. Meanwhile, Microsoft Excel helps to analyze through descriptive statistics analysis.

Digital Elevation Model (DEMs) with open access has many advantages and disadvantages. Especially those DEM data are free to access and have their own limitation and different accuracies. These DEMs will be compared with Kuantan River Basin that retrieved from DID to check the highest accuracy between DEMs that is suitable to use in Malaysia particularly for Kuantan River Basin.

4.2 ASTER

From the Figure 4.5, it shows the comparison of Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) and Department of Drainage and Irrigation (DID) data has a very huge difference and seems that all the ASTER's line varies with DID data. From ASTER Global Digital Elevation (GDEM), ASTER covers land surfaces between 83°N and 83°S and is composed of 22,600 1°-by-1° tiles (Aster Global Digital Elevation Model (GDEM)). Tiles that contain at least 0.01% land area are included. Moreover, it is in GeoTIFF format with geographic lat/long coordinates and a 1 arc-second (30 m) grid of elevation postings. Pre-production estimated accuracies for this global product were 20 meters at 95 % confidence for vertical data and 30 meters at 95 % confidence for horizontal data (Aster Global Digital Elevation Model (GDEM)). The perimeter and area produced from ASTER is 268 km and 1,559 km^2 respectively. Compared with DID, the perimeter is 238 km and area is 1,685 km^2. It shows that watershed area for ASTER is (7.49%) smaller than DID watershed area.

Initial validation studies concluded that the ASTER generally meets the pre-production accuracy predications, but results vary and include areas where ASTER accuracy does not meet the pre-production estimates (Aster Global Digital Elevation Model (GDEM)). This, is one of the factor that boundary near Soi River (Figure 4.2) varies a lot from DID. Besides that, the topography of the land surface is one of the most fundamental geophysical measurements of the Earth, and it is a dominant controlling factor in virtually all physical processes that occur on the land surface. As ASTER has a negative bias in flat and gentle regions(Wong, Tsuyuki, Ioki, & Phua, 2014). Thus, this factor may affect the area with low topographical area. Even though, it has negative bias toward low region, ASTER has several advantages, including good correlation over vegetated area and high spatial resolution (Pakhale & Gavit, 2010).

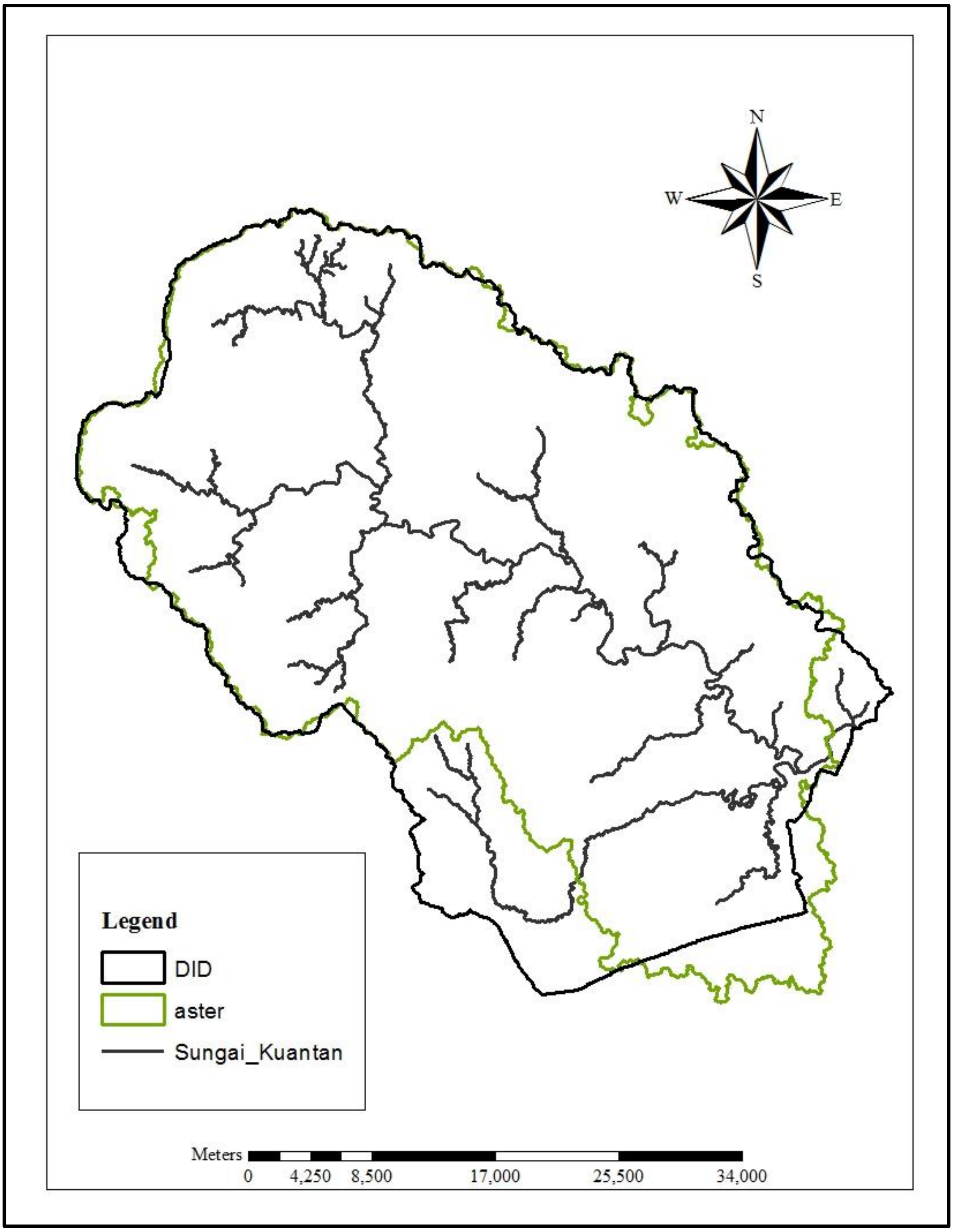

Figure 4.1 Comparison of watershed boundaries produced from ASTER and DID

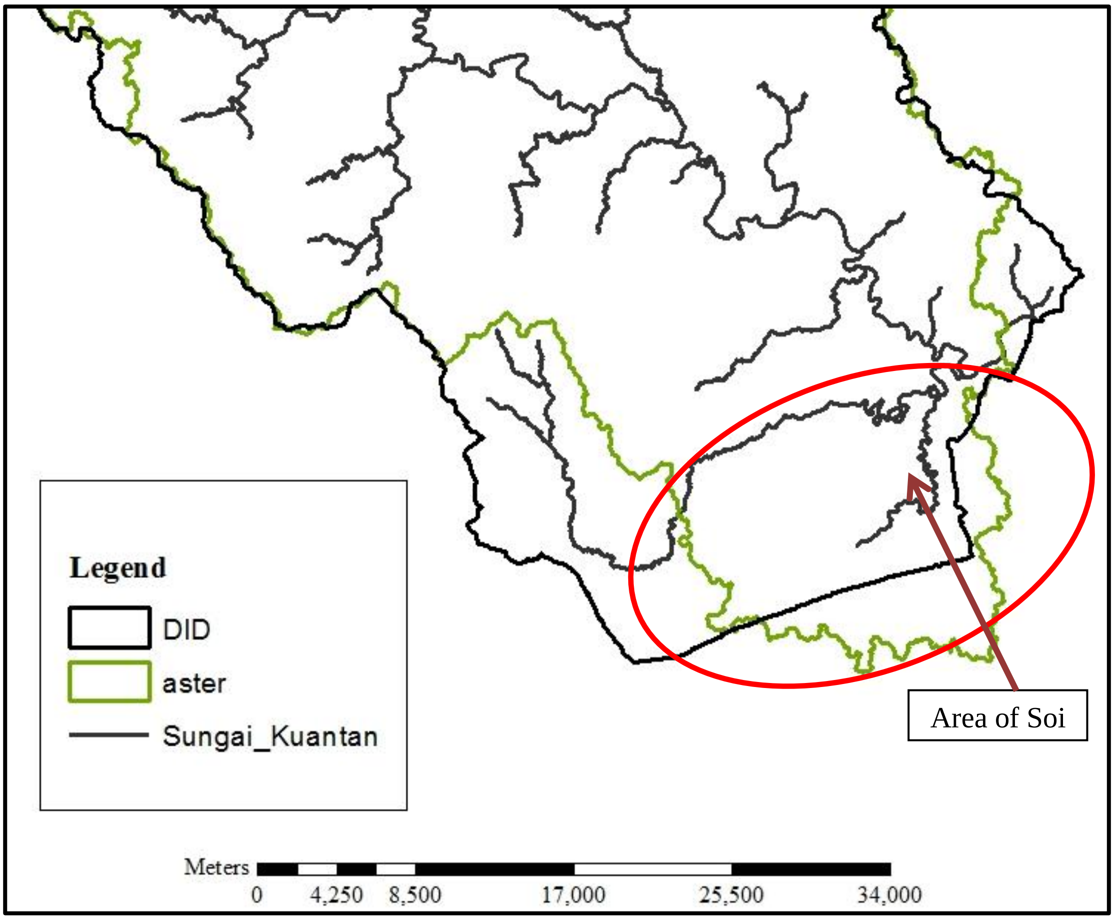

Figure 4.2 The boundaries line varies around the area of Soi River

4.3 SRTM-30 m

By late 2015, the highest-resolution topographic data generated from NASA's Shuttle Radar Topographic Mission (SRTM) in 2000 was to be released globally which has been announced by the White House in September 23, 2014. Additionally, the announcement was made at the United Nations Heads of State Climate Summit in New York. From that onward, all global SRTM data have been released and the schedule was accelerated as stated by (Jet Propulsion Laboratory).

From the figure 4.3, it shows the comparison of Shuttle Radar Topographic Mission with 1-arc-second global resolution (30 meters @ 98 feet) and DID data which has a clear view and seems that all the SRTM's line overlap with DID data. The perimeter and area produced from SRTM-30 m is 234 km and 1,629 km^2 respectively. Compared with DID, the perimeter is 238 km and area is 1,685 km$^{2.}$ It shows that watershed area for SRTM-30 m is (3.36%) smaller than DID watershed area.

Although, it has high resolution with full resolution (Jet Propulsion Laboratory, 2000) the term "resolution" refers to the size of the smallest feature observable in the data; there are still some parts of Kuantan river basin that cannot be observable due to the low terrain area. For instance, the most noticeable region is the area of Soi River as shown on Figure 4.4.

Furthermore, note that small stream channels are discernible only in the 30-meter data and larger stream channels are much more clearly characterized by the 30-meter data (Lavoie, 2014). Which indicate that Soi river has lower elevation than 30-meter. Stream channel patterns control water supply and stream-related natural hazards, such as flash floods. The 30-meter data can improve the study of such concerns here and elsewhere around the world. Lastly, SRTM elevation data are also used in nearly every scientific discipline concerned with the environment near Earth's surface, as well as in many civil applications, such as land use planning.

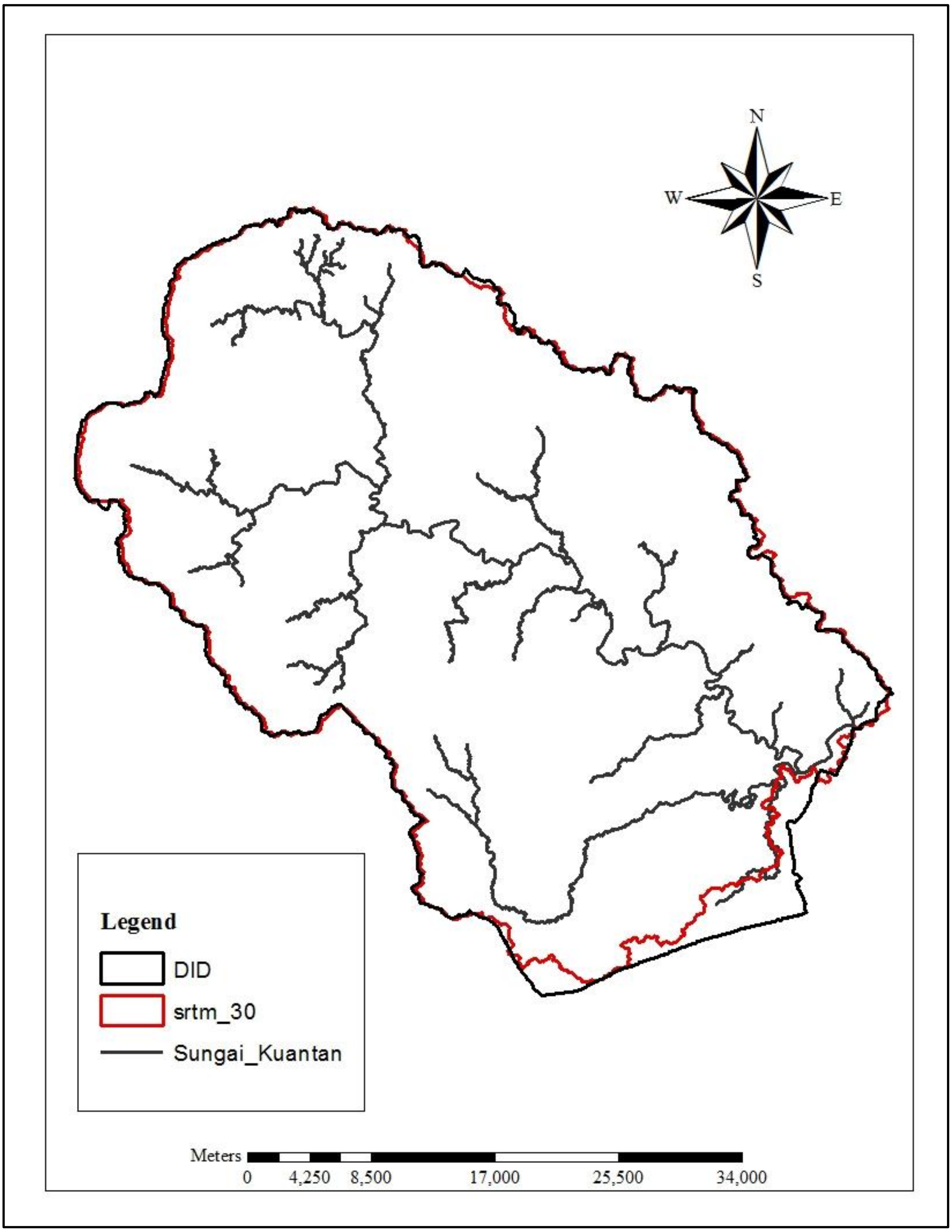

Figure 4.3 Comparison of watershed boundaries produced from SRTM-30 m and DID

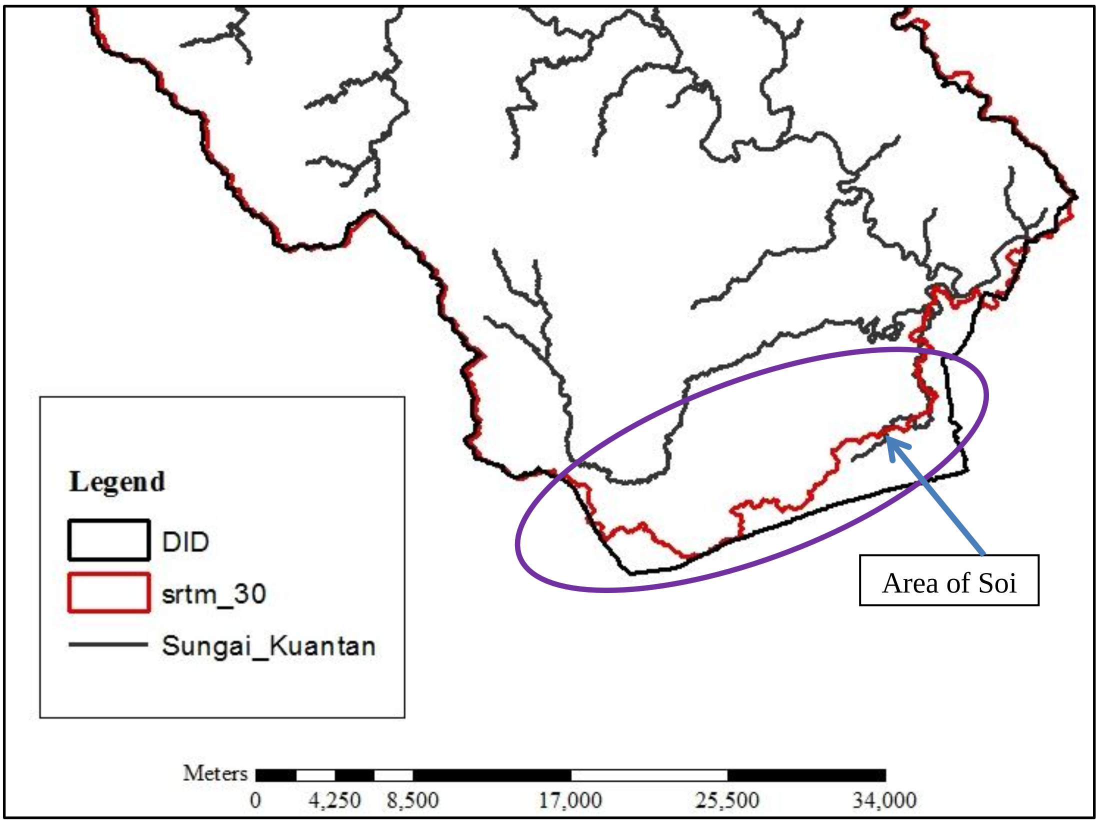

Figure 4.4 The boundaries line varies around the area of Soi River

4.4 SRTM-90 m

From the Figure 4.5, it shows the comparison of Shuttle Radar Topographic Mission (SRTM) with 3-arc-second global resolution (90 meters @ 295 feet) and DID data which has a clear view and seems that all the SRTM's line overlap with DID data. For most of the world, SRTM data were originally made publicly available at a three-arc-second pixel size (1/1,200 of a degree of latitude and longitude), which is about 90 meters (295 feet) (Lavoie, 2014). The perimeter and area produced from SRTM-90 m is 215 km and 1,633 km^2 respectively. Compared with DID, the perimeter is 238 km and area is 1,685 km^2. It shows that watershed area for SRTM-90 m is (3.12%) smaller than DID watershed area.

Although, it has high resolution with full resolution that revealed by much smaller of 90-m pixels, in short, the term "resolution" refers to the size of the smallest feature observable in the data (Jet Propulsion Laboratory, 2000); there are still some parts of Kuantan river basin that cannot be observable due to the low terrain area. For instance, the most noticeable region is the area of Soi River as shown on Figure 4.6. Thus, 90-meter pixels were too large to display the full resolution of the SRTM DEM.

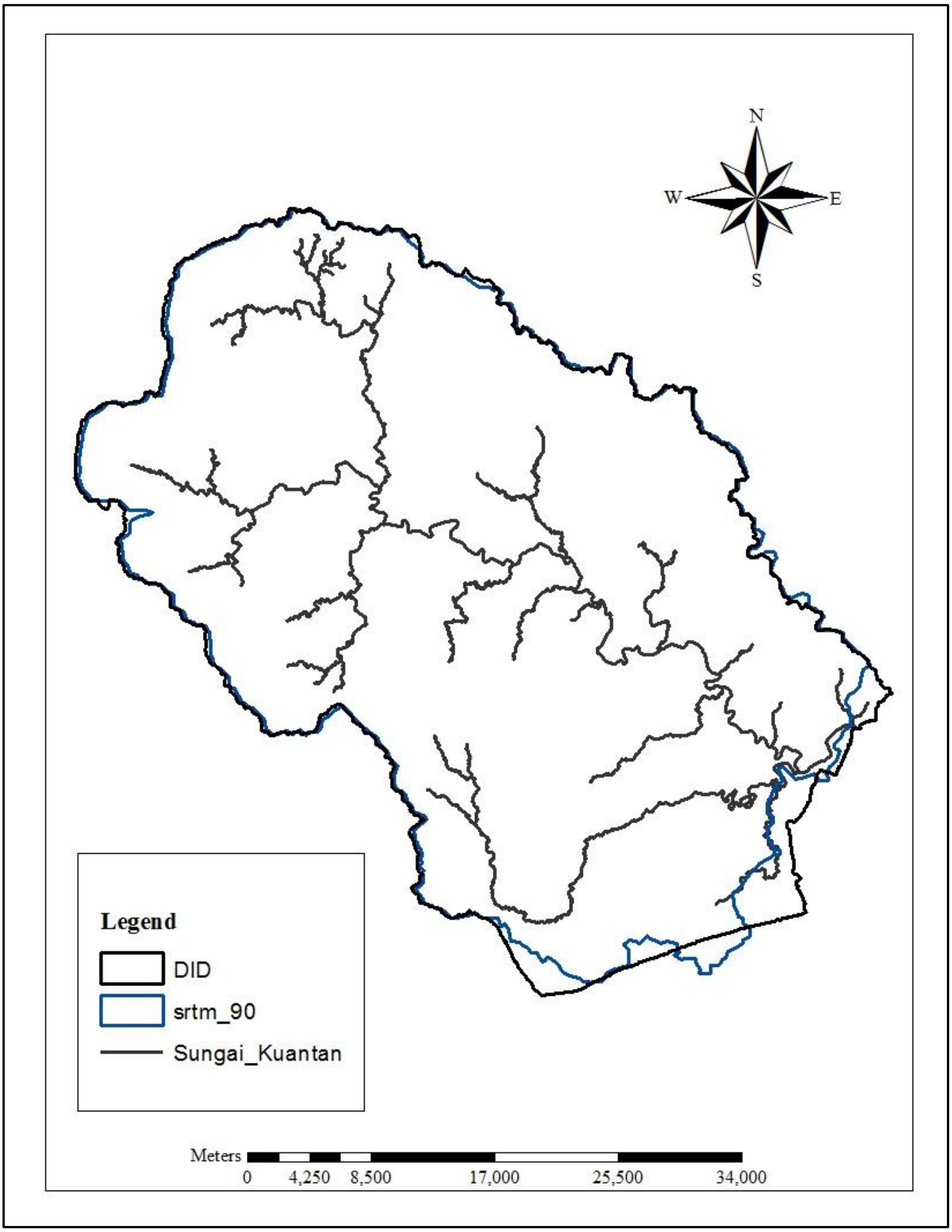

Figure 4.5 Comparison of watershed boundaries produced from SRTM-90 m and DID

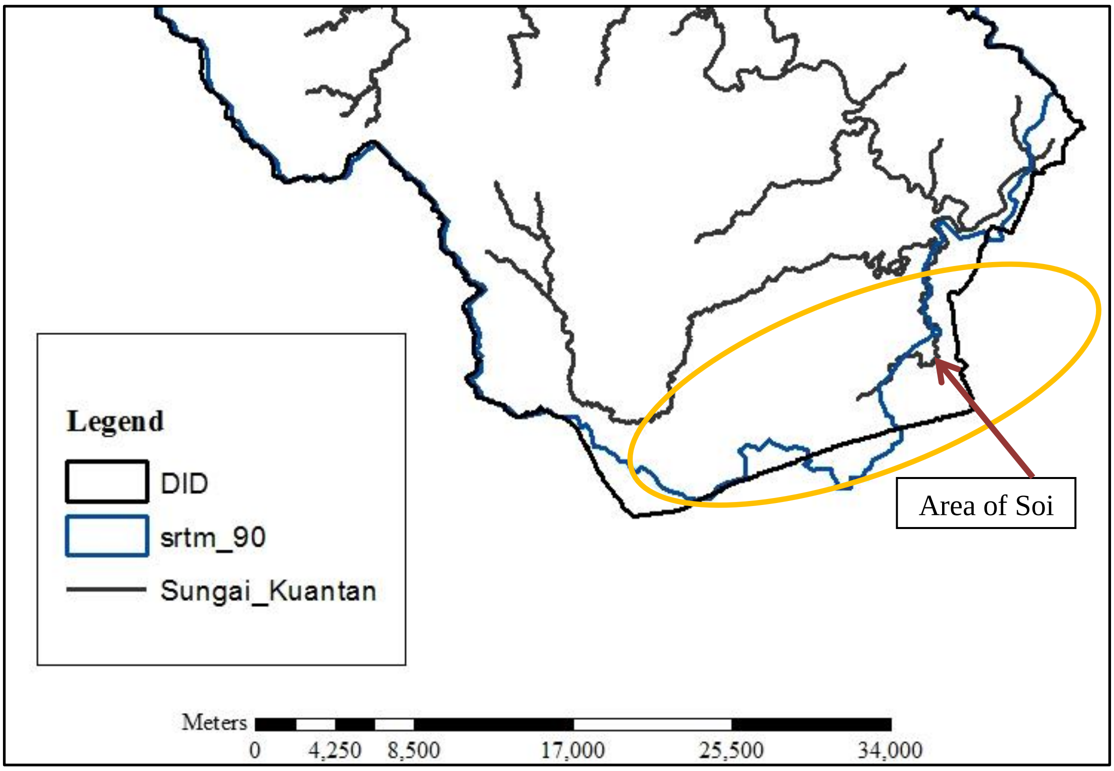

Figure 4.6 The boundaries line varies around the area of Soi River

4.5 Analysis from Descriptive Statistic

There are small different between Kuantan River basin (KRB) from DID and the SRTM watershed boundaries (Figure 4.7) while the ASTER boundaries varies a lot from DID. The area of watershed boundaries from DID is 1,685 km^2, while the SRTM-30 m based watershed area is 1,629 km^2, for SRTM-90 m based, the area of watershed is 1,633 km^2 and lastly the ASTER based watershed area is 1,559 km^2 which is smaller than DID boundary.

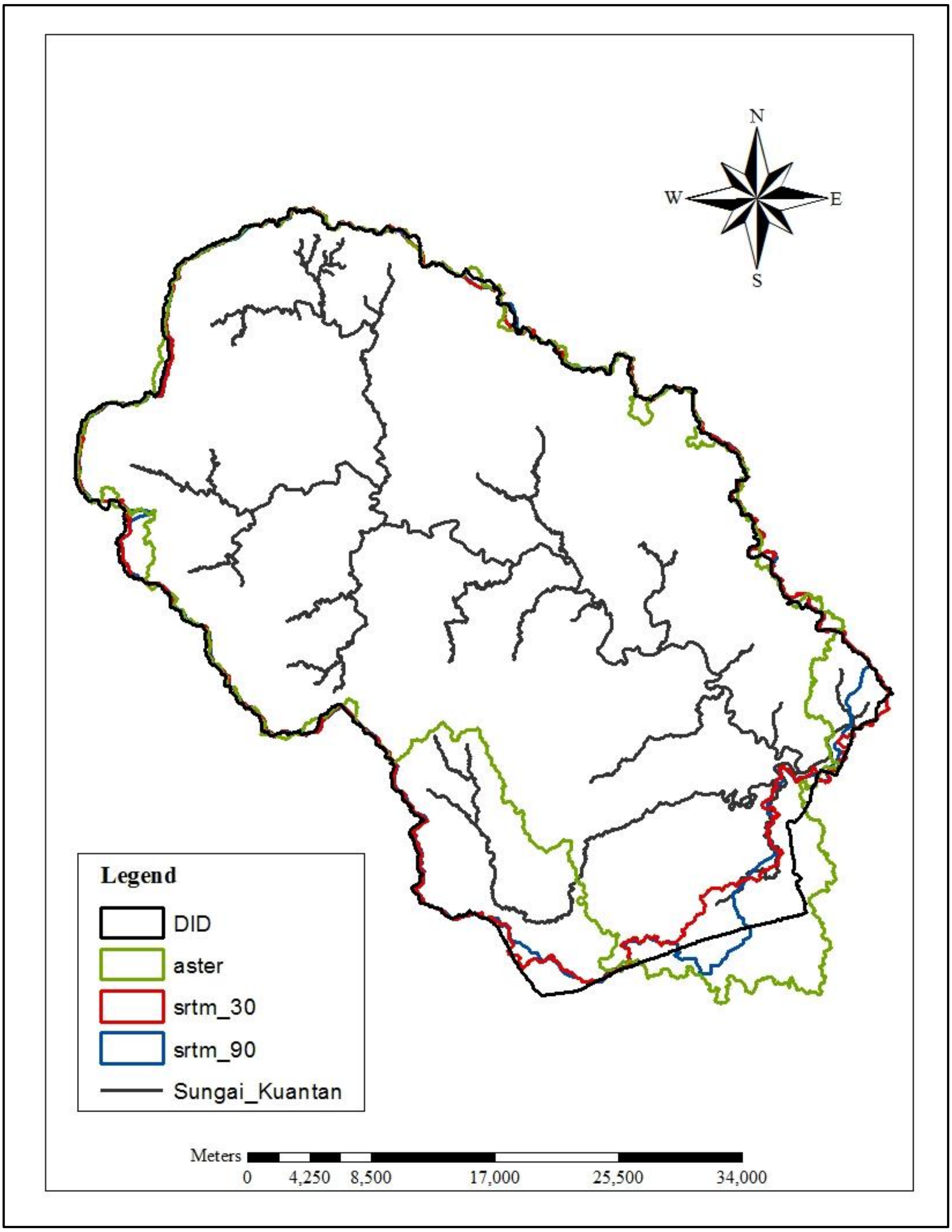

Figure 4.7 Comparison of watershed boundaries produced from Digital Elevation Models (DEMs) and DID

4.5.1 ASTER

Analysis of watershed boundaries between ASTER and DID is compared visually. A total of 20 points on ASTER and DID are taken. DID is subject as benchmark to compare the accuracy between DEMs. The points taken are to measure the nearest distance between DID and the DEMs (Table 4.1). Here, the points are divided into 4 segments that are north, east, south and west and each segment have 5 points. Thus, from this segment, the affected area can be detected. From Figure 4.8 the affected area that can be seen clearly is on south area.

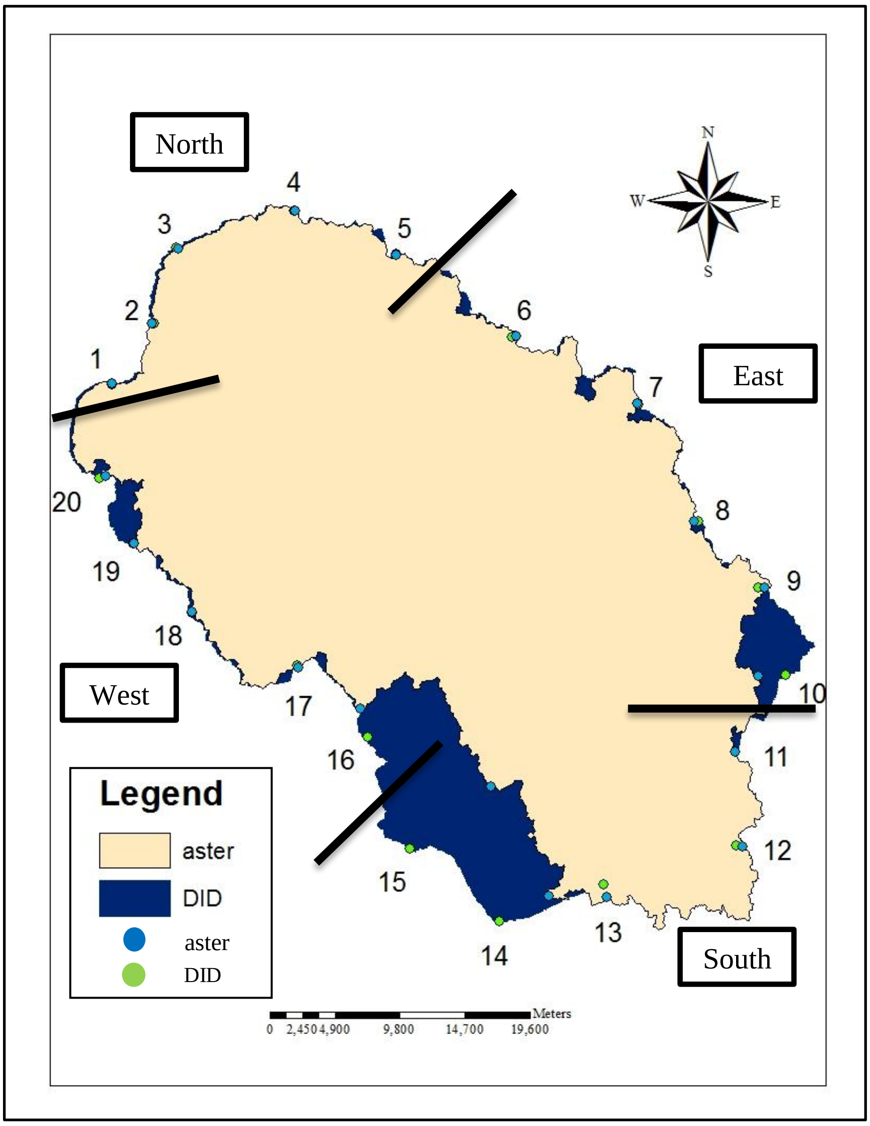

Figure 4.8 20 points on ASTER and DID

Table 4.1 Coordinates Distance Between Points

Segment/DEM	DID MAP		ASTER		
Coordinates	x	y	x	y	Distance between coordinates (m)
North					
1	543793.969	443122.158	543819.090	443189.202	71.596
2	546939.444	447683.532	546815.656	447713.018	127.251
3	548663.749	453412.637	548815.106	453318.927	178.018
4	557567.096	456185.436	557630.270	456216.076	70.212
5	565209.876	452920.844	565239.579	452889.904	42.890
				Average =	97.994
East					
6	573959.728	446696.148	574308.967	446716.021	349.804
7	583541.312	441549.000	583421.233	441643.911	153.059
8	588070.182	432739.354	587740.389	432740.546	329.795
9	592569.689	427747.550	593051.490	427739.328	481.871
10	594632.250	421156.050	592597.429	421090.781	2035.868
				Average =	670.079
South					
11	590781.181	415332.482	590781.181	415332.482	0.000
12	590905.841	408306.548	591336.490	408214.505	440.375
13	580891.913	405348.530	581107.844	404363.096	1008.814
14	573032.652	402577.704	576760.709	404516.572	4202.097
15	566256.056	408027.571	572415.690	412744.425	7758.209
				Average =	2681.899
West					
16	563082.031	416438.978	562572.479	418583.523	2204.250
17	557783.196	421893.479	557838.121	421732.788	169.819
18	549803.412	425869.216	549829.905	425898.526	39.509
19	545397.113	431075.750	545456.248	431074.382	59.151
20	542870.814	436006.073	543329.529	436153.697	481.884
				Average =	590.922

4.5.2 SRTM-30 m

Analysis of watershed boundaries between SRTM-30 m and DID is compared visually. A total of 20 points on SRTM-30 m and DID are taken. DID is subject as benchmark to compare the accuracy between DEMs. The points taken are to measure the nearest distance between DID and the DEMs (Table 4.2). Here, the points are divided into 4 segments that are north, east, south and west and each segment have 5 points. Thus, from this segment, the affected area can be detected. From Figure 4.9 the affected area that can be seen clearly is on south area.

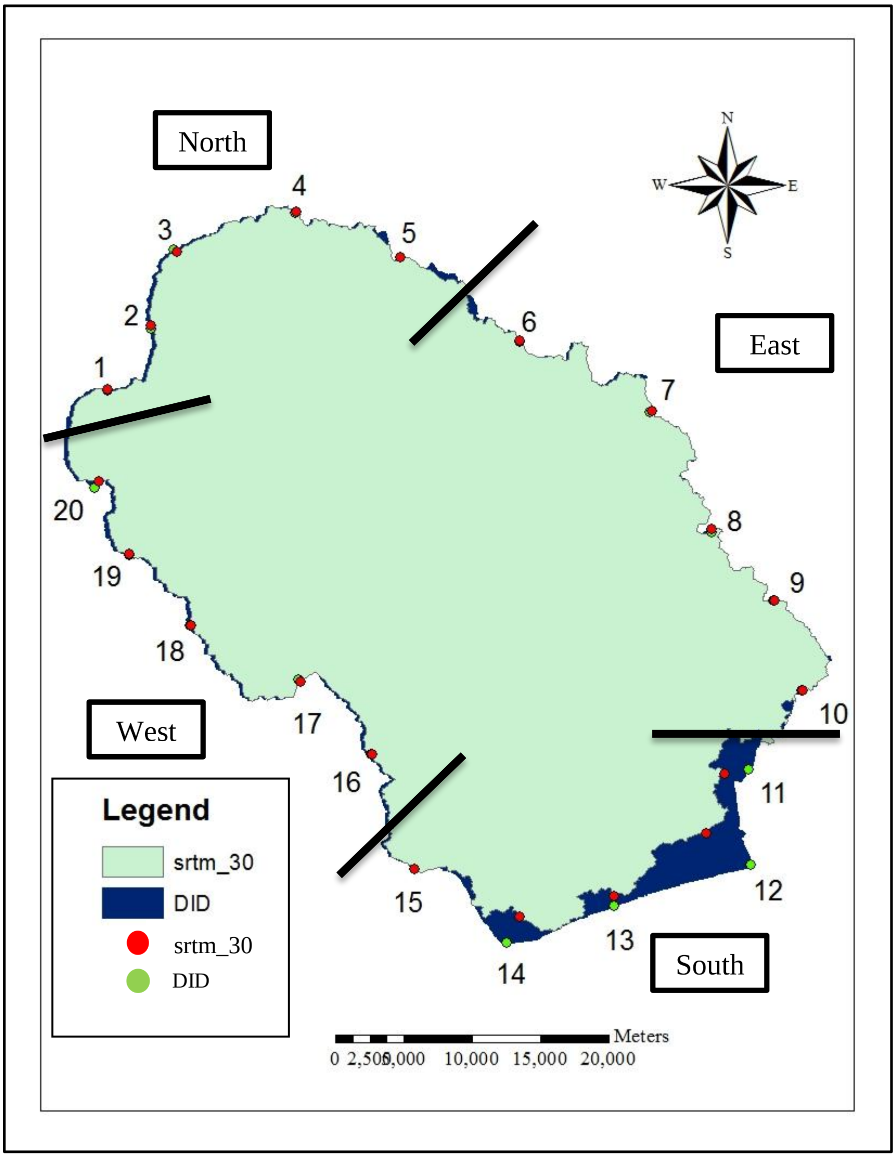

Figure 4.9 20 points on SRTM-30 m and DID

Table 4.2 Coordinates Distance Between Points

Segment/DEM	DID MAP		SRTM-30 m		
Coordinates	x	y	x	y	Distance between coordinates (m)
North					
1	543793.969	443122.158	543794.416	443215.440	93.283
2	546939.444	447683.532	546997.424	447897.031	221.232
3	548663.749	453412.637	548846.877	453320.810	204.861
4	557567.096	456185.436	557623.238	456252.386	87.374
5	565209.876	452920.844	565239.594	452888.559	43.880
				Average =	130.126
East					
6	573959.728	446696.148	573985.435	446759.401	68.277
7	583541.312	441549.000	583662.502	441608.069	134.819
8	588070.182	432739.354	588009.826	432983.363	251.363
9	592569.689	427747.550	592660.973	427685.229	110.529
10	594632.250	421156.050	594730.250	421127.981	101.941
				Average =	133.386
South					
11	590781.181	415332.482	588964.879	415022.136	1842.625
12	590905.841	408306.548	587683.177	410597.524	3954.002
13	580891.913	405348.530	580921.262	406025.455	677.561
14	573032.652	402577.704	573958.561	404483.813	2119.094
15	566256.056	408027.571	566256.056	408027.571	0.000
				Average =	1718.656
West					
16	563082.031	416438.978	563205.194	416439.176	123.163
17	557783.196	421893.479	557939.031	421770.045	198.798
18	549803.412	425869.216	549896.798	425898.441	97.852
19	545397.113	431075.750	545366.846	431138.213	69.410
20	542870.814	436006.073	543146.339	436435.314	510.061
				Average =	199.857

4.5.3 SRTM-90 m

Analysis of watershed boundaries between SRTM-90 m and DID is compared visually. A total of 20 points on SRTM-90 m and DID are taken. DID is subject as benchmark to compare the accuracy between DEMs. The points taken are to measure the nearest distance between DID and the DEMs (Table 4.3). Here, the points are divided into 4 segments that are north, east, south and west and each segment have 5 points. Thus, from this segment, the affected area can be detected. From Figure 4.10 the affected area that can be seen clearly is on south area.

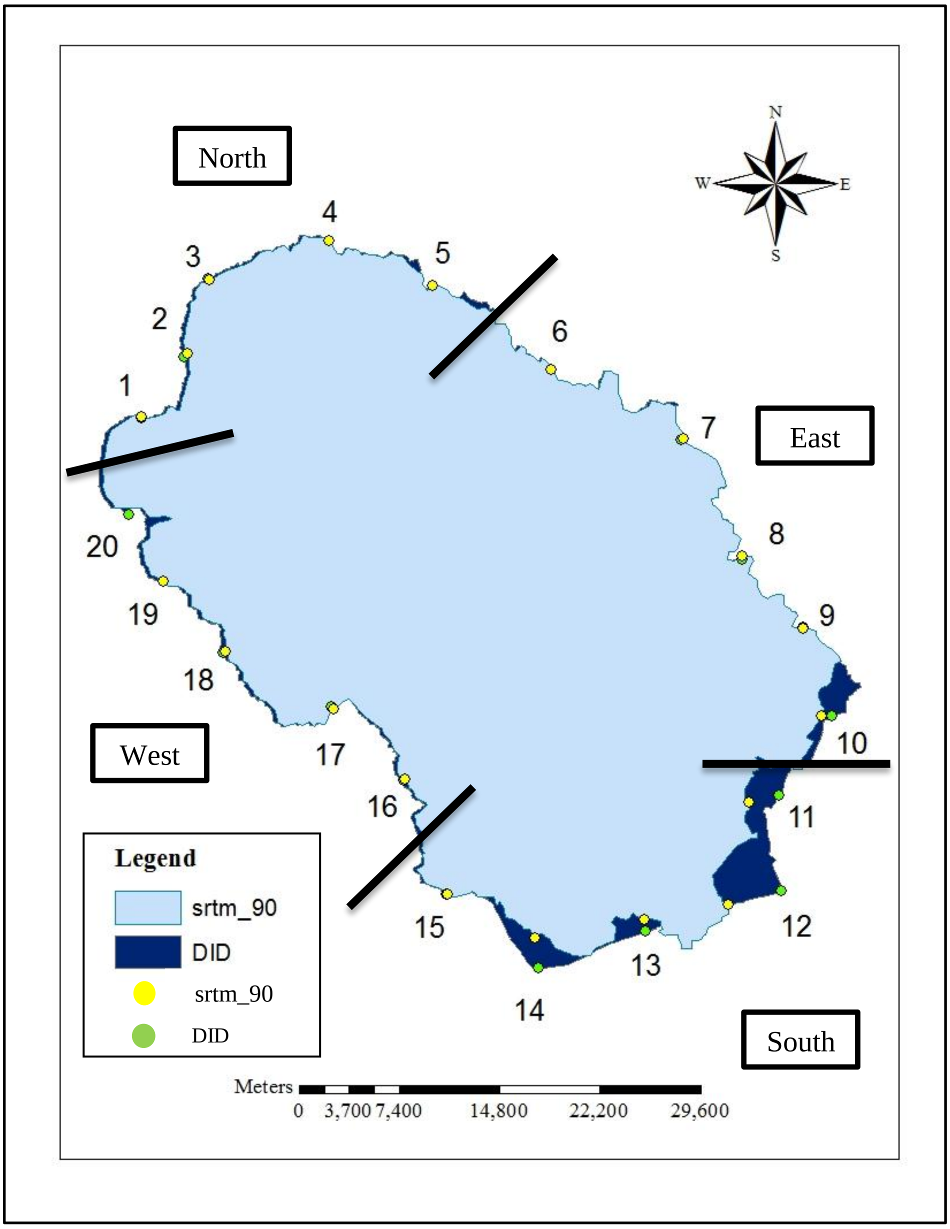

Figure 4.10 20 points on SRTM-90 m and DID

Table 4.3 Coordinates Distance Between Points

Segment/DEM	DID MAP		SRTM-90 m		
Coordinates	x	y	x	y	Distance between coordinates (m)
North					
1	543793.969	443122.158	543795.142	443245.244	123.092
2	546939.444	447683.532	547122.968	447867.613	259.936
3	548663.749	453412.637	548754.987	453287.984	154.476
4	557567.096	456185.436	557568.452	456216.376	30.970
5	565209.876	452920.844	565208.503	452889.194	31.680
				Average =	120.031
East					
6	573959.728	446696.148	573959.728	446696.148	0.000
7	583541.312	441549.000	583693.522	441610.891	164.312
8	588070.182	432739.354	588042.421	432953.067	215.509
9	592569.689	427747.550	592570.112	427627.603	119.948
10	594632.250	421156.050	593923.683	421216.978	711.182
				Average =	242.190
South					
11	590781.181	415332.482	588564.030	414868.222	2265.236
12	590905.841	408306.548	586990.610	407257.821	4053.253
13	580891.913	405348.530	580859.700	406182.633	834.725
14	573032.652	402577.704	572788.316	404855.502	2290.865
15	566256.056	408027.571	566286.945	408060.666	45.270
				Average =	1897.870
West					
16	563082.031	416438.978	563207.221	416503.775	140.965
17	557783.196	421893.479	557965.949	421709.488	259.329
18	549803.412	425869.216	549958.386	425930.047	166.485
19	545397.113	431075.750	545398.958	431105.784	30.091
20	542870.814	436006.073	542931.930	436530.239	527.717
				Average =	224.917

The size of watershed may vary depending upon size of a stream (Kumar & Dhiman, 2014)It was observed that the manual (DID) and automated (DEMs) approach initially resulted in dissimilar watersheds shows on (Table4.4). The manual approach was observed as tedious, time consuming and had limitations as it required inputs in the form of topographic maps, which is a sometimes difficult to procure(Kumar & Dhiman, 2014). The precise delineation of watersheds also requires understanding of water divide on maps and geo-informatics related skills. In contrast, the inputs required for automatic delineation of watersheds are freely available and doesn't require much skilled knowledge. Besides, the user also gets a faster result. The watershed boundary line generated using automated approach is smoother compared to manually delineated watersheds.

Table 4.4 Descriptive statistics of DEMs between differences in parameters

Parameters/DEMs	ASTER	SRTM-30 m	SRTM-90 m	DID
Perimeter (km)	268	234	215	238
Area (km^2)	1,559	1,629	1,633	1,685
% Difference in Perimeter	+ 12.61%	-1.68%	-9.66%	-
% Difference in Area	-7.48%	-3.32%	-3.09%	-

Next, from the by segment analysis as shown in Table 4.5, which consist north, east, south and west, ASTER indicates highest average distance between coordinates with north 97.994 m, east 670.079 m, south 2681.899 m and west 101.224 m. While for SRTM-30 m, the north area is 130.126 m, east 133.386 m, south 1718.656 m and west 199.857 m. From the third DEM which is SRTM-90 m, north 120.031 m, east 242.190 m, south 1897.870 m, west 224.917 m. As conclusion, all DEMs have problem on south segment. Around south segment it shows highest average distance between coordinates which indicate bad result as the points distance far from each other. This, may due to the negative bias of DEMs and low penetration around that area (Wong et al., 2014). While, on north segment shows lowest average distance between coordinate which means most of the point are close to DID this may be due to the high spatial resolution of the DEMs (Pryde et al., 2007)

Table 4.5 Average distance between coordinates on each segment

	Average Distance Between Coordinates		
Segment/DEMs	**ASTER**	**SRTM-30 m**	**SRTM-90 m**
North	97.994	130.126	120.031
East	670.079	133.386	242.190
South	2681.899	1718.656	1897.870
West	590.922	199.857	224.917
TOTAL	1010.224	545.506	621.252

*unit in meters

The Euclidean Distance ArcGIS tools that measures the straight-line distance from each cell to the closet source were used to obtain the statistical descriptions of the differences in distance between DEMs and the manual boundary which are summarized in Table 4.6. From Table 4.6, it shows SRTM-30 m has the lowest average number of different in distances between DEMs that is 545.506 m. This indicates that the lower the average number, the nearer the distance between DEM and DID. While the standard deviation, measures how spread out number are between points on DID and DEMs. Again, SRTM-30 m shows lower standard deviation whereas ASTER shows highest standard deviation with 1898.256 m. For the maximum value in different in distance it shows that SRTM-30 has lowest value with 3954.002 m while SRTM-90 m with 4053.253 m and lastly, ASTER with 7758.209 m has highest maximum value between DEMs.

Table 4.6 Descriptive statistics of DEMs between the differences in distance and limits (DID)

Parameters/DEMS	ASTER	SRTM-30 m	SRTM-90 m
Mean	1010.224	545.506	621.252
Standard Error	424.463	221.089	234.433
Median	253.907	128.991	165.399
Mode	#N/A	#N/A	#N/A
Standard Deviation	1898.256	988.741	1048.416
Sample Variance	3603375.794	977608.194	1099175.774
Minimum	0	0	0
Maximum	7758.209	3954.002	4053.253

*unit in meters

4.6 Summary

From the analysis, it shows that SRTM-30m has a lot in common with DID data in term of perimeter of Kuantan River Basin (KRB). Unfortunately, for ASTER differ a lot especially on the bottom of the right side of the KRB this may due to the low region on that area, which DEM cannot accurately penetrate below its ability. Thus, it will just assume the boundary on that area. Lastly, for the SRTM-90 m has a bit different with SRTM-30 m also on the low region of area Soi River. In conclusion, all DEM has problem gathering accurate data on low region area.

CHAPTER 5

CONCLUSION

5.1 Introduction

This chapter will provide a summary of the purpose, methodology, and results of this study. Then, conclusions will be discussed based on research insights gained regarding study findings and limitations. In addition, recommendations will be proposed for future study of this matter of issues.

5.2 Conclusion

The watersheds boundaries from 3 differences Digital elevation Models (DEMs) are successfully delineated by using GIS software. The accuracy of the watershed boundaries on DEMs is highly dependent on the accuracy and good quality of Digital Elevation Model available (DEM).

SRTM-30 m data have several advantages such as provide important fundamental data for topographic analysis in many fields. Not only that, it has the highest resolution topographic dataset ever produced for the Earth’s land surface. As for SRTM-90 m, it has a slight different from SRTM-30 m due to the different in resolution. Meanwhile, ASTER data has higher spatial resolution and wider coverage than the SRTM-30 m but have negative bias toward flat region.

From the analysis, it shows SRTM-30 m has the lowest average number of different in distances between DEMs that is 545.506 m. This indicates that the lower the average number, the nearer the distance between DEM and DID. While the standard deviation, measures how spread out number are between points on DID and DEMs.

Again, SRTM-30 m shows lower standard deviation whereas ASTER shows highest standard deviation with 1898.256 m. For the maximum value in different in distance it shows that SRTM-30 has lowest value with 3954.002 m while SRTM-90 m with 4053.253 m and lastly, ASTER with 7758.209 m has highest maximum value between DEMs.

Next, from the by segment analysis, which consist north, east, south and west, ASTER indicates highest average distance between coordinates with north 97.994 m, east 670.079 m, south 2681.899 m and west 101.224 m. While for SRTM-30 m, the north area is 130.126 m, east 133.386 m, south 1718.656 m and west 199.857 m. From the third DEM which is SRTM-90m, north 120.031 m, east 242.190 m, south 1897.870 m, west 224.917 m. As conclusion, all DEMs have problem on south segment. Around south segment it shows highest average distance between coordinates which indicate bad result as the points distance far from each other. While, on north segment shows lowest average distance between coordinate which means most the point are close to DID.

Finally, SRTM-30 m appears to have highest accuracy with 1.68% difference in perimeter and 3.32% difference in area compared to DID and suitable to be used in Kuantan.

5.3 Recommendation

The recommendations that can be made from this study are first, the uses of ArcGIS 10.2 software should be widely used in the field of civil engineering like geotechnical, environmental, etc. Not only that, SRTM-30 m can be used as DEM for delineate watershed boundary. Inaccessibility to the 1 arc second resolution SRTM-30 m was also one limitations of this study that could help in assessment of the degree of the terrain detail loss when it is averaged to 3 arc second resolutions DEM. Moreover, further study on flat terrain can be enhanced and the negative bias on ASTER toward low region can be corrected. Lastly, further study are recommended on the DEMs quality (detailed terrain features) effect after the model is calibrated for more accurate DEM that can generated from very high resolution sources likes LIDAR and IKONOS with much focus on the model setup, calibration and validation.

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