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A Comparative Study of Delineated Watersheds Using ASTER and SRTM in Johor, Malaysia

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Abstract

The availability of watershed delineation that has been generated from DEM data is difficult to obtain and the accessibility of DEM data which are unrestricted and precise are hard to obtain in Malaysia. The aim of this study is to examine the accuracy of watershed delineation between Digital Elevation Model (DEM) from ASTER and SRTM in Johor State Malaysia. In this study, free online data sources from USGS website are used to delineate watershed from ASTER and SRTM satellite imageries. The hydrological modelling tool namely ArcSWAT is utilized to delineate watersheds for both DEM datasets. Both DEM data that had been mosaiced using ERDAS imagine and their DEM is generated using ArcGIS. Watershed boundary for the whole Johor State is then being delineated by using ArcSWAT. ASTER and SRTM accuracies were verified using correlation analysis and mean center distance with data from Department of Irrigation and Drainage (DID). Study indicated that DID watershed area is correlated to ASTER and SRTM at 67.60% and 67.85%. While for DID watershed perimeter demonstrated that it is related to ASTER and SRTM at 60.33% and 61.71%. ASTER watershed number displayed better result compared to SRTM at 97.27%. In addition, total mean center distance for ASTER and SRTM are 148.485 and 200.200 where it shows the total mean center distance of ASTER is almost close with DID. Area difference for ASTER is related to SRTM at 95.35% and perimeter difference for ASTER is associated to SRTM at 98.60%. The results from this study have successfully indicated that both ASTER and SRTM DEMs are suitable for watershed delineation for Johor State at free and reliable sources.

Keywords

Watershed, Delineation, DEM, ASTER, SRTM

1 INTRODUCTION

Hydrological modelling such as watershed delineation have been used for various purposes such as to manage and control water quality. Watersheds can be processed using Digital Elevation Model (DEMs) data and river line data. The utilization of Geographic Information System (GIS) and remote sensing (RS) in the industry have brought about the accessibility of DEMs. The DEM data can be extracted from various sources of data mainly satellite imageries and conventional surveying method. With improved advanced technologies, watersheds can now be delineated faster.

An integrated data analysis and modelling are required in watersheds management. This includes hydrological, geological and biological processes(Pryde et al. 2007). It is fundamental to find ways to expedite action and management of these processes, especially with large dataset. It is typical that large size of watershed is due to large water bodies. The planimetric area of watershed can be calculated from demarcation and delineation of watersheds boundaries. However, it is usually a challenge to do so without the development of remote sensing and GIS. This advancement of remote sensing and GIS have stimulated and widen the use of watershed modelling internationally (Ghoraba 2015). GIS is indeed the right tool for the effective administration of complex and large database and to contribute to the digital representation of watershed features that has been used in such models. According to Ghoraba (2015), GIS is guaranteed in the reliability of modelling by producing more typical approach in accordance with watershed conditions, defining the proficiency of the modelling process and watershed features, and in time, help to escalate the approximation ability of hydrological modelling. Additionally, DEM has largely been used in numerous ways for hydrological modelling due to the current growth of technologies. DEM is needed not only to generate watershed boundaries, other than that it can be used for flood stimulation and surface runoff study.

The importance of this research is to guide users in generating watershed using data sources that are reliable and free to obtain. This can save time and money for the users. Moreover, this study is to examine if freely available data can be used to process delineation of watershed in large area and to assess the accuracy of the data in hydrological studies. Furthermore, being able to assist researchers in choosing the most appropriate size of resolution for the image to generate watershed delineation in large area is of importance aspect. Therefore, the aim of this study is to examine the reliability of watershed delineation between ASTER and SRTM Digital Elevation Model (DEM) in the state of Johor, Malaysia. Objectives of the study include generating watershed and river using ASTER and SRTM, to evaluate its performance between both DEM in performing watershed boundary delineation, and finally to compare the accuracy of both DEM in terms of correlation analysis, mean center distance, area difference and perimeter difference.

2 LITERATURE REVIEW

Watersheds can be defined as a region of land that draw off rain water into different locations such as to wetland, pond, stream, and other waterways (Gilland et al. 2009).

During the occurrence of rain, water from raining will move over throughout agriculture land, forest, and urban land area before finally entering waterways. This resulted in the land and water to make up a watershed system. These watersheds will come in different number of sizes, where usually the large watershed is produced from large waterbodies. Watershed is essential in filtering for runoff that will happen during rain or snowmelt and provide water sources for drinking, irrigation, and other industries.

Contour map can be digitized and further processed to produce DEM aside from data that are collected by means of remote sensing techniques such as satellite imageries and arial photos (Hosseinzadeh 2011). DEM can be used to visualize surfaces such as viewing its topographic area in the form of digital content. Additionally, DEM provide a convenient way in viewing topographic surface in digital form and has been used widely. Another more commonly used term to represent topographic surface is digital terrain model (DTM). DEM however provide a successful method in representing ground surface and allow an automated extraction in a direct way for hydrological features. This resulted in added benefit for cost effectiveness, processing capability, and accuracy assessment as compared to conventional methods such as field survey, paper topographic maps and photographic interpretations (Vaze et al. 2010).

There are several sources for free online DEM data and one of them is Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER). According to Thome (2017), the image resolution of this data ranges from 15 to 90 square metres and has 14 different electromagnetic spectrum bands. ASTER dataset can be used in various applications such as in monitoring the land surface temperature (LST) and the elevation value from ASTER data can be used to derive slope, aspect, and watershed boundary of an area.

Other than that, Shuttle Radar Topography Mission (SRTM) is also a well-known source for DEM. SRTM has captured the elevation on near global scale using two synthetic aperture radars which are C-band system and an X-band system with 90 metres and 30 metres image resolution. The goal of C-RADAR is to generate connecting mapping coverage whereas the X-RADAR create data along separate strips with 5km wide (Kramer 2017). These strips will offer close to connecting coverage at higher latitudes.

DEMs and topographic data are generally obvious and useful in creating hydrological modelling. However, acquiring the data and information is strictly insufficient and most users highly rely on published DEMs or topographic maps that were published by government agencies such as Department of Survey and Mapping Malaysia (JUPEM) and Department of Irrigation and Drainage (DID) (Rusli and Majid 2012). There are also several ways in getting the hand of elevation data such as on-site measurement like detail survey to create contour map and topographic map. This however takes a lot of time and may be costly and tedious for a large area, especially to turn topographic map from government agencies to a digital DEM data.

According to Rusli and Majid (2012), there are lacking of free and accurate DEM data in Malaysia. Until today, the awareness of data sharing among the agency and personnel is still low. Several approaches have been used to obtain the elevation value such as digitizing the contour lines form topographic map, generating DEM from unmanned aerial vehicle (UAV), LiDAR and also via surveying technique (traversing and levelling). Various sources of DEM data that have been used in previous studies to delineate the watershed boundary (Ahmadi et al. 2012; Anornu et al. 2012; Gamett 2010; Trisakti and Carolita 2010). Watershed delineation is important and has been made use of for many reasons, for example, watershed delineation allows us to study water quality, to create hydrological modelling, water management and many more.

3 METHODOLOGY

Area of interest for this study is in the state of Johor, Malaysia. With a size of approximately 19,210km^2, Johor is situated in the southern region of Malaysia, center coordinate is 2° 6'11.02"N and 103°19'1.25"E as shown in Figure 1. It has 21 rivers and plays an integral part in providing water to neighboring country, Singapore.

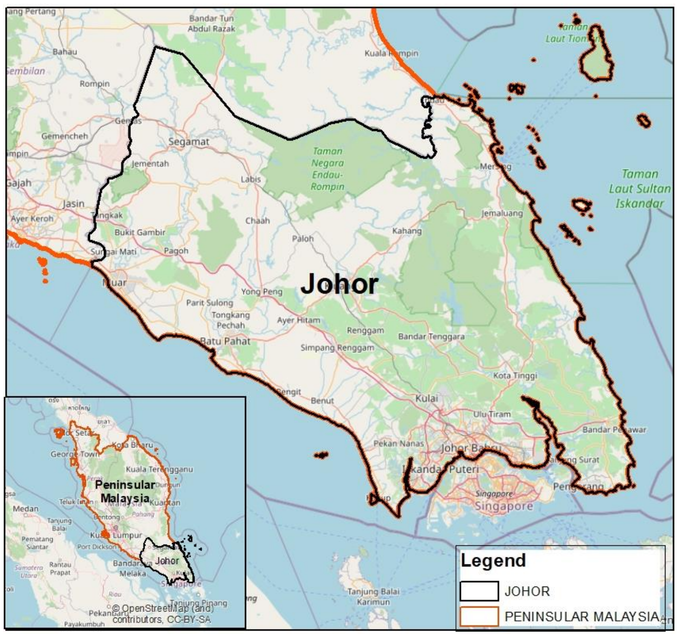

Figure 1. Study area (OpenStreetMap contributors 2017).

The software that has been used is ERDAS Imagine and ArcSWAT. ERDAS Imagine is used as a remote sensing system for the extraction and classification of multispectral image data (Srivastava et al. 2017). Then, the pre-processed data will be stimulated using Soil and Water Assessment Tool (SWAT) model that is integrated with ArcGIS software. The ArcSWAT model allowed the researchers to fit in more physical data than the ArcHydro model, resulting in a more accurate representation of the watershed. Moreover, ArcSWAT is easier to use for researchers with little GIS experience (Bryan and Curran 2004). ArcHydro is a set of tools that used to support geospatial and temporal data analyses especially related to soil and water assessment. According to Bryan and Curran (2004), ArcHydro does a good job at data management and ArcHydro is a better choice when a large amount of data is required to be collected and included in model such as with larger watershed. ArcSWAT is an open source hydrological model containing several number of model applications that can be used in many studies such as in catchment to continental scales (Abbaspour et al. 2015).

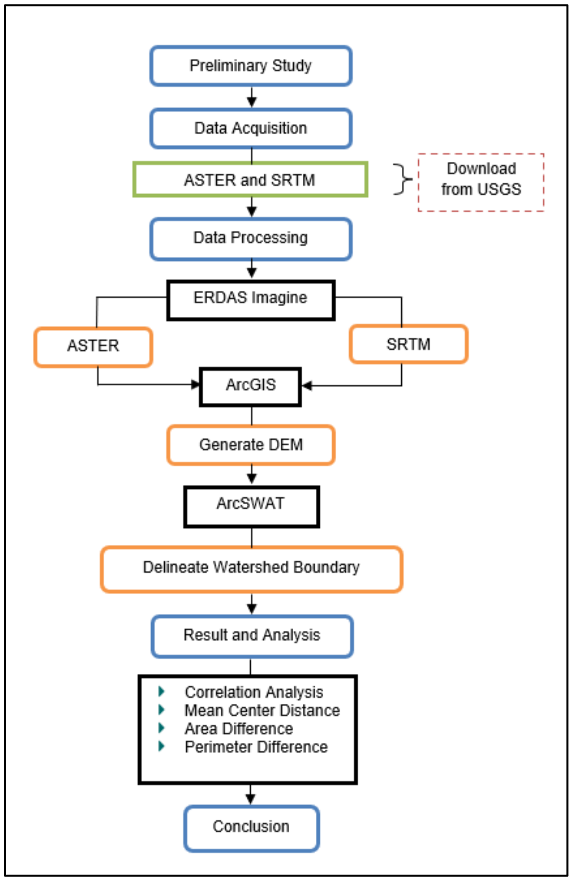

Figure 2. Work methodology.

Figure 2 shows the flowchart and phase of work that was done to accomplish this research. It has four fundamental stages which are first stage which is preliminary study, second stage is a data acquisition which collect two different data from USGS website, third is data processing which processed the collected data and mosaiced them in ERDAS Imagine, using ArcGIS to generate the DEM and then delineated the watershed boundary using ArcSWAT and the last stage is result and data analysis by correlation analysis, mean center distance, area difference and perimeter difference.

3.1 Preliminary Study

Good quality digital elevation data (DEM) is the main concern in this study. This includes finding the suitable data sources including the quality and accessibility of DEM data. Some of the high accuracy of DEM data are privately owned and cannot be accessed freely. Thus, in this study, the Shuttle Radar Topography Mission (SRTM) and Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) of Johor state, Malaysia were downloaded from Earth Explorer USGS website. Throughout this study, the characteristics, specification, accuracy and error related to both datasets were reviewed.

3.2 Data Acquisition

The crucial element in GIS is utilizing the appropriate data to obtain the relevant results. Free online datasets which are ASTER and SRTM of Johor, Malaysia have been used in this study. Both datasets can be downloaded from Earth Explorer USGS website. Other than that, the river line and watershed boundary data from Department of Irrigation and Drainage of Malaysia (DID) were used as a reference to validate the accuracy of watershed delineation from ASTER and SRTM. Watershed boundaries from DID have been delineated using a 20-metre interval contour line.

GDEM of ASTER is downloaded from free sources which is the Earth Explorer USGS website. It has a 30-metre resolution of image and in World Geodetic System (WGS84) projection. The ASTER GDEM is in GeoTIFF format which is Geo-referenced Tagged image file (GeoTIFF) format. In this research, the projection of ASTER was converted from WGS84 to Kertau Rectified Skewed Orthomophic (RSO) Malaya. The Johor state of ASTER GDEM was obtained after all the 6-degree tiles were clipped into one DEM image. The SRTM DEM is also downloaded from Earth Explorer USGS website. Similar to ASTER, SRTM has 30 metre resolution of image and in World Geodetic System (WGS84) projection. The GeoTIFF SRTM DEM proceeded after the projection of SRTM was converted from WGS84 to Kertau Rectified Skewed Orthomophic (RSO) Malaya.

3.3 Data Processing

The following stage is data processing. SRTM and ASTER were processed to delineate the watershed boundary. The downloaded SRTM DEM and ASTER are originating from various sources and have different specifications. Therefore, both data need to be converted into the same projection and coordinate system so that the comparison of watershed boundary delineation can be made easily. In this study, both DEM data were transformed from WGS84 to the local coordinate which is Kertau RSO Malaya. Before that, ASTER and SRTM data will be mosaicked into one raster image using the MosaicPro tool in ERDAS Imagine software. The final processing stage is to delineate watershed boundaries for SRTM and ASTER using ArcSWAT software.

3.4 Data Analysis

Data analysis is a process of transforming and modelling the processed data to extract the useful information to accomplish the aim and objective of this study. In this study, the correlation analysis and mean center distance were used to analyse the derived watershed boundary from ASTER and SRTM. The produced results which include area, perimeter and mean centre distance of watershed will be compared with watershed boundary from DID delineated using 20 metre interval contour line containing 21 rivers. According to Dudovskiy (2018), correlation can be used to analyse the extent of relationships between different variables. The correlation analysis is performed to identify the strength of relationships between a pair of variables. The systematic relationship is found if there are correlation between a pair of variables. The changes in one variable will alter the value of other variable over a certain period of time (DJS Research Ltd 2017).

Next, graph comparison and correlation analysis are used to compare the number of watersheds, mean center distance and area and perimeter of watershed delineation boundary between both datasets. The graph comparison is to observe the comparison between both DEM data, ASTER and SRTM. Thus, better data of watersheds can be chosen.

The comparison of mean center distance between watershed boundaries delineated from ASTER and SRTM have been made with watershed boundaries from DID. Based on ESRI (2018), the mean center distance is the average x, y and also z of all features to track the changes in the distribution or to compare the distribution of features. The mean center distance tool creates new point features where each feature represents a mean center. This tool requires projected data to accurately measure distances (ESRI 2018). In this study, the case field is specified, the input features are grouped according to case field values and a mean center distance is calculated from average x and y values for the centroids in each group. The x and y coordinates for the center features are feature attributes of the output features class where the values are stored in the fields x-coord and y-coord. Then, the number of watersheds between ASTER and SRTM was compared to each other. The area difference between DID data and both ASTER and SRTM was conducted. Lastly, the perimeter difference also was conducted between three (3) types of datasets, ASTER, SRTM and DID data. The area and perimeter for ASTER and SRTM are selected according to the DID watershed boundary and then, classed the area and perimeter into watershed boundary class. All the analyses were completed using graph comparison and correlation analysis between two DEM data.

4 RESULTS AND DISCUSSION

Figures 3 and 4 show the map of watershed boundaries delineated from ASTER and SRTM respectively. The DEM's that are derived from ASTER and SRTM show the same image accuracy when compared between both DEM's. This is because ASTER and SRTM have the same resolution value which is 30 metres. Meanwhile, the elevation of the surface of the ASTER and SRTM show a variation between both. Table 1 shows the maximum and minimum elevation derived from the selected DEM data.

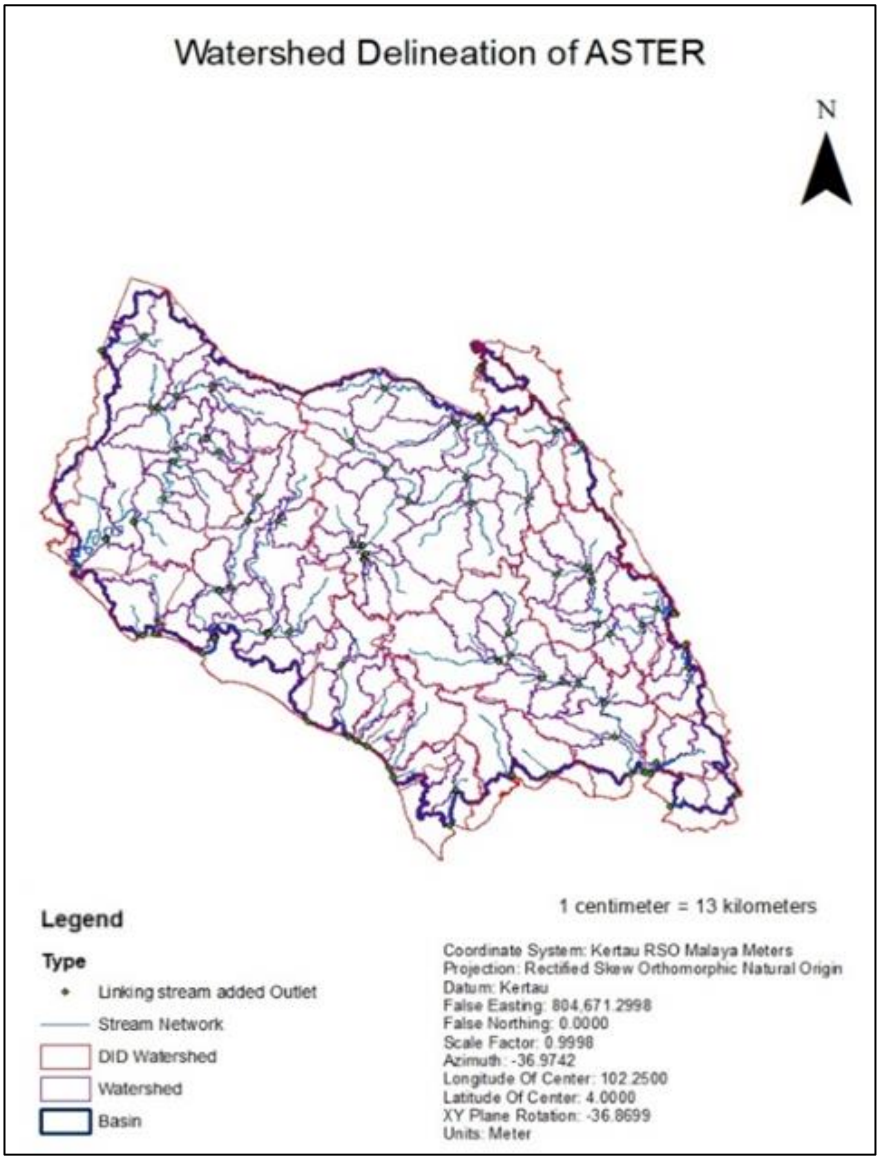

Figure 3. Watershed boundary derived from ASTER.

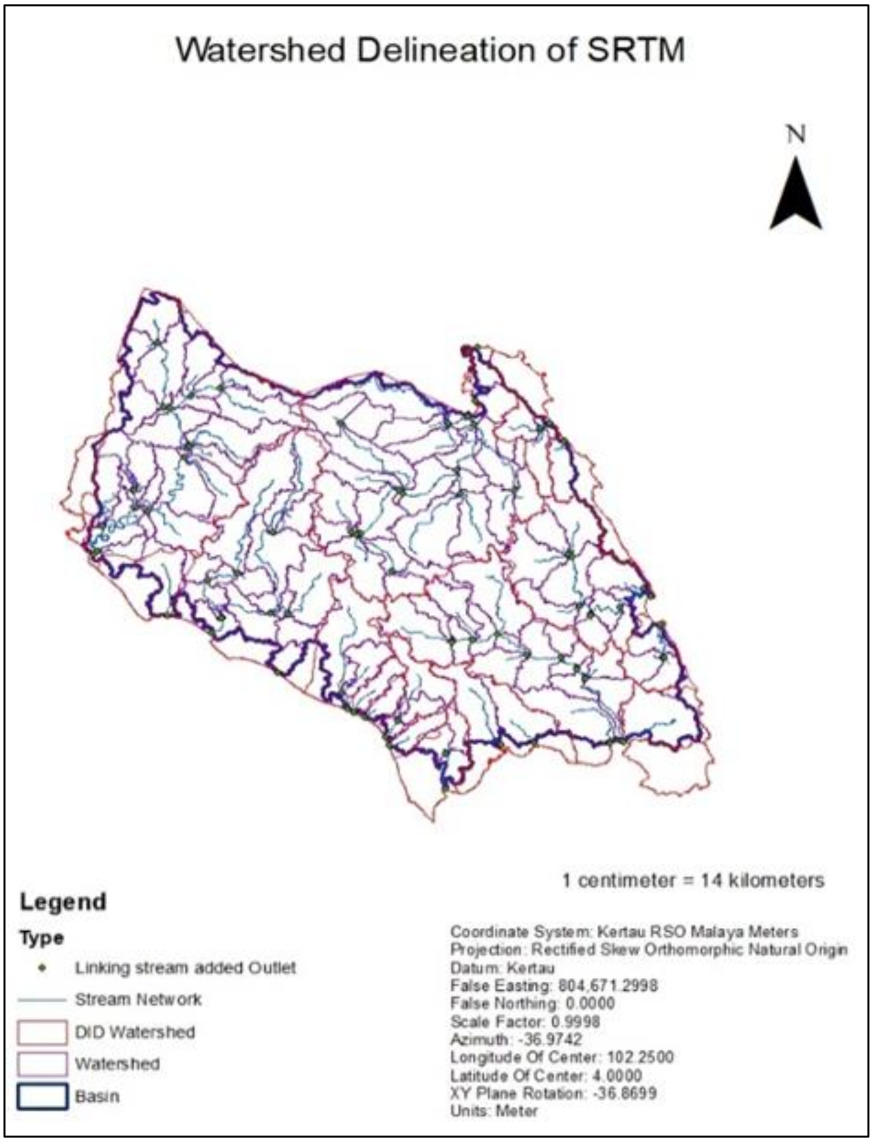

Figure 4. Watershed boundary derived from SRTM.

Table 1. The maximum and minimum of the elevation.

ASTER		SRTM	
Min	Max	Min	Max
-6.000	112.000	-19.000	127.000

In Table 1, it shows that the ASTER image data is cleaner compared to SRTM image data. As the minimum value for SRTM is -19.000 and the ASTER minimum value has lower negative value which is -6.000, the negative value of DEM image may be caused by depression holes or defects to the data. The higher the negative value, the higher the depression hole. The depression was removed to ensure the processing result is smooth. Other than that, the minimum value can also cause imperfections of the data where the error of contour DEM happens.

The delineation of a stream network is based on a channel initiation threshold which represents the number of discharges needed to maintain a channel head with contributing cells serving as a replacement for discharge. The number of stream networks is varying even though the resolution of both DEMs is the same, which is 30-metre resolution. Table 2 shows the number of stream networks for both DEM's. The number of stream networks produced from ASTER and SRTM are less compared to the DID number of stream networks. This is because the DEM from satellite image resolution is 30-metre as compared to DID resolution with 20-metre accuracy.

Table 2. The number of stream network produced from each DEMs.

DEM	Number of Stream Network
ASTER	146
SRTM	125

The watershed delineation of ASTER and SRTM were validated with reference data from DID. The watershed boundary from DID has been divided into several classes which is from J1, J2, J3 until J21 and the watershed boundary delineation that generated from ASTER and SRTM also was divided into several classes based from the DID watershed boundary. The classes were divided as J because the study area of the watershed delineation is located in Johor state and J classes stand for Johor classes. All the watershed boundary was using kilometer (km) units. Further analyses are discussed in following subsections.

4.1 Correlation Analysis

In this study, correlation analysis is used to examine the performance between watershed boundaries delineated from ASTER and SRTM with DID data. Area and perimeter of watershed derived from ASTER and SRTM dataset were compared and were correlated with DID data. The correlation coefficient, R^2 and analysis of trendline graphs were generated to visualize the relationship between the independent (DID) and dependent (ASTER or SRTM) variables in the graph. The closer R^2 is to 1.00, the better the relationship between those selected parameters. Figure 5 and Figure 6 show the results of the correlation for both DEM area data after being compared with DID data. The correlation analysis data is using all the 21 of DID watersheds that have already been categories into several classes.

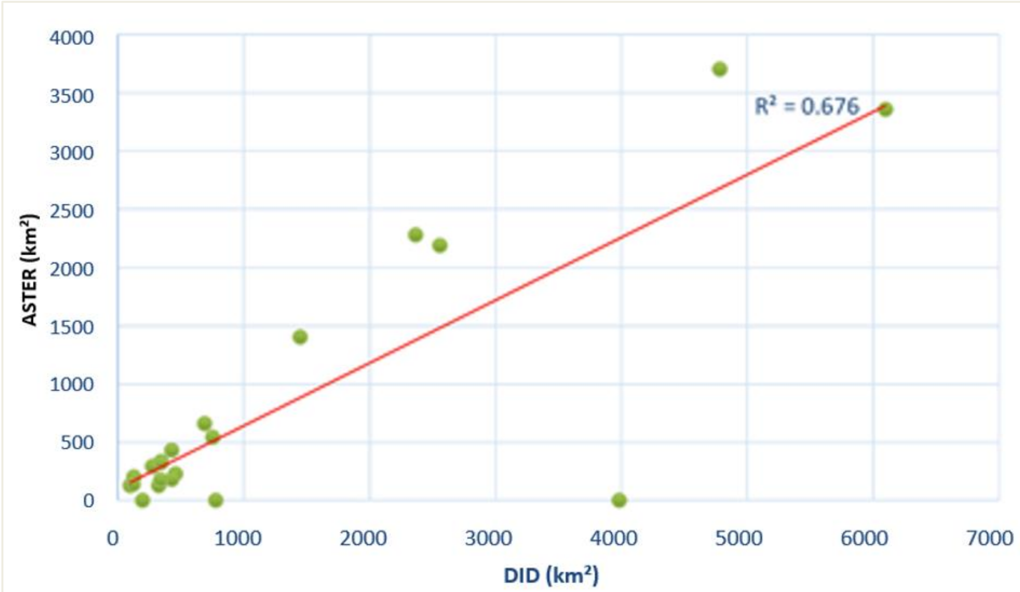

Figure 5. Association between ASTER and DID in Area.

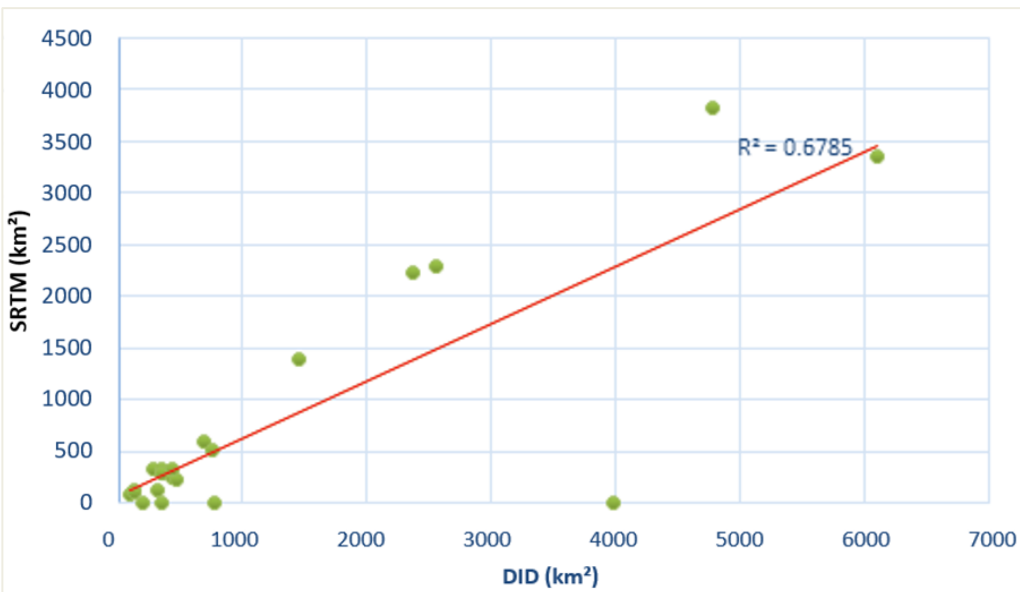

Figure 6. Association between SRTM and DID in Area.

As referred to Figure 5, the correlation value between watershed area delineated from ASTER and DID is 0.676. In Figure 6, the correlation value between watershed area delineated from SRTM and DID is 0.6785. From both correlation results, the generated R^2 was nearly the same and it shows that the area of watershed delineated from each dataset is correlated at 67%. The results show a moderate relationship between watersheds derived from ASTER and SRTM with DID data.

Furthermore, the correlation of watershed boundary perimeter derived from ASTER and SRTM with DID are shown in Figure 7 and Figure 8 respectively. From Figure

7, the association between ASTER and DID data is decreased with correlation value R^2 is 0.6033. However, the association between SRTM and DID data is better with correlation value R^2 is 0.6171. Thus, the correlation value R^2 for DID watershed perimeter shows it is related to ASTER watershed perimeter at 60.33% and it is related to SRTM watershed perimeter at 61.71%. The assumption that can be made from the perimeter correlation result is that SRTM is nearly close to the DID data. Thus, it can be concluded that both data are quite comparable with the DID data nevertheless in terms of perimeter, SRTM is much better compared to ASTER.

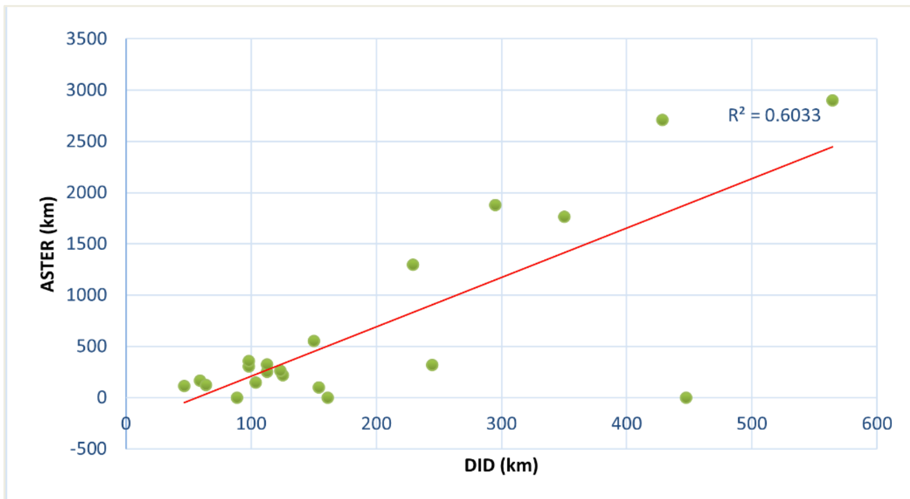

Figure 7. Association between ASTER and DID in perimeter.

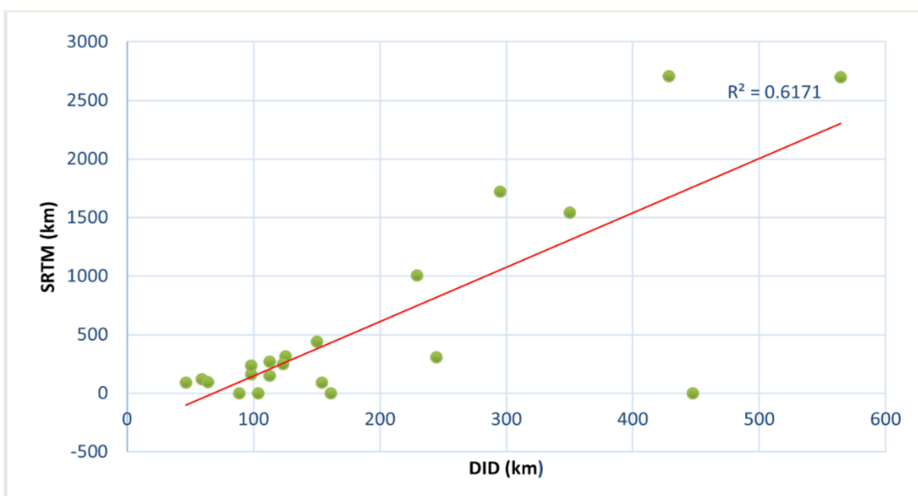

Figure 8. Association between SRTM and DID in perimeter.

4.2 Mean Center Distance

The measured mean center distance is the average x, y and also z of watershed boundary delineated from ASTER and SRTM. Figure 9 shows the comparison graph between both DEM with DID data. The highest mean centre distance derived from ASTER is 15.764 km in J8 and the lowest distance is 2.390km in J14. As for SRTM, the highest mean centre distance is 17.900km in J5 and lowest distance is 1.353km in J6. ASTER data produced a smaller gap as compared to SRTM. Overall results show that ASTER is much better in mean center distance analysis as compared to SRTM. This happens because the boundary of watersheds that have been produced such as in J11 as for SRTM is negligible compared to the boundary from DID. This makes the mean center distance for SRTM become bigger. Thus, it will produce a bigger gap compared to ASTER, its boundary is quite equivalent with DID data.

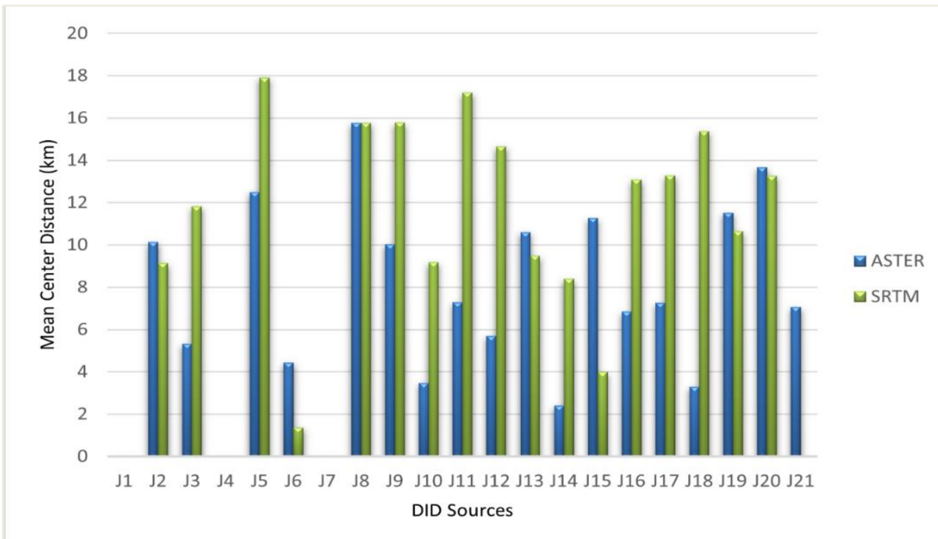

Figure 9. Comparison between ASTER and SRTM in mean center distance.

The graph of association between ASTER and SRTM in mean center distance is shown in Figure 10. The result shows the correlation value R^2 between ASTER and SRTM is 0.3125 which is very distant from one (1) value. This means, in mean center distance, the ASTER data has a bigger gap with SRTM data, and it also shows the relationship between the ASTER GDEM and SRTM DEM data have a weak relationship correlation. Besides that, its correlation value R^2 shows that ASTER mean center distance is associated with SRTM mean center distance at 31.25%. From the result, the total distance for ASTER is 148.485km which is better than SRTM at 200.200km. This strongly indicate that ASTER was better DEM to generate watershed delineation than SRTM as calculated in mean center distance.

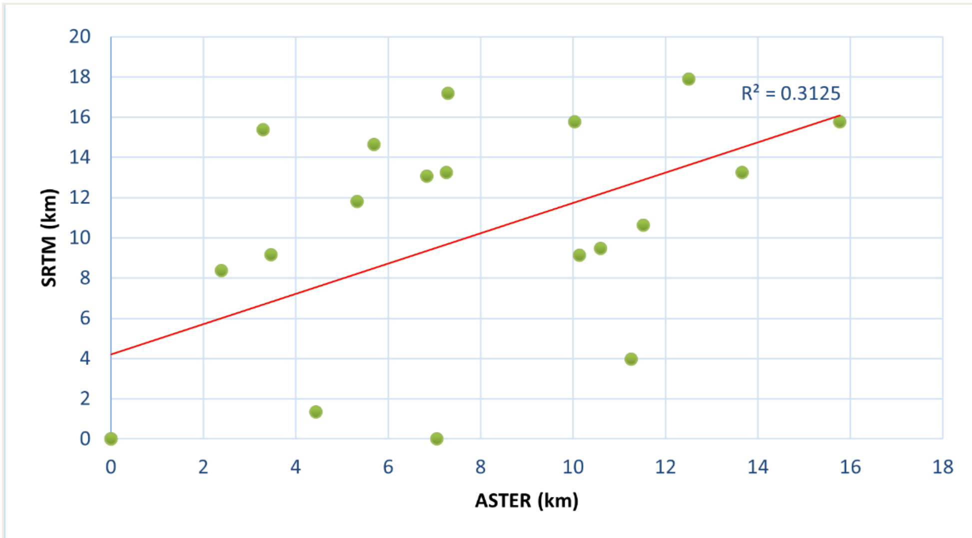

Figure 10. Association between ASTER and SRTM in mean center distance.

4.3 Area Difference

In Figure 11, it shows the result of the comparison in area difference of watershed delineation between ASTER and SRTM. Area of watershed from both DEM data was compared with the area of watershed from DID and the area difference between the data was calculated. The highest area difference for ASTER is 2741.645 km² in J2 and the lowest is 9.757 km² in J5. The highest area difference for SRTM is 2752.099 km² in J2 and its lowest area difference is 0.068 km² in J13. The area difference from SRTM is bigger compared to ASTER, for instance in J5, area difference for ASTER is only 9.757 km². However, for SRTM the area difference is 183.391 km². The gap of area difference between two (2) of the DEM data is bigger which means that the accuracy of ASTER in area is much better compared to the SRTM.

The association between ASTER and SRTM in the area was shown in Figure 12. The correlation value R^2 for correlation analysis was 0.9535 which indicates that ASTER area difference is correlated to SRTM area difference at 95.35%. It also shows the gap between those two (2) of DEM datasets is smaller. The correlation coefficient scatter plot shows the relationship of area difference between ASTER and SRTM have a strong correlation relationship. Even though the mean for ASTER and SRTM of higher area difference does not show immense value difference, ASTER proved it has small area difference compared with SRTM. Hence, it demonstrates that ASTER in terms of area difference was better than SRTM.

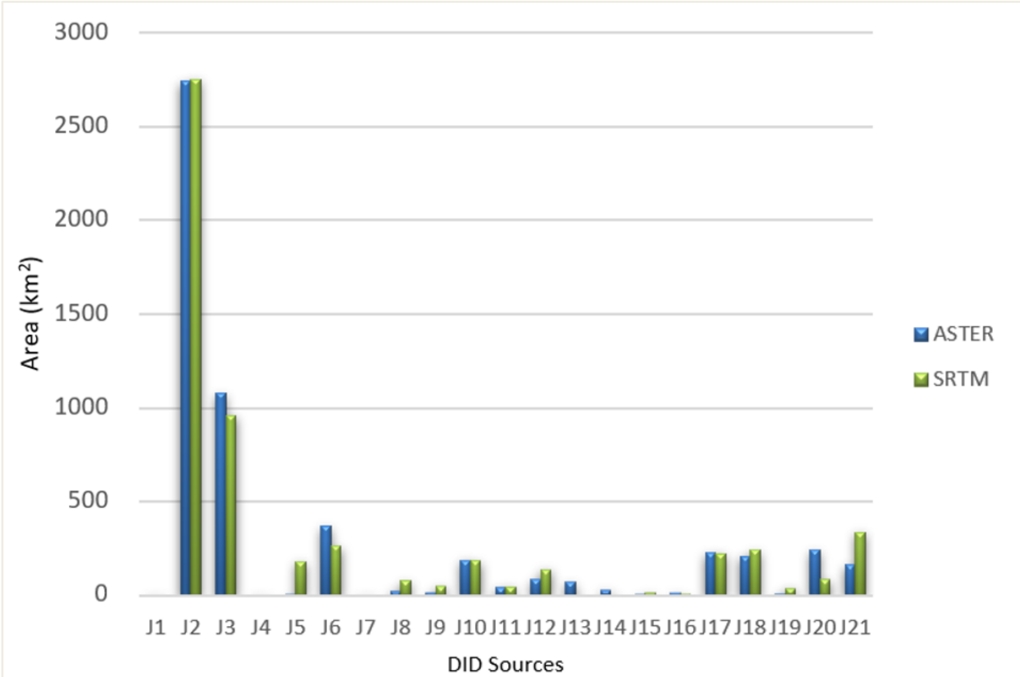

Figure 11. Comparison between ASTER and SRTM in area difference.

4.4 Perimeter Difference

The graph in Figure 13 shows the comparison between ASTER and SRTM in perimeter differences. The perimeter from ASTER and SRTM was compared with perimeter from DID data. From the graph, it shows that the ASTER perimeter shows a bigger difference when compared with the DID data where the highest perimeter difference is 2335.570 km and the lowest perimeter difference is 45.983 km. While for the SRTM, the highest difference is 2278.409 km and the lowest difference is 35.379 km. Yet, it shows that the perimeter difference from ASTER is bigger than SRTM which makes the SRTM accuracy better compared to ASTER.

Figure 14 shows the association between ASTER and SRTM in perimeter difference. From the graph, it shows the correlation value R^2 for the correlation analysis was 0.986 where it indicates that ASTER perimeter difference is related to SRTM perimeter difference at 98.60%. Therefore, it also shows that ASTER and SRTM have small differences in gaps and are nearly the same in the perimeter. This shows that correlation coefficient scatter plots for the relationship of perimeter difference between ASTER and SRTM have a strong correlation relationship. Hence, both DEM data, ASTER and SRTM can be used in watershed delineation. The graph shows the mean for ASTER and SRTM of higher perimeter difference which does not show huge value difference, but SRTM have proved it to have small perimeter difference compared to SRTM.

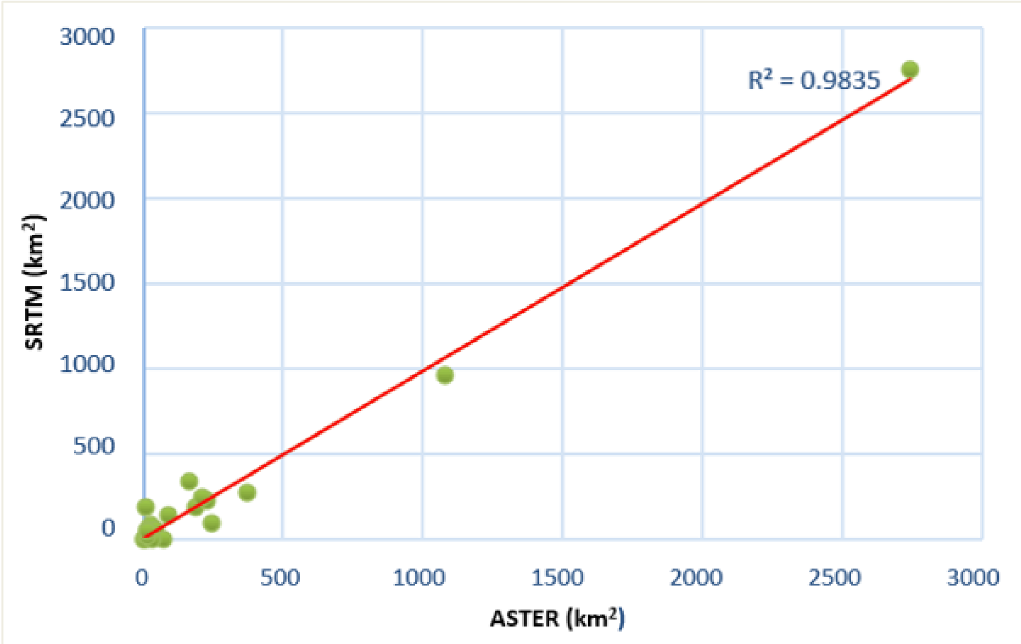

Figure 12. Association between ASTER30 and SRTM90 in area difference.

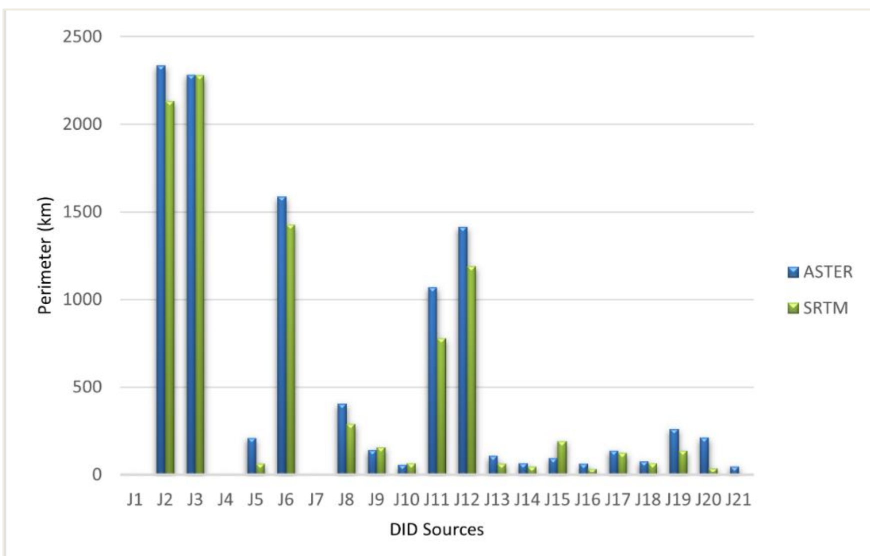

Figure 13. Comparison between ASTER30 and SRTM90 in perimeter difference.

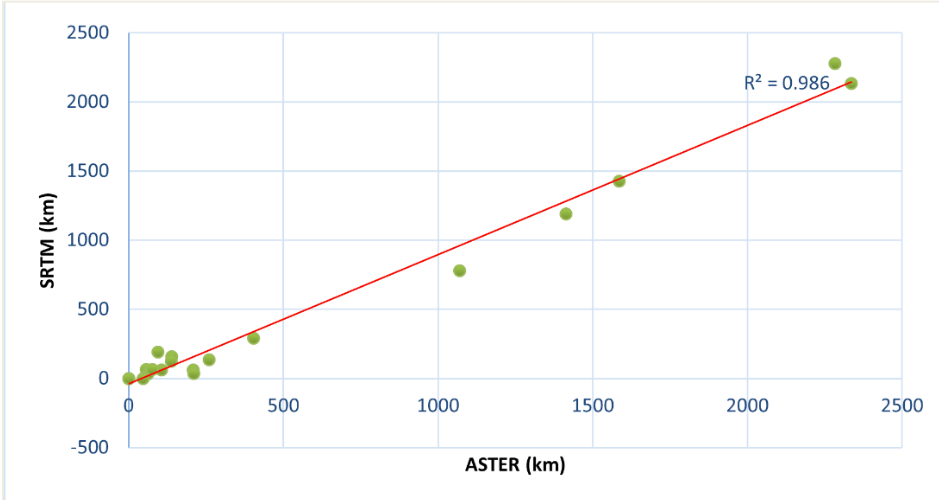

Figure 14. Association between ASTER30 and SRTM90 in perimeter difference.

5 CONCLUSION

This study has successfully delineated watershed boundaries from free online open-source dataset. The selected ASTER and SRTM have the potential to generate a good watershed boundary for Johor, Malaysia. The produced watersheds from both datasets have a natural representation as compared to the watersheds from Department of Irrigation and Drainage (DID) data. The watershed boundary delineation from ASTER and SRTM were compared with watersheds from DID which had been delineated using a 20-metre interval contour line.

The correlation analyses have been made to evaluate the relationship between area and perimeter derived from ASTER and SRTM as compared with reference data. The results show that SRTM produced slightly better watershed boundaries than ASTER. Besides, as for mean center distance and area difference, ASTER gave better results as compared with the SRTM. ASTER on the other hand generates more watershed compared to SRTM, its mean center distance also shows that ASTER had small distance value and ASTER's gap for area difference is smaller than SRTM even though it had stronger correlation relationship with 95.35%. Besides that, in perimeter difference, SRTM gave a better result compared to the ASTER. Although its correlation value R^2 is 98.60%, SRTM had a smaller gap perimeter difference.

In future, it is recommended to use ASTER or SRTM to produce watershed delineation in a wide area because this research has proved the accuracy of both DEM data that are good and appropriate. From this research, the watershed produced in a large area using DEM data was virtually the same with the watershed from DID. The area and perimeter of watershed that have been produced was nearly the same with area and perimeter of watershed from DID.

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