JOJAPS

eISSN 2504-8457

Journal Online Jaringan COT POLIPD (JOJAPS)

The Impact of Using Digital Elevation Model (DEM) From Difference Sources in Hydrological Applications

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Abstract

Digital Elevation Model (DEM) plays an important role in a variety of applications including those in hydrology. Hydrologic engineers require these data to generate a number of quantities such as slope, stream network, watershed, etc. This elevation data may come from various sources with different characteristics especially the accuracy. Different levels of accuracy may produce different results, thus this study investigates the extent of potential discrepancies when different sources of DEM are used. Three sources of elevation data are used, i.e. Light Detection and Ranging (LiDAR), Interferometric Synthetic Aperture Radar (IFSAR) and Shuttle Radar Topography Mission (SRTM). Using functions available in Geographical Information System (GIS), a number of quantities is generated which includes slope, flow direction, catchment and stream network. Comparisons are made by benchmarking IFSAR and SRTM against LiDAR as LiDAR data is known to be the most accurate to date. The findings are quantified, analysed and also passed to the experts for comments. It is found a major difference in slope coverage, where for instance, 20% is of 30° – 60° slope is found in LiDAR whereas only 2% in IFSAR and none in SRTM. The total area of catchment for IFSAR differs by 0.27% while SRTM by 0.35%. The difference in stream total length is 5% in IFSAR and 12% in SRTM. Based on these results, the experts agree that LiDAR is the best choice while IFSAR data only suits certain applications such as floodplain management and flood forcasting. SRTM data is at lower rank as it is unsuitable for such applications but are acceptable, to a certain extent, to generate the catchments.

Key-word: - Digital Elevation model (DEM), Light Detection and Ranging (LiDAR), Interferometric Synthetic Aperture Radar

1. Introduction

The world topographic features can be modelled with better accuracy with the development of technology in mapping. The issue of 3-dimensional mapping highly rise and the topographic modelling or Digital Elevation Model (DEM) is increasingly used with many applications. There are various ways of capturing and creating elevation data, including field surveying, stereo photogrammetric, Unmanned Aerial Vehicles (UAV), airborne scanning, Light Detection and Ranging (LiDAR) and Interferometry Synthetic Aperture Radar (IFSAR). There are also several other methods to obtain data such as Global Positioning System (GPS), satellite imaging (remote sensing), and also from the existing topographic maps.

Nowadays, availability of data sharing through the world able to access easily with open source data. Data required to user requirement can be downloaded with zero cost or purchase depends on the accuracy. The sources of DEM from satellite imaging can be obtained from a few websites such as Shuttle Radar Topography Mission (SRTM) and Advanced Space borne Thermal Emission and Reflection (ASTER). SRTM data are available on the USGS web site through Earth Explorer application and also through the website ASTER GDEM. DEM is essential in addressing issues related to impacts of climate change, disaster management, environmental management, urban planning and infrastructure design. Terms DEM is used to express the height of the earth's surface in a uniform grid. There are other terms that are often used together with the DEM which is Digital Terrain Model (DTM) and Digital Surface Model (DSM). DEM acquisition costs are largely influenced by the technique and accuracy required. Although airborne LiDAR is regarded as the most expensive technique, it has become the choice of technology for obtaining digital elevation data in a variety of application (Liu, 2011).

Various techniques have been used to compare the accuracy of elevation data. From the literature, the DEM from LiDAR data is considered the best can be achieved with a height of 10-50 cm accuracy with 68% confidence level (ICSM, 2008). LiDAR is one of the most accurate and effective data collection and the result of comparing visual examination shows that there is a close similarity between the contours extracted from digital topographic map, IFSAR DEM and LiDAR DEM data (Wan Mohd Naim Wan Mohd, 2014).

This study discusses the DEM accuracy assesment on difference namely LiDAR data, IFSAR data (airborne) and SRTM data. Previous studies has conducted to analyse the DEM accuracy assessment of LiDAR, IFSAR and SRTM. The study on LiDAR has conducted such as accuracy asessment on derived DEM (Aguilar, 2008) and critical isues on LiDAR DEM generation(Liu, 2011). IFSAR has been analyse in the production of digital Cartographic in North Alaska (Garrity, 2004). The comparison between IFSAR and LIDAR also has conducted in terms of production and acuracy asessment (Mercer, 2001). There are various of study on analysis of SRTM DEM in methodology and practical results (C. Heipke, 2002).

The derived DEM then will analyse for the hydrological application. Elevation is main driving force of water movement and due to that DEM are mostly fundamental for all hydrological application (FÜRST, 2002). Since mid-1980s, the era of spatial modelling in hydrology has begun with DEM and remote sensing data have been used for catchment studies (Nawshin Rumman, 2005). Catchment and sub-catchments can be calculated from DEM and represent surface drainage accurately. The accurate stream network can be derived from higher resolution of DEM but the highest resolution not necessarily offers the best result (Thassawan Hanuphab, 2012).

2. Methodology

The flow chart of the research methodology is shown in Figure 1.1. Generally, there are four (4) phases or stages involved in this study. Each phase of the study describes the procedures to achieve the objective of the study. The first phase is the preliminary study. This stage involves the problem formulation of the study. LiDAR and IFSAR data are acquired from private company while the SRTM data are downloaded from USGS website. The second phase is data identification. This phase involves the study of data characteristic i.e the format and the conversion process. Data processing and manipulation is the third phase involve the producing of surface model, slope map, flow direction and the watershed delineation. The fourth phase is the analysis for the output results as obtained in the phase 3.

The elevation models are developed from each data and the comparison were analyses. The Outputs are presented graphically include profile, slope, sub-catchments and stream networks with using ArcGIS software. The output data are analysed for the hydrological analysis. The final phase discusses the overall accuracy of the different data sources and explains the impact by using the data for the hydrological works.

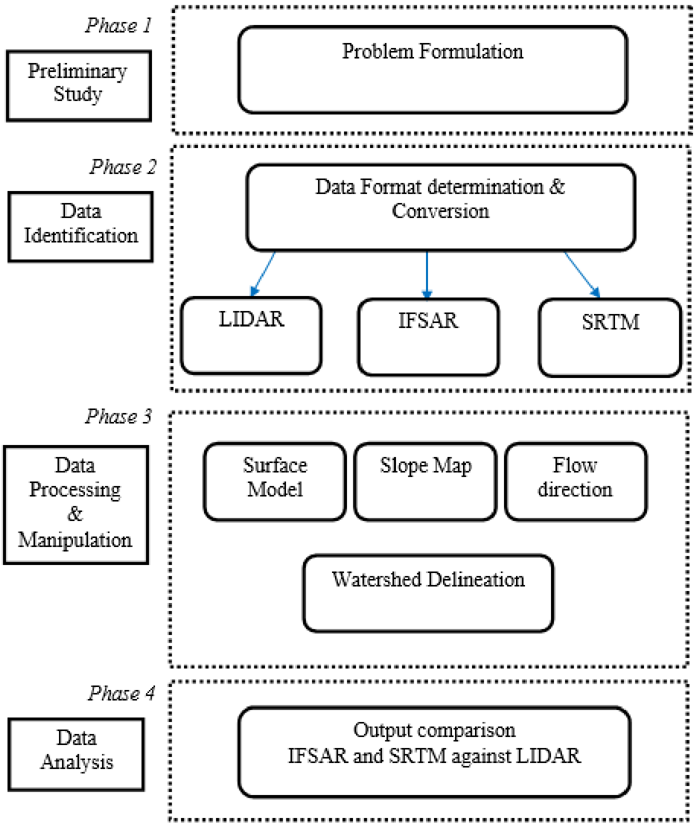
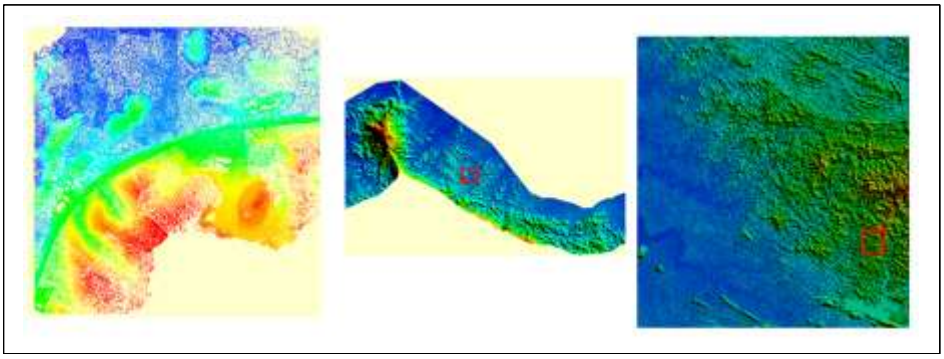


Figure 1.1: Flowchart of research methodology

3. Data Processing

Preliminary study include the study on the different sources of elevation data. The 3 types of data chosen are LiDAR, IFSAR and SRTM data. LiDAR and IFSAR data are acquired from the private sector. The LiDAR data produce from the airborne data collection, while the IFSAR data by the purchase of NEXTMap Malaysia dataset. The SRTM data downloaded from the USGS website with reference to the same location. Total area involved in this study is about 80 hectare. The data must fall in the same location for the process of accuracy evaluation measurement (figure 1.2)



i) LiDAR Data ii) IFSAR Data iii) SRTM Data

Figure 1.2: Data Sources

The first process, the clip tools function is used to extract the data with the same size. The format and size of the data are identified for the data processing requirement. This process is very important to reduce the time of data processing and to ensure all the datasets are represented for the same location. The DEM generated using topo to raster tools.
Then the next procedure is watershed delineation. The watershed delineation involves the determination of Depressionless DEM, Flow Direction, Flow Accumulation, watershed outlet points and finally the process of delineating the watershed (ESRI, 2014).

The LiDAR data is treated as the best quality data and accuracy when benchmarking the IFSAR and SRTM data. The topography represent more accurately with higher resolution DEM (Saksena, 2014). From the literature review LiDAR best accuracy is around 10cm in Z compared to IFSAR which is approximately 0.5m in Z (Dowman, 2003) while SRTM is expected to have 16m vertical accuracy (Sandwell, 2002).

The surface models in this study are generated using raster and TIN. The data are converted into point data. The interpolation of raster data is accomplished using Kriging method. Since IFSAR and SRTM in raster format, the processing is similar but it is different for LiDAR data because it is a point cloud format (x,y,z). Each output were analysed in comparison between IFSAR and SRTM compared with LiDAR. This phase involves a study of the implications and the difference from the comparison. A comparative analysis conducted including profile analysis, DEM surface analysis, Point data analysis, flow direction analysis, catchment and stream network analysis. The interview process is conducted to get an overview of the methodology and findings of the study. Experts in the fields of hydrology has been selected to be interviewed about the suitability of the DEM from LiDAR, IFSAR and SRTM in the field of hydrology focus on delineation watershed. Two experts from private company and local university involve to proof the used of derive DEM from the sources of the data. The person of expertise on hydrology whose has interviewed are Mr. Ahmad Zuhri Bin Ismail as a Managing Director of GeoEnvi Solution Sdn Bhd and Mr Kamarul Azlan Bin Mohd Nasir (Senior Lecturer of Department of Hydraulics & Hydrology UTM).

4. Result & Analysis

The comparison of DEMs profile along a given line as illustrated in figure 1.3 with sampling of 20 points. Figure 1.3 shows the profiles along the same line for LiDAR, IFSAR and SRTM. The IFSAR data has some similarity with LiDAR and the result shows consistence in certain points. This profile shows that the LiDAR actually a very detail data with high density data. While IFSAR and SRTM from the interpolation surface.

Visual inspection in Figure 1.3 shows that the overall IFSAR DEM almost similar to LiDAR in range below ±2 meter. Compared to SRTM the point is quite different in certain area due to the DEM grid resolution which is 30 meter.

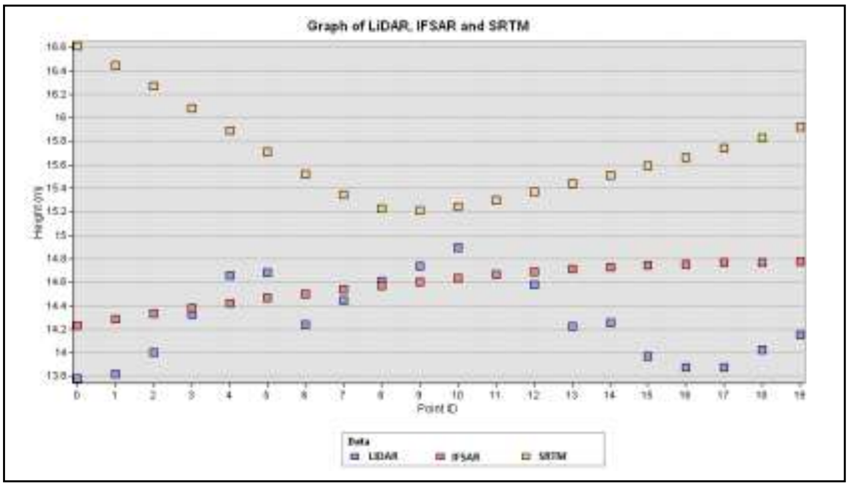
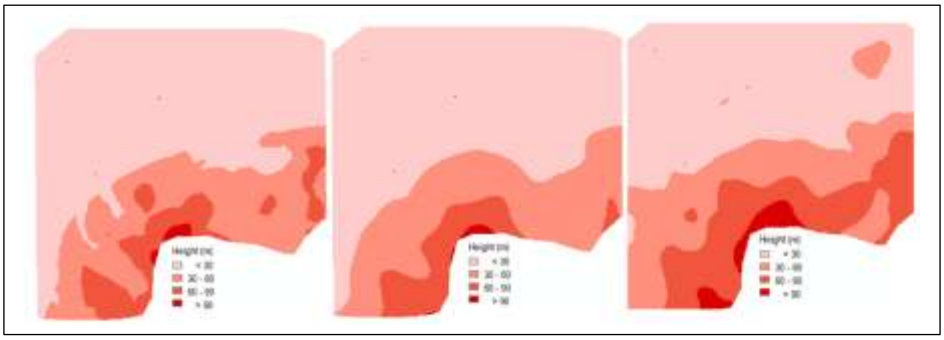


Figure 1.3: Profiles in scatter plot of LiDAR, IFSAR and SRTM

The DEM are classify to the same value which is < 30 m, 30 m – 60 m, 60 – 90 m and > 90 m. The result of LiDAR (figure 1.4(i)) and IFSAR (figure 1.4(ii)) almost similar by the interpolation of height including the high area and low area but LiDAR look very details. Different with SRTM (Figure 4.1(iii)), the value above 90 meters is larger compared to LiDAR and IFSAR. SRTM data also interpolate of larger area which classify 60 m- 90 m data.

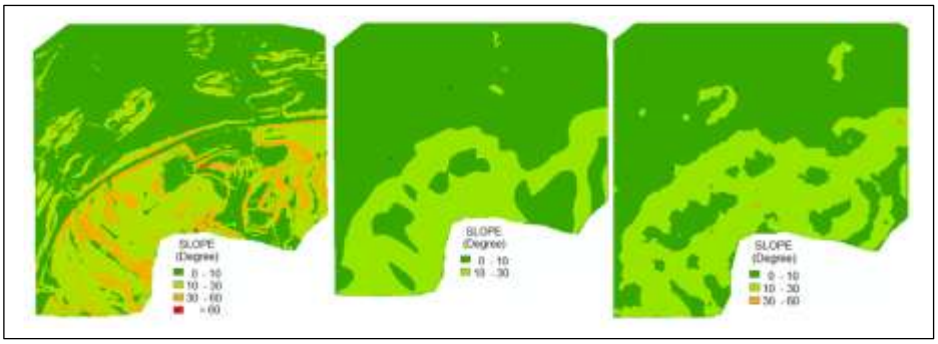
Elevation statistics of point data illustrated that the highest points of LiDAR data is 104.999 m and the lowest point is 12.671 meter. The highest points of IFSAR data is 100.345 meter and the lowest is 12.551 meter, while the SRTM data given the highest value is 106 meter and the lowest is 14 meter.



i) LiDAR DEM ii) IFSAR DEM iii) SRTM DEM

Figure 1.4: DEM analysis

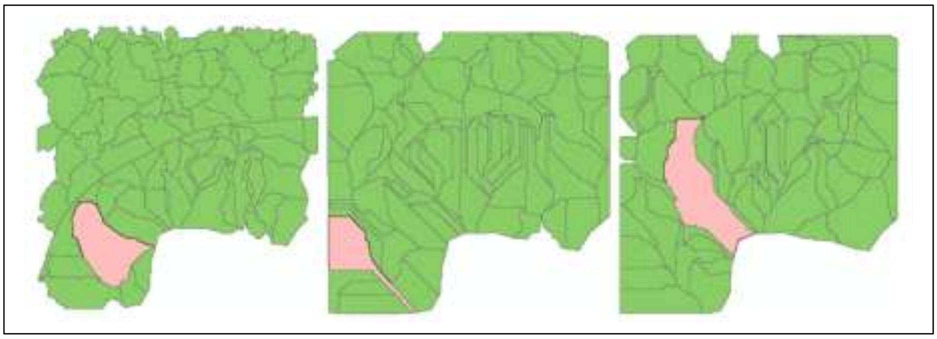
Figure 1.5(i) to 1.5(iii) illustrated the slope of DEM. The slope are classify to 0° -10°, 10° – 30°, 30° – 60° and above 60°. Graphically, both IFSAR and SRTM indicate the same slope are at 0° -10° and 10° – 30°. Slope SRTM also spotted a 30° – 60° same with the LiDAR data but at a very small portion. The result shows that the 20% of slope map LiDAR with 30° – 60°, but there is only 2% spotted in SRTM DEM and none in IFSAR DEM.



i) Slope from LiDAR ii) Slope from IFSAR iii) Slope from SRTM

Figure 1.5: Slope analysis

The result of the generated catchment indicate that the largest catchment is slightly in similar area, but not at the same area for LiDAR (figure 1.6(i)) and IFSAR (1.6(ii)). The total catchment of LiDAR and SRTM is 95 sub catchments but IFSAR derived 98 sub catchments. SRTM sub catchment (figure 4.5(iii)) is in different area but still not too different. This is due to the different DEM resolution which is IFSAR DEM is better resolution compared to SRTM. The results of catchment analysis is shown in Table 4.2. The differences of total area for IFSAR compared to LIDAR is 0.27% while SRTM is 0.35%.



i) LiDAR ii) IFSAR iii) SRTM

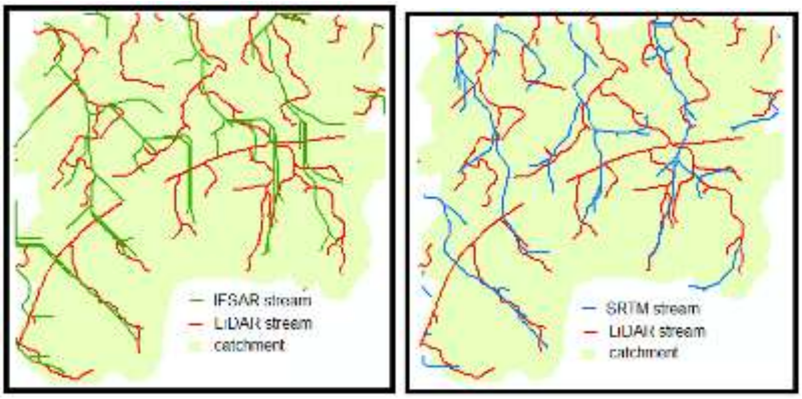
Figure 1.6: Sub Catchment analysis

The longest stream network derived from the 3 model has been compared in table 1.7. The design and analysis of any hydrologic project, length records is necessary (Ragunath, 2006). The result shows that the longest stream derived is from LiDAR DEM which is in 33354 m^2 area of sub catchment the slope of the river is 0.012995. Slope of the river is important value to indicate the run off. The stream slope IFSAR and SRTM indicate higher slope compared to LiDAR. However small difference indicate in IFSAR slope which is 0.067 m.

Table 1.7: Comparison the Longest stream

DEM	Catchment Area (m2)	Stream Length (m)	Stream slope (m)
LiDAR	33354	427.944	0.012995
IFSAR	16794	331.595	0.080408
SRTM	58905	419.581	0.107250

The displacement result between stream networks illustrated in figure 1.8(i) and 1.8(ii). Both result shows the same networks but IFSAR stream better than SRTM. The measurement shows that the displacement between IFSAR and LIDAR is range below than 2 meters but SRTM shows above 5 meters inconsistency. However, the streams still connected with the same network. The sample of stream in high and low areas are compared. This method is to derive the behavior of stream over the terrains. The result show that the high elevation given less of displacement compared to low area. The comparison of displacement is range below than 1 meter. According to P.Wicramagamade, DEM in high elevation exist stronger match between low elevation (P. Wickramagamage, 2011).



i) IFSAR compared to LiDAR ii) SRTM compared to LiDAR

Figure 1.8: Stream network analysis

The findings from the interview can be analyses that the derived DEM from LiDAR, IFSAR and SRTM is reliable for GIS application in hydrology. From the first experts interview, Mr. Ahmad Zuhdi Ismail declared that LiDAR and IFSAR is suitable for delineation watershed in generating catchments and stream networks but LiDAR represent better than IFSAR. LiDAR and IFSAR also suitable for floodplain management and flood forecast application. SRTM is not suitable for floodplain applications but can be used for generating the catchments.

The second expert opinion, Mr. Kamarul Azlan Mohd Nasir also expressed that IFSAR and LiDAR very suitable for the condtruction of the DEM. Nevertheless to obtain high precision data value, site investigation should be carried out as sometimes there are doubts in data acquisition. However, he also agreed that the SRTM data are not suitable for floodplain and generating the stream networks but are appropriate to generate the catchments

5. Conclusion

The understanding of surface topography is the major concerned in the earth sciences. The availability of topographic data worldwide has improving the research on the world phenomenon. However with difference sources of data, the major discussed is how accurate the data for the certain applications and the cost of data acquisition. Nowadays, the advance technology in mapping has improving the accuracy in data acquisition. The suitable of method with desire application will give the best cost estimation.

GIS has become a very useful tool in hydrology especially in water management. GIS able to model the spatial data of hydrological data such as delineate watershed. The watershed can be determine with using DEMs and hydrologic data. Some limitation occurs especially the data processing with using different software. Global mapper is easy to use due to adapted variety of format data, while ArcGIS is limited for ESRI format only. However the software have their own capabilities. To reduce the time of data processing, the data have to divide in a part. Although LiDAR is affordable to users but the cost of data collection and the effectiveness of raw data processing is a big challenging.

Base on the overall results can be summarized that IFSAR data is suitable for the hydrological analysis with the DEM and watershed analysis. The DEM resolution of IFSAR data is 5 meter. However for small area the data has some inconsistency compared to large area. The relative accuracy shows that the 30 meter resolution of SRTM data still capable in representing watershed and stream networks with different below than 3 meters in low elevation data. The final result shows that the lower resolution of DEM will give less accuracy especially in low elevation data. The results proven that SRTM data insufficient for delineate watershed in low elevation area.

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