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The Assessment of Topography Model Based on Global Digital Elevation Model (DEM) in Selangor

Mohamad Amirul Danial Noorzamani[1], Muhammad Seri Hidayat Azlan[1], Nournaqie Afsar Jaliasna[1], Nornajihah Mohammad Yazid[2]*

[1] *Department of Civil Engineering, Centre for Diploma Studies, Universiti Tun Hussein Onn Malaysia, Pagoh Higher Eduvatio Hub, 84600, Pagoh, Johor, MALAYSIA*

[2] *Neo Environmental Technology, Department of Civil Engineering, Centre for Diploma Studies, Universiti Tun Hussein Onn Malaysia, Pagoh Higher Eduvatio Hub, 84600, Pagoh, Johor, MALAYSIA*

*Corresponding Author: nornajihah@uthm.edu.my
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Abstract

Selangor, a state in Malaysia, frequently experiences floods due to its topography and driven by consistent rainfall in the region. An accurate topographic data is crucial for effective flood management and natural disaster management. In the current era of technology, the exploration risk mapping will be easier by applying the Geographic Information System (GIS) based on Digital Elevation Model (DEM). Thus, this study aims to evaluate the accuracy of topography model based on DEMs in Selangor using GNSS Levelling. Next, select the DEMs for the Selangor and examine the most suitable DEMs based on SRTM, ASTER, TanDEM-X and verified with GNSS Levelling data. Then, map the topography in Selangor based on DEM data that contributes to risk assessment using MATLAB software. The result indicate that TanDEM-X has the lowest standard and the highest correlation with 2.365m and 0.9981m, respectively. As a result, TanDEM-X is selected as an appropriate DEM for Selangor, and it represents a significant impact for the next study related to geoid computation, floods, sea level rise and many more.

1. Introduction

A Digital Elevation Model (DEM) is a numerical depiction of the Earth's topography, offering fundamental data about the landscape's elevations and contours [1]. DEM can be created through various methods, including photogrammetry, interferometry, ground-based surveys, and laser scanning. Some DEM datasets, such as Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), Shuttle Radar Topography Mission (SRTM), and TerraSAR-X add-on for Digital Elevation Measurement (TanDEM-X), are freely accessible as open-source resources. Digital Elevation Model (DEM) and the related attributes they provide, such as slope, aspect, drainage area, curvature, topographic index, and more, are vital parameters for extracting information or evaluating various processes through terrain analysis.

In addition to Data Elevation Model (DEM), Global Navigation Satellite System (GNSS) is also one of the platforms to find data related to map topography. The Global Navigation Satellite System, or GNSS, is utilized by numerous location-based services and applications. These include mobile apps that operate on "smart" gadgets and facilitate a wide range of personal activities in addition to meeting societal and commercial demands [2]. This can make it easier for the public to access data related to topographical maps everywhere.

There is also software that can help in finding information related to this study. Among them are Matrix Laboratory (MATLAB) and Global Mapper. MATLAB is an interactive environment and high-level programming language that is mainly used for scientific and engineering applications, data analysis, and numerical computing. For numerical computations based on matrices, MATLAB is the most effective software available [3]. A software programmer for geographic information systems (GIS) called Global Mapper is used for a number of mapping and geospatial data analysis tasks.

Disasters related to the monsoon in Malaysia include floods, strong winds, landslides, and coastal erosion, with recent years also witnessing extreme and drought events [4]. For instance, extreme rainfall from December 9 to 11, 2004, caused severe floods on Peninsular Malaysia's east coast [5]. Recently, in 2023, Selangor experienced flash floods, exacerbated by factors like soil erosion, which occurs naturally but is worsened by human activities [6]. Issues also arise from the incompatibility and resolution of topographic data. Additionally, rising sea levels affect DEM data, submerging low-lying coastal areas and altering elevation readings [7]. To address these problems, validating the accuracy of DEM from open-source data is crucial, with a multi-DEM model based on Tandem-X 90m, SRTM, and ASTER evaluated against GNSS alignment data across Selangor. This study presents an effort to select the global digital elevation model for the Selangor region. Secondly is to map examine the Global Digital Elevation Model (DEM) based on SRTM, ASTER, TanDEM-X and GNSS levelling data. Lastly is to map the topography in Selangor based on global digital elevation model data that contributes to study related to flood, risk assessment and many more using MATLAB software.

The findings of this study will evaluate the accuracy of topographic models based on Global Digital Elevation Models (DEM) in Selangor using GNSS Leveling. This assessment is important to assess and mitigate the effects of natural disasters such as floods, landslides and storm surges, as accurate topographic data is essential. This research has the potential to improve disaster preparedness and response, water resource management, and disaster management as a whole, thereby having a significant impact on society and for future research use.

2. Methodology

This study aims to evaluate topographic models based on Global Digital Elevation Model (DEM) in Selangor. In contrast, the DEM Model is an important base layer component in the modelling of Flood Probability Maps. Fig. 1 represents the accuracy assessment process flowchart that will be used in this study.

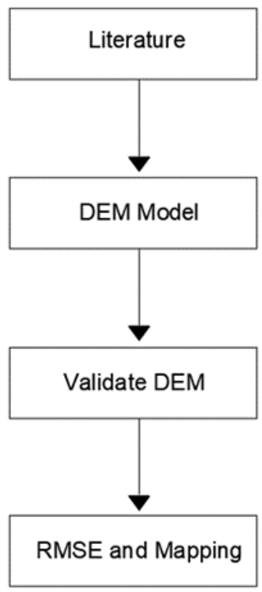


Fig. 1 Flowchart Process Evaluate Topographic of DEM using GNSS Levelling

2.1 DEM Model Selection

Basically, the surface of the earth is the outermost layer of the planet that includes solid land, bodies of water, and the atmosphere. As everyone knows, there are a lot of ways to use different digital storage technologies to exhibit surfaces digitally. One of the simplest ways to show topographic surfaces is with DEMs. In this study, we will use DEMs to trace the surface of the earth in the study area, which is in Selangor. DEMs are the most basic and widely used type of digital topography. Any digital representation of a topographic surface that functions as a quantitative model of that surface is what it is [8].

Global DEMs are available in a number of public search databases. These include TanDEM-X (TerraSAR-X add-on for Digital Elevation Measurement), NASA's Advanced Spaceborne Thermal Emission Reflectometer (ASTER), and the Shuttle Radar Topography Mission (SRTM). Three different types of data were generated, each with a resolution of 12m, 30m, and 90 m. Table 1 shows the comparison between ASTER, SRTM and TanDEM-X.

Table 1 The comparison between multi-DEM

	ASTER	SRTM30/90	TanDEM-X
Data Source	ASTER	Space Shuttle Radar	InSAR
Data Provider	METI/NASA	NASA/CGIARCSI	DLR and AIRBUS
Year of Release	2011	2003	2016
Period of Data Acquisition	2009 Ongoing	11 Days (During 2000)	2005 Ongoing
Spatial Resolution	1-arc second (30m)	3-arc second (90m)	0.4-arc second (12m), (30m) & (90m)
DEM Vertical Accuracy	±20 m	±10 to 16 m	±10 m

Based on Table 1, ASTER has a 30-meter resolution and ±20 meters vertical accuracy, released in 2011 by METI/NASA. SRTM30/90, released in 2003 by NASA/CGIARCSI, offers a 90-meter resolution with ±10 to ±16 meters accuracy. TanDEM-X, introduced in 2016 by DLR and AIRBUS, provides resolutions of 12 meters, 30 meters, and 90 meters with ±10 meters accuracy, using InSAR technology. These DEMs are essential for environmental research, remote sensing, and geographic information systems applications.

2.2 The Assessment of the GDEM based on SRTM, ASTER, TanDEM-X with GNSS Levelling Data

Remote sensing products, particularly digital elevation models (DEMs), are crucial for creating global elevation models at various resolutions, with satellite remote sensing being the most effective method [9]. DEMs, now primarily derived from satellite images, were historically sourced from aerial stereo imagery. Digital surface models (DSMs) represent the actual surface, including plants and buildings, and are more extensive and cost-effective than older methods. Selecting the appropriate DEM is critical due to the different geometries and sensors used. Satellite DEMs from programs like ASTER and the Shuttle Radar Topography Mission (SRTM) are widely used in environmental research, remote sensing, and GIS applications.

This study uses a standard deviation to find the most accurate DEMs. The standard deviation is a statistical metric used to express how much a group of data values vary or are dispersed. It shows the degree to which individual data points vary from the data set mean. Higher precision and accuracy in the levelling measurements are indicated by a lower standard deviation. By locating and minimizing error sources, this technique may be utilized to enhance the quality of the levelling process while also assisting in determining the consistency and dependability of the measurements. Comparing data from SRTM, TanDEM-X, and ASTER to GNSS is essential for confirming accuracy, appraising quality, and establishing DEM appropriateness for various spatial analytic and modeling applications. GNSS gives direct elevation readings at specified spots on Earth's surface. By comparing these GNSS-derived heights to similar elevations from DEMs at the same places.

2.3 Topographical Mapping of Selangor Using Global Digital Elevation Model Data

Using data from the Global Digital Elevation Model (DEM), a topographical mapping of Selangor is an important geographical research project. Using modern software and geospatial data, this aims to produce an accurate and comprehensive map of Selangor's topography. It can be used to understand Selangor's complex terrain by using

Global DEM data, showing elevation changes and geographical features. In addition to adding to our knowledge of the topography of the area, this study is important for a variety of uses, including managing floods disasters. An example of software that can be used to obtain data is MATLAB.

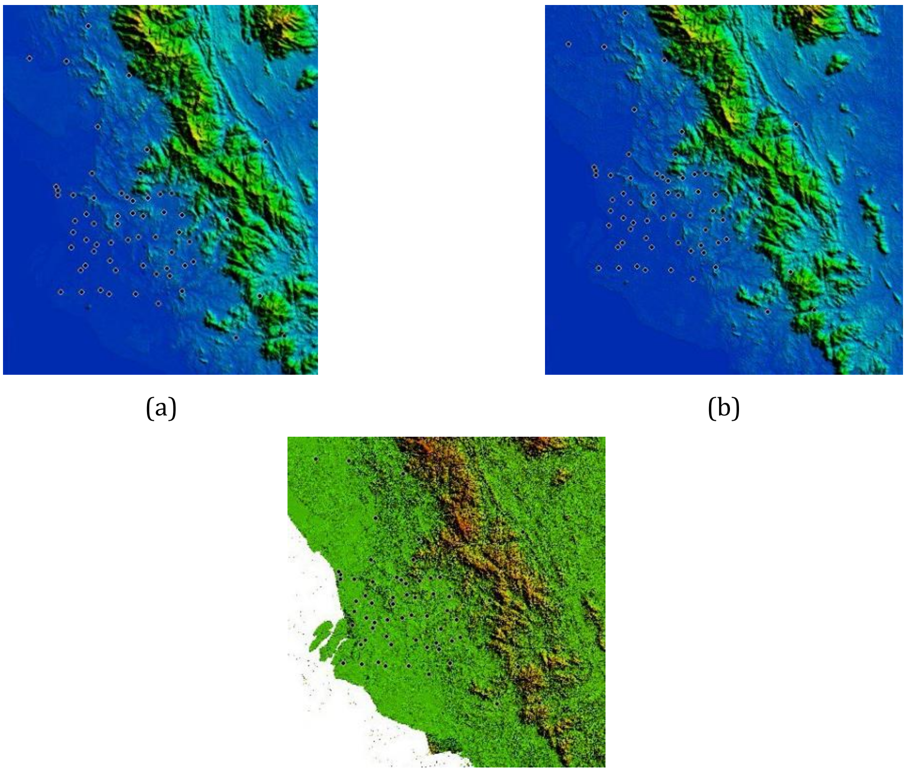
MATLAB is a high-performance language for technical computing. Mapping in MATLAB involves visualizing geographic data on a map. The Mapping Toolbox in MATLAB provides functions and tools specifically designed for geospatial data analysis and visualization. It integrates computation and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation. During the last few years, MATLAB has become an increasingly popular tool in earth sciences [10]. The MATLAB typical uses include Modeling, simulation, and prototyping. MATLAB software also can get Data analysis, exploration, visualization Scientific and engineering graphics

3. Results and Discussion

This study begin by detailing the data collection process, which includes the methodology used, the DEM data source, and the specific parameters used in this study. This basic information ensures a clear understanding of how data is collected and prepared for analysis. At the end of this study, the best DEM can be selected by comparing the three DEM data. The output of the study was verified with standard deviation and correlation coefficient, R values between global DEM leveling data and selected GNSS.

3.1 The selection of DEM for the Selangor region

For the Selangor region, the selection of a Global Digital Elevation Model (DEM) has been made to ensure accurate topographic representation. The selected models include three DEM model which is TanDEM-X, SRTM and ASTER. To validate this model, a comprehensive analysis was conducted using 63 points located in the Selangor region. These points provide a reference point for evaluating the accuracy and reliability of each DEM. The evaluation process, illustrated in Fig. 2(a), (b), and (c), shows 63 points that have been analyzed in the Global Mapper software with three different DEM models which is ASTER, SRTM and TanDEM-X.



(a) (b) (c)

Fig. 2 63 points from (a) ASTER, (b) SRTM, and (c) TanDEM-X in Selangor

Based on Fig. 2(a), (b), and (c), there is no significant difference between SRTM and ASTER visuals. While there is a significant difference in TanDEM-X visuals. This is because, when viewing these datasets in Global

Mapper, the visual differences are likely due to the higher resolution and greater accuracy of the TanDEM-X data compared to SRTM and ASTER. TanDEM-X provides more detailed and accurate representations of terrain features, while SRTM and ASTER might appear smoother or less detailed due to their lower resolutions and differing processing methodologies.

The orthometric heights (H) from all DEMs, collected using Global Mapper, were compared to evaluate the vertical accuracy of each Global DEM in this study. Fig. 3 shows the minimum and maximum height of the terrain through DEM varies from 1.9945m to 173.3063m based on the verification of orthometric height from GNSS and GDEM observations which are able to show the height value for the entire terrain. Fig. 3 shows the results of GNSS and GDEM leveling data validation in the Selangor region. Evaluating the accuracy of the DEMs is essential before they can be utilized by the local community in the future. The highest elevation data obtained through Global Mapper software is from the ASTER model, which measures 173.3063m at the point 61. Conversely, the lowest elevation data is from the TanDEM-X model, measuring 1.9945 at point 38.

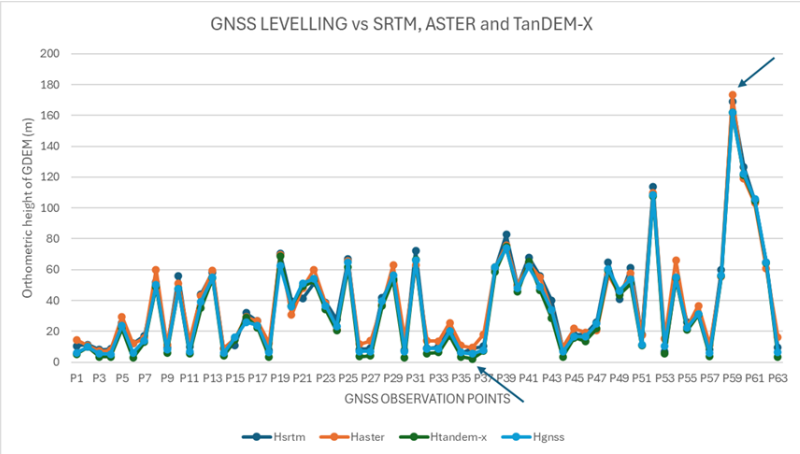


Fig. 3 Comparison between GNSS Levelling data and Digital Elevation Models (DEMs)

3.2 The Analysis of the Validation DEM with GNSS Levelling Data in Selangor

The validation of the Digital Elevation Model (DEM) using GNSS levelling data involved comparing the elevations obtained from the DEM with those measured through GNSS (Global Navigation Satellite System) leveling techniques. This process allowed for the assessment of the accuracy and reliability of the DEM. As shown in Table 4, the correlation accuracy between GNSS leveling data and elevation values produced by SRTM, ASTER, and TanDEM-X. Where, the data validation and analysis is performed based on the standard deviation and correlation coefficient, R values. Using Global Mapper software, the study exported data to a table containing values for Min (m), Max (m), Mean (m), and Correlation (m). This comprehensive analysis provides crucial insights into the performance and applicability of different DEMs in various geographical contexts. Table 2 presents the final assessment of six DEMs.

Table 2 Final Assessment of SRTM, ASTER, TanDEM-X

Accuracy Assessment	SRTM	ASTER GDEM	TanDEM-X
Min (m)	-6.7521	-11.0646	-3.3088
Max (m)	12.4613	8.495	9.5651
Mean (m)	0.243811	-0.47952	4.238827
Correlation, R (m)	0.994648	0.991963	0.998173

Based on the data presented in Table 2, the accuracy and performance of the three Digital Elevation Models (DEMs), SRTM, ASTER GDEM, and TanDEM-X has been analysed based on the comparison with GNSS leveling data. The minimum elevation values show that ASTER GDEM has the lowest minimum value at -11.0646 meters, indicating it might have higher deviations at lower elevations compared to SRTM and TanDEM-X. TanDEM-X, with a minimum value of -3.3083 meters, suggests fewer errors at lower elevations. In terms of maximum elevation, SRTM records the highest value at 12.4613 meters, indicating greater variability or higher peaks in the data, while ASTER GDEM and TanDEM-X have lower maximum values, with TanDEM-X being slightly higher than ASTER GDEM.

The mean elevation values reveal that TanDEM-X has the highest mean at 4.238827 meters, suggesting a positive bias in its elevation measurements. ASTER GDEM has a negative mean value of -0.47952 meters, indicating a slight underestimation in elevation. SRTM, with a mean value close to zero at 0.243811 meters, indicates the least average bias among the three DEMs. The correlation coefficients show that all three DEMs have very high correlation with the GNSS leveling data, indicating strong agreement. TanDEM-X has the highest correlation coefficient at 0.998173, suggesting it has the best overall correlation with GNSS measurements.

TanDEM-X appears to have the best overall correlation with GNSS leveling data, indicating high reliability, although its mean elevation value suggests a positive bias. ASTER GDEM shows good correlation but has a negative mean elevation value, suggesting a tendency to underestimate elevations, and it has the lowest minimum elevation, indicating higher potential errors at lower elevations. Each DEM has its strengths and potential areas of improvement, with TanDEM-X showing the best correlation, SRTM having the least bias, and ASTER GDEM presenting good performance with some underestimation in elevation value.

3.3 Topographic map in Selangor

Selangor's topography, as examined using Global Digital Elevation Model (DEM) data, offers a diversified landscape that greatly contributes to scientific and environmental studies. Selangor's terrain varies from lowland coastal areas to steep inland regions, giving a wealth of elevation data useful for hydrological modelling, land use planning, and ecological studies. The comprehensive elevation information provided by DEMs enables researchers to identify flood-prone zones, assess watershed characteristics, and track changes in landforms over time. The most accurate data among SRTM, Aster and TanDEM-X has been chosen after using the standard deviation formula to analyse the data that is nearest to 1. Table 3 shows the accuracy assessment for standard deviation data (m) for each three DEMs that is SRTM, Aster and Tandem-X.

Table 3 Standard deviation of SRTM, Aster GDEM and Tandem-X

GDEM	Standard Deviation (m)	RANK
SRTM	3.643	2
ASTER	4.051	3
TANDEM-X	2.365	1

The standard deviation ranking position for TanDEM-X is first based on Table 3, which is 2.365m. This represents TanDEM-X is the most suitable to be used in Selangor compared to the other two. While ASTER shows the highest standard deviation which is 4.051m that makes it not suitable to be used for the Selangor area. The elevation of every data obtained mapped using Matlab software to achieve the third objective. The mapping is a sample to compare the view of these DEM. In order to illustrate the elevation value based on global DEM in Selangor region, these three DEM model samples are compared. Fig. 4 represents the mapping using MATLAB software of Selangor region. By comparing these three leveling models using MATLAB, and it can be used for performing statistical analysis, visualizing data, and analyzing errors. The differences between these three samples is their own accuracy, every point from these samples have different longitude and magnitude data. This approach helps in understanding the performance and accuracy of each model in representing elevation data.

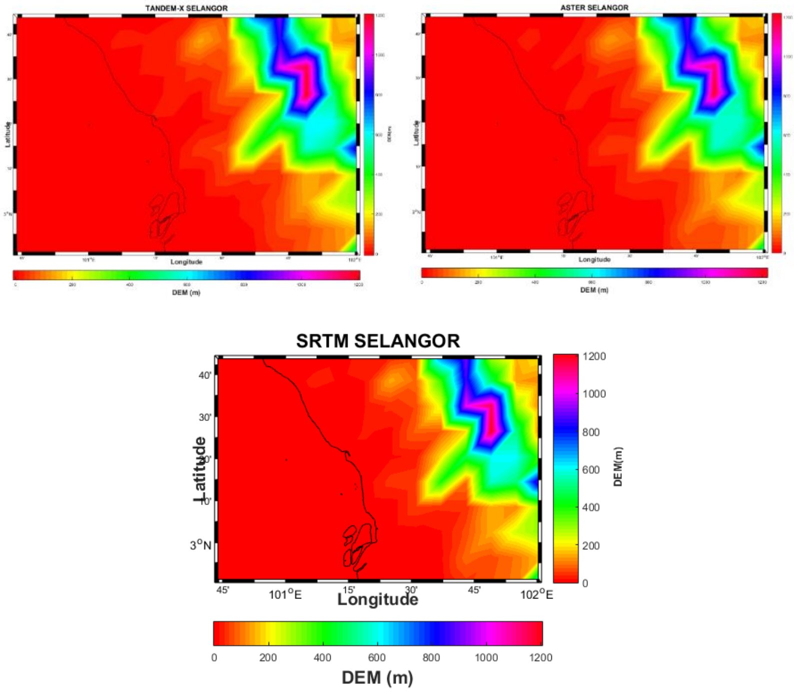


Fig. 4 Comparison orthometric height derived between TanDEM-X, ASTER and SRTM model.

4. Conclusion

This study aimed to evaluate the most precise datasets from open-source DEM which are SRTM, ASTER and TanDEM-X. The orthometric height calculated via GNSS levelling was compared to the corresponding values from open-source DEM datasets. The statistics show that TanDEM-X has the highest vertical accuracy, with a standard deviation of 2.365m. On the other hand, SRTM and ASTER represents standard deviation values of 3.643m and 4.051m respectively. Based on these findings, TanDEM-X appears as the best solution for a variety of topographic applications in Selangor. The successful completion of this levelling survey demonstrates the value of through fieldwork and data analysis in civil engineering and construction projects. The findings not only aid in informed decision-making, but also contribute to the long-term viability and safety of site projects. Future surveys and continual monitoring will be required to ensure that the elevation data remains accurate and relevant as the project advances. This data can be used in future research for development and disaster management including flood, coastal erosion and landslide that can impact this region.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Mohamad Amirul Danial, Muhammad Seri Hidayat, Nournaqie Afsar, Nornajihah;* ***data collection:*** *Mohamad Amirul Danial, Muhammad Seri Hidayat, Nournaqie Afsar;* ***analysis and interpretation of results:*** *Mohamad Amirul Danial, Muhammad Seri Hidayat, Nournaqie Afsar;* ***draft manuscript preparation:*** *Mohamad Amirul Danial, Muhammad Seri Hidayat, Nournaqie Afsar. All authors reviewed the results and approved the final version of the manuscript.*

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