

Selection of a Suitable Digital Elevation Model for Diverse Terrain Nature: Integrating Different Elevation Data Sources

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Abstract

Accurate representation of Earth's diverse terrains is fundamental for geospatial applications, from urban planning to environmental modeling. This research explores the challenge of selecting an appropriate Digital Elevation Model (DEM) for diverse terrain types, focusing on the vertical accuracy in different topographical settings. The study uses various elevation data sources, including the Shuttle Radar Topography Mission (SRTM), Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), high-precision Light Detection and Ranging (LiDAR), data from Unmanned Aerial Vehicles (UAVs), and fine-grained 1:10000 digital vector data. The research aims to identify the suitability of DEMs for diverse topographical natures, revealing the complex interplay between terrain diversity and DEM accuracy. The findings show that the 1:10000 digital vector data layer is the best DEM for three distinct terrain types: highly hilly, moderately hilly, and flat. ASTER, 1:10000 digital vector data, and SRTM provide roughly identical DEM accuracy for flat terrain. The study emphasizes the need for a tailored approach in selecting DEMs to represent Earth's diverse terrains accurately.

Keywords: ASTER, DEM, LiDAR, SRTM, UAV, Vertical accuracy

1 Introduction

A Digital Elevation Model (DEM) is a three-dimensional representation of the Earth's surface that includes the elevation data of the terrain. DEMs are digital datasets that provide a detailed and accurate picture of the terrain's shape, and they are created using a variety of remote sensing techniques, including Radio Detection and Ranging (RADAR), Light Detection and Ranging (LiDAR), and photogrammetry (Fuad et al., 2018).

The diverse nature of terrain has a significant impact on the planet's ecology, weather patterns, and the human population's distribution and lifestyle. Terrain affects the availability of natural resources, such as water, timber, and minerals, and it shapes the way people interact with the environment, such as agriculture, transportation, and urbanization (Elkhrachy, 2018).

The accuracy and resolution of DEMs play a vital role in terrain analysis. High-resolution DEMs enable the detection of detailed landform features such as ridges, valleys, and steep slopes, and facilitate the derivation of key topographic parameters—slope, aspect, and curvature—that strongly influence vegetation patterns, water flow, erosion processes, and sediment transport. (Akturk & Altunel, 2019).

DEM data is used in a range of applications related to terrain analysis, such as watershed management, flood risk assessment, geological mapping, and transportation planning. For example, DEMs can be used to identify areas of potential landslides, map flood-prone areas, and plan transportation routes based on terrain characteristics.

2 Methodology

Concerning the requirement and availability of data, three study areas were selected. Bandarawela, as the highly hilly area, Belihuloya, as the moderately hilly area, and KDU Southern Campus, Sooriyawewa, as the flat area (Figure 1).

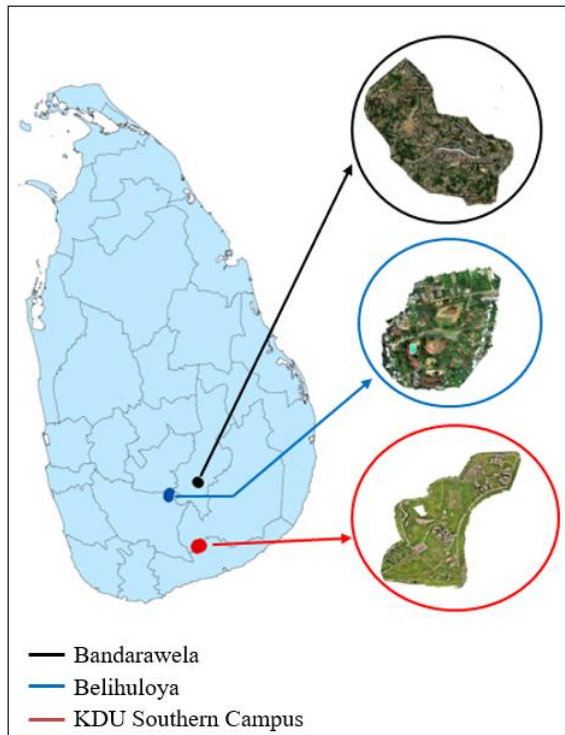


Figure 1: Study Areas

The methodology used in this study is shown in Figure 2. Initially, the DEMs were created from non-satellite-based data.

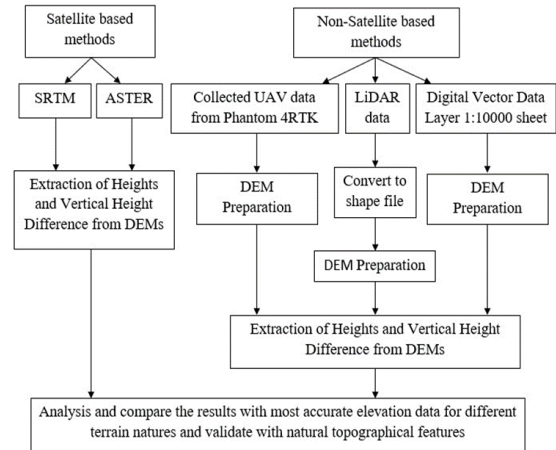


Figure 2: Methodology of the Research

Digital vector data layers at a scale of 1:10,000 are geospatial datasets that provide detailed and precise information about various geographic features. Sheet data is the division of the data into individual map sheets or tiles, organized based on a grid system or administrative boundaries. The terrain layers of the topographic data were used to produce the DEM, and the DEM was created in ArcMap.

UAVs have become increasingly popular tools for data collection in various industries, including agriculture, environmental monitoring, infrastructure inspection, surveying, and more. UAV data processing involves the conversion of raw data captured by drones into meaningful and actionable information. This processed data can then be used for analysis, visualization, and decision-making. UAV data processing plays a crucial role in making sense of the vast amount of information collected by drones, enabling industries to make informed decisions, monitor changes, and improve various processes. Pix4D software was used to generate point orthomosaic images and their cloud data. Pix4D is a sophisticated software used for creating accurate 3D maps, models, and data from aerial imagery, particularly captured by drones. It employs advanced photogrammetry techniques to process overlapping images and generate detailed outputs. The software's capabilities include photogrammetry, aerial mapping, point cloud generation, 3D modelling,

orthomosaic creation, volume calculation, vegetation analysis, and integration with GIS tools.

In ArcGIS, a LAS dataset is a file format designed for efficient lidar data management and analysis. The process involves creating a LAS dataset through the ArcCatalog interface, initiated by right-clicking on a folder and selecting the appropriate option. The dataset is then produced, potentially requiring specification of parameters like coordinate systems. LiDAR data is added to the LAS dataset, and filters can be applied to refine the point cloud information based on various criteria. Finally, raster creation is possible, converting the lidar point cloud into a raster format, with options to use attributes like elevation, intensity, or RGB values for raster generation. This workflow streamlines the handling and analysis of lidar data within the ArcGIS environment.

In the mapping application, vertical accuracy is computed by vertical Root-Mean-Square-Error (RMSE). Root Mean Square Error (RMSE) is a commonly used metric to measure the accuracy of a regression model's predictions. It is also applicable in the context of comparing different DEMs as a form of statistical analysis. Comparing different DEMs using RMSE can help assess their accuracy and identify areas of discrepancy. The RMSE is a specific number that describes the error surface, while the Mean Error (ME) represents the error surface's systematic bias. The following Equations 1 and 2, were used to calculate ME and RMSE, respectively.

- Mean Error

$$ME = \frac{1}{n} \sum (E_0 - E_m) \quad (1)$$

- RMSE

$$RMSE = \sqrt{\sum (E_0 - E_m)} \quad (2)$$

E_0 : Observed elevation

E_m : modeled elevation

n: Number of tested points

Further, in three study areas, a profile was built to show the elevation fluctuation across the produced profile of line features over SRTM, ASTER, and 1:10000 digital vector data DEMs. Table 1 shows the locations of the created cross-sectional profile lines. When designing the cross-sectional line, the lines were drawn most probably perpendicular to the contours and covering all elevation ranges, which then can identify the more undulations of the terrain of that area.

Table 1: Cross-Sectional Profile Line Locations

Location	Starting point (Decimal Degree)		Ending point (Decimal Degree)	
	N	E	N	E
Bandarawela	80.992	6.828	81.018	6.808
Belihuloya	80.768	6.716	80.801	6.725
KDUSouthern Campus	80.992	6.352	81.012	6.358

3 Results and Discussion

A. Statistical Analysis of Satellite-Based Methods for Study Areas

The two DEMs, SRTM and ASTER, were opened in one project in ArcMap. The error map was generated using the raster calculator tool. Value for each pixel in raster representation was obtained from the Raster to Point tool. The statistics of the attribute table of points give the Standard deviation of the area and the RMSE value between SRTM and ASTER DEM.

Table 2: The RMSE and ME Values for SRTM DEM with Respect to the ASTER DEM

Location	Mean Error	RMSE
Bandarawela	-3.34473	11.187236
Belihuloya	-4.456958	6.501365
KDU Southern Campus	-8.650164	3.683502

According to Table 2 above, in Bandarawela, the calculated RMSE of 11.187 signifies a relatively higher level of discrepancy between the SRTM and ASTER DEMs. This could be attributed to the inherent challenges of accurately

representing the complex topography of hilly regions. Factors such as occlusion due to vegetation, variations in slope, and the presence of shadows may have contributed to the observed differences. Consequently, caution should be exercised when employing these DEMs for applications that demand precise elevation information in such areas, like hydrological modeling or site planning for infrastructure.

Moving to Belihuloya, the RMSE of 6.501 indicates a moderate level of discrepancy between the two DEM datasets. While the variance is lower compared to the hilly region, it is still noteworthy. The accuracy of DEMs can be influenced by factors such as interpolation methods, sensor characteristics, and temporal variations. Therefore, when utilizing these DEMs for tasks such as landform analysis or vegetation modeling in moderately hilly regions, it is recommended to consider the potential impact of these differences on the outcomes.

In flat terrain, the RMSE value of 3.684 reflects a relatively minor level of deviation between the SRTM and ASTER DEMs. Flat terrains are generally easier to capture accurately due to less complex elevation changes and minimal occlusion effects. The smaller RMSE suggests that both DEM datasets perform reasonably well in such areas, making them suitable for applications like urban planning, flood modeling, and precision agriculture.

A. Statistical Analysis of Non-Satellite-Based Methods for Study Areas

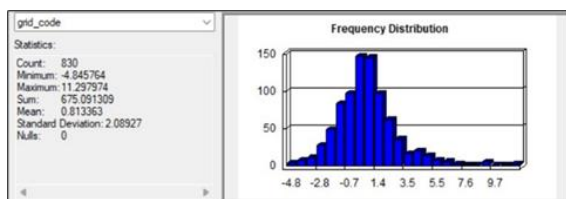


Figure 3: RMSE Value for the DEMs Generated from UAV Data and 1:10000 Digital Vector Data in Belihuloya Area

The obtained RMSE value of 2.08927 showcases the favourable performance of UAV-derived DEMs in a moderately hilly area when compared

to 1:10000-scale digital vector data. This result underscores the potential of UAV technology for capturing accurate elevation information and highlights its compatibility with more traditional data sources. However, a comprehensive understanding of the accuracy and limitations of both datasets is essential when choosing the most suitable data source for specific applications in diverse terrains. The above Figure 3 shows the RMSE value for the DEMs generated from UAV and 1:10000 digital vector data in the Belihuloya study area.

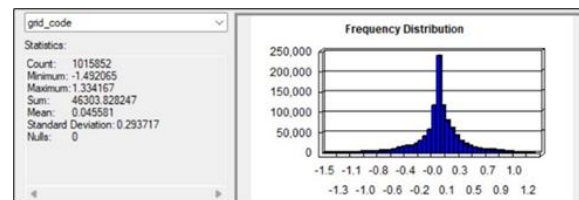


Figure 4: RMSE Value for LiDAR Data & UAV Data for Belihuloya

The remarkably low RMSE value of 0.293717 in the comparison between UAV-derived and LiDAR-based DEMs in a moderately hilly area highlights the maturity of these technologies and their ability to provide accurate elevation information, as shown in the above Figure 4. This result empowers decision-makers to choose the most proper data source based on their specific needs and constraints. Nevertheless, as with any data comparison, a nuanced understanding of the dataset's accuracy, strengths, and limitations is essential to ensure reliable outcomes across a variety of applications.

To create the comparison in the study areas, the cross-section was stretched. The topography of the research area was depicted using cross-sectional topography. The following Figures 5, 6, and 7 show the elevation differences that occurred during the comparison of cross-sectional data.

0.02. SRTM shows a higher elevation than ASTER and 1:10000 digital vector data in several locations.

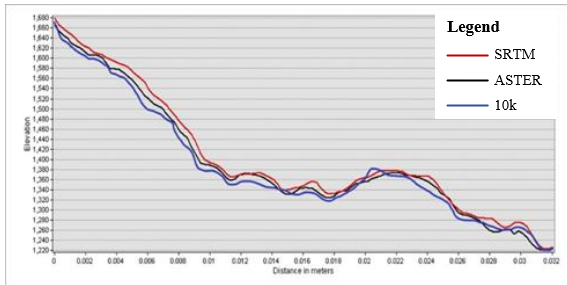


Figure 5: Profile Line in Study Bandarawela Based on SRTM, ASTER and 1:10000 Digital Vector Data Layer

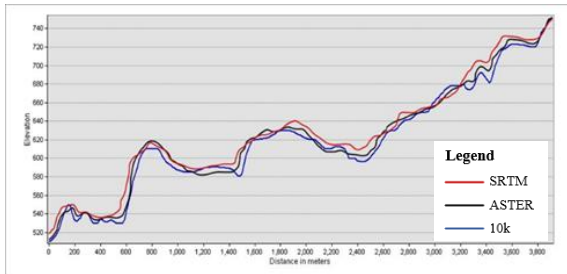


Figure 6: Profile Line in Study Belihuloya Based on SRTM, ASTER and 1:10000 Digital Vector Data Layer

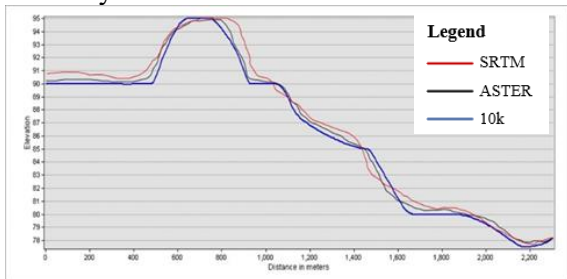


Figure 7: Profile Line in Study KDU Southern Campus Based on SRTM, ASTER and 1:10000 Digital Vector Data Layer

The profile analysis conducted across the Bandarawela area highlights the diverse performance characteristics of SRTM, ASTER, and 1:10000 vector data layer DEMs. The results underscore the importance of carefully evaluating dataset selection based on the specific terrain characteristics and application requirements. The profile line created in Bandarawela, which reaches the highest altitudes of 1700 m, shows that the research area's topography has greater undulations in its height. Although 1:10000 digital vector data, ASTER, and SRTM rated first, second, and third, respectively, among the data examined in terms of topographic information, it may be suggested that 1:10000 digital vector data provided the most irregular surface. The values of the three DEM representations are slightly comparable throughout the range of 0.018 to

The profile analysis performed across the Belihuloya area underscores the varying performance of SRTM, ASTER, and 1:10000 vector data layer DEMs. The results shed light on the challenges and advantages associated with each dataset within this specific terrain type, aiding in informed decision-making for a range of geospatial applications. There are some moderate undulations in the elevation of the terrain in the research area, as shown by the increases of up to 750 m in the somewhat difficult terrain of Belihuloya. It might be suggested that the irregular surface was formed by 1:10000 digital vector data. The values shown by the three DEM representations are somewhat similar within the 2800–3000m range. SRTM provides more elevation in numerous places in this study area compared to ASTER and 1:10000 digital vector data. As always, a thorough consideration of dataset characteristics and terrain complexities is vital when selecting the right DEM source for a given task.

The profile analysis undertaken in the KDU Southern campus area, comparing SRTM, ASTER, and 1:10000 vector data layer DEMs, reveals key insights into their accuracy within this specific terrain type. The results show that SRTM, a globally available dataset, offers a reasonable approximation of elevation in flat regions, despite minor discrepancies likely due to radar-based limitations. ASTER, with its multispectral imaging and stereo capabilities, proves strong alignment with ground truth elevations, making it particularly helpful in capturing fine elevation details in flat areas. Meanwhile, the 1:10000 vector data layer DEM, known for its precision, strongly agrees with ground truth elevations, making it an excellent choice for tasks requiring high accuracy, such as infrastructure planning. These findings underscore the importance of selecting DEM sources based on application requirements and highlight the strengths of each dataset in accurately representing elevation in flat terrains.

4 Conclusion

This research focused on selecting a suitable Digital Elevation Model (DEM) for diverse

terrains by integrating various elevation data sources. Key objectives included developing DEMs from multiple data sources, assessing their suitability for varied terrain, and validating their vertical accuracy. Satellite-based data (SRTM DEM, ASTER DEM) and non-satellite-based data (LiDAR, UAV, digital vector) were integrated, emphasizing data quality and resolution. Techniques like interpolation and data fusion were employed, revealing the ability to use data source strengths to mitigate weaknesses. Results showed significant vertical accuracy differences in highly hilly areas for satellite-based DEMs, while DEMs from non-satellite-based data showed smaller differences. Based on an analysis, LiDAR data is the most accurate source for creating a digital elevation model (DEM) in hilly regions. Producing LiDAR data for any terrain type can result in a more accurate digital elevation model. This study showed that the 1:10000 digital vector data layer is the best proper DEM for three distinct terrain types: highly hilly, moderately hilly, and flat. ASTER, 10k, and SRTM all provide roughly identical DEM accuracy for flat terrain. Overall, the study provides valuable insights for informed DEM selection, considering terrain characteristics and data quality in geospatial analysis.

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