Research Journal of Agricultural Science, 58 (3), 2026; ISSN: 2668-926X;

http://doi.org/10.59463/RJAS.2026.3.49

DIGITAL TERRAIN MODELING BASED ON LiDAR AND SRTM DATA AND EVALUATION OF MORPHOMETRIC PARAMETERS IN THE GIS ENVIRONMENT

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Abstract. *The paper presents a modern approach to digital terrain modelling through the use and integration of altimetric data from LiDAR and SRTM sources, processed and analysed in the GIS environment. The study is based on real data, complemented with information obtained from global digital elevation models, used to generate a digital terrain model (DTM). The data used included SRTM models and LiDAR datasets, supplemented with field measurements by GNSS technology and total station, for the purpose of validation and positional correction. The data processing was carried out using GIS applications, in particular Global Mapper, which allowed the integration, filtering and interpolation of data, as well as the generation of three-dimensional models. The methodology adopted included the generation of point clouds, the realization of the digital terrain model by interpolation methods (TIN), as well as the derivation of morphometric parameters such as slope, longitudinal and transverse profiles and altimetric variations. The results obtained highlight the advantages of using LiDAR data compared to SRTM models, especially in terms of accuracy and level of detail. At the same time, SRTM data offers extensive coverage and high accessibility, making it useful in regional-scale studies. The integration of these types of data leads to reliable and efficient digital land models applicable in areas such as agriculture, environmental analysis and spatial planning. In addition, the proposed approach demonstrates a high degree of flexibility in integrating geospatial data from multiple sources, allowing for more detailed terrain characterization and supporting more accurate spatial analysis and decision-making processes.*

Keywords*: LiDAR, SRTM, digital terrain model, GIS, Global Mapper, morphometric analysis, 3D model, altimetric data*

INTRODUCTION

Digital terrain modelling is an essential component of modern geospatial analysis, providing a quantitative representation of the land surface and supporting the interpretation of terrain characteristics in a wide range of applications. Digital terrain models are increasingly used in agriculture, environmental monitoring, hydrological analysis, spatial planning, infrastructure design and land administration, where the accuracy of elevation information directly influences the reliability of subsequent spatial analyses (BURROUGH and MCDONNELL, 1998; LONGLEY et al., 2015). The development of modern surveying and remote sensing technologies has significantly improved the methods used for acquiring and processing topographic data, allowing digital terrain models to be generated with increasingly high spatial resolution and altimetric accuracy (LI et al., 2005).

The quality of a digital terrain model depends on several factors, including the characteristics of the original elevation data, spatial resolution, acquisition technology, interpolation method and terrain morphology. Consequently, selecting an appropriate elevation data source represents an important stage in terrain analysis, particularly when models obtained

from different acquisition technologies are compared. Geomorphometric analysis based on digital elevation data allows the extraction of relevant terrain parameters, including slope, elevation differences, surface profiles and other morphometric characteristics that can support the interpretation of landforms and spatial processes (HENGL and REUTER, 2009; SMITH et al., 2011).

Among the most widely used sources of altimetric data are LiDAR (Light Detection and Ranging) technology and SRTM (Shuttle Radar Topography Mission) data. LiDAR is an active remote sensing technology capable of acquiring dense three-dimensional information about the land surface and provides high-resolution elevation data suitable for detailed terrain analysis (WEHR and LOHR, 1999). Its capacity to identify relatively small variations in elevation makes LiDAR particularly useful for detailed topographic surveys, engineering applications and analyses in areas where micro-relief characteristics are important.

In contrast, the Shuttle Radar Topography Mission provides digital elevation data with extensive spatial coverage and relatively easy accessibility. SRTM represented a major development in global terrain mapping and continues to be widely used in regional and large-scale geospatial studies (FARR et al., 2007). Evaluations of SRTM performance have demonstrated its usefulness for terrain representation, although its accuracy and capacity to reproduce local relief variations depend on terrain characteristics and spatial resolution (RODRIGUEZ et al., 2006). These characteristics make the comparison between LiDAR and SRTM particularly relevant because the two data sources represent different approaches in terms of spatial resolution, level of detail, accessibility and potential fields of application.

Global digital elevation models such as ASTER GDEM provide an additional source of altimetric information and can complement SRTM data in regional terrain studies. Their availability facilitates comparative analyses between elevation datasets obtained through different technologies and enables the assessment of their behaviour under various geomorphological conditions (NASA/METI, 2013). Such comparisons are especially important in predominantly low-relief regions, where relatively small vertical errors may influence the representation of contour lines, slopes and local terrain variations.

The integration of elevation data from different sources within a GIS environment provides the possibility of combining terrain modelling, morphometric analysis and cartographic representation within a common workflow. GIS applications facilitate data reprojection, interpolation, filtering, visualization and the generation of three-dimensional terrain models, while also allowing the comparison of spatial datasets with different resolutions and acquisition characteristics (LONGLEY et al., 2015; CONRAD et al., 2015). The integration of remotely sensed information with field measurements obtained using modern geodetic technologies can additionally contribute to the validation and interpretation of digital terrain models. Recent geodetic applications have demonstrated the importance of integrating GNSS measurements and geospatial processing for obtaining reliable spatial information in topo-cadastral applications (ȘMULEAC et al., 2025).

For Western Romania, the evaluation of different elevation datasets is particularly relevant due to the predominantly plain relief and the relatively small altimetric variations characteristic of large agricultural areas. Under these conditions, the capacity of a digital elevation model to reproduce subtle changes in terrain configuration becomes important for applications related to agriculture, drainage, water management, land planning and detailed topographic analysis. A comparative evaluation of LiDAR, SRTM and ASTER data can therefore contribute to identifying the advantages and limitations of each source and to selecting

an appropriate dataset according to the required level of detail and the spatial scale of the application.

The main purpose of this work is the digital modelling of the terrain based primarily on LiDAR and SRTM data and the evaluation of the resulting morphometric parameters in the GIS environment. ASTER GDEM data are additionally considered as a global elevation source for comparative purposes. The study aims to analyse differences in terrain representation, level of detail and altimetric behaviour, as well as to evaluate the applicability of the analysed datasets under the specific conditions of Western Romania. Particular attention is given to the integration of remotely sensed elevation data with field measurements and to the identification of an appropriate balance between accuracy, spatial resolution, accessibility and intended application.

MATERIAL AND METHODS

The study was conducted for the purpose of comparative evaluation of digital terrain models obtained from LiDAR and SRTM data, in order to identify differences in accuracy and level of detail. Unlike photogrammetric methods used in other studies, this research focuses on altimetric analyses based on data from active remote sensing and global elevation models.

LiDAR data was used to obtain a detailed model of the land surface, which is characterized by high resolution and superior accuracy. SRTM data were used to complement and extend the analysis, which provide extensive spatial coverage, being suitable for regional scale analyses (FARR et al., 2007; RODRIGUEZ et al., 2006).

For the purpose of validation and positional correction, measurements made in the field by GNSS technology and total station were used, which allowed the verification of the accuracy of the altimetric data.

The data processing was carried out using the Global Mapper application, which allowed the import, reprojection and integration of data from different sources. The data were reprojected into the national coordinate system Stereographic 1970, using the parameters specific to the Dealul Piscului 1970 datum. Subsequently, digital terrain models were generated using TIN (Triangulated Irregular Network) and GRID interpolation methods (HENGL and REUTER, 2009).

Based on the models obtained, morphometric parameters of the land were derived, such as slope, level differences and longitudinal and transverse profiles. The calculation of the slope was made using the relation:

$$\alpha = \arctan(\Delta Z/d)$$

where:
α represents the angle of the slope,
ΔZ stands for the difference in level,
d represents the horizontal distance between points.

Also, to evaluate the differences between the data sets used, a comparative analysis was performed between the altimetric values obtained from LiDAR data and those from SRTM models, using statistical indicators such as RMSE (Root Mean Square Error).

The data processing included steps of filtering, classification and generation of three-dimensional models, as well as visualization of the results in the form of thematic maps and 3D models, used for the interpretation of terrain features (HENGL and REUTER, 2009; CONRAD et al., 2015).

As part of the data processing, the Global Mapper application was also used to access online sources of altimeter data, through the integrated geospatial data download module. Thus, digital elevation models from global sources, such as ASTER GDEM (Advanced Spaceborne Thermal Emission and Reflection Radiometer Global Digital Elevation Model), were additionally analysed, along with SRTM data already used in the study (NASA/METI, 2013).

ASTER GDEM models, with spatial resolution of approximately 30 m, were included in the analysis to allow a direct comparison between different sources of globally available altimetric data. Their integration into the GIS environment allowed the assessment of differences in the accuracy and level of detail of the land surface (Figure 1).

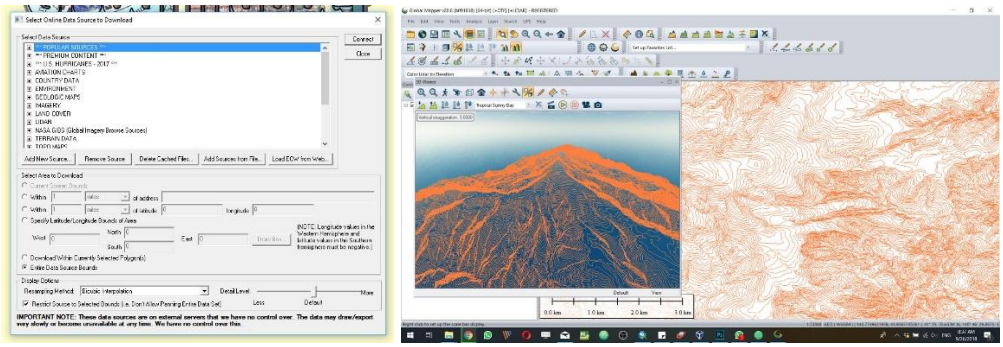


Figure 1. Global Mapper application interface used to access and integrate SRTM and ASTER data

Comparing the results obtained with those reported in the literature, it is confirmed that LiDAR data offer the highest accuracy and the highest level of detail, while SRTM models represent an optimal solution for regional analyses. In contrast, ASTER models have significant limitations, especially in lowland areas, where relative errors become more pronounced.

For each type of data used (LiDAR, SRTM and ASTER), digital terrain models and contour lines were generated, using the specific functionalities of the Global Mapper application. The process involved interpolating the altimetric data and converting them into vector representations, necessary for morphological analysis of the terrain.

For a further evaluation of the behaviour of the analysed models, longitudinal land profiles were generated on representative directions. The analysis of these profiles revealed significant differences between the models used, especially in terms of local altimetric variations. The LiDAR model features high continuity and increased detail fidelity, while the SRTM model provides a generalized representation, and the ASTER model introduces artificial variations in relief.

To evaluate the applicability of these models in the specific conditions of western Romania, characterized by predominantly plain relief, a comparative analysis of the quality of the contour lines and the altimetric values extracted from each type of model was carried out. This analysis aimed to identify the optimal data source for the faithful representation of relief variations in areas with low altimetric differences.

RESULTS AND DISCUSSIONS

The results obtained from the altimetry data processing highlighted significant differences between the digital terrain models generated based on LiDAR, SRTM and ASTER data. The comparative analysis was carried out both in terms of graphical representation (contour lines, 3D models) and numerical values extracted from the field.

http://doi.org/10.59463/RJAS.2026.3.49

The models based on LiDAR data provided the highest level of detail, allowing for the clear identification of micro-relief variations and anthropogenic elements. The contour lines generated from this data are uniform and accurate, faithfully reflecting the actual configuration of the terrain. In addition, the altimetric differences calculated based on LiDAR data showed the smallest deviation from field measurements.

In the case of SRTM models, the results showed good stability of the modelled surface, being suitable for regional-scale analyses. The generated contour lines are continuous and relatively uniform, but the level of detail is lower than that obtained from LiDAR data. However, in the plain areas of western Romania, SRTM data proved to be accurate enough for the general representation of the relief (FARR et al., 2007; RODRIGUEZ et al., 2006).

The ASTER GDEM models showed higher surface variability, being affected by noise and local errors. The contour lines generated from these data are less uniform, and in some cases there are discontinuities or artificial variations in the relief (NASA/METI, 2013). These aspects limit the use of ASTER data in detailed analyses, especially in areas with low elevation differences (Table 1).

Table 1

Comparing the performance of digital terrain models

Model	**Spatial resolution**	**Altimetric accuracy**	**Level of Detail**	**Behaviour in lowland areas**
LiDAR	very high	very high	Very detailed	excellent
SRTM	~30 m	Good	Environment	Good
ASTER	~30 m	variable	Reduced	Weak

For an applicative interpretation of the results obtained, Table 2 presents the areas of use and recommendations associated with each type of digital model analysed, depending on the level of detail and requirements of the geospatial applications.

Table 2

Areas of use and recommendations for the analysed digital land models

Model	**Recommended areas of use**	**Level of detail required**	**Recommendation**
LiDAR	cadastre, engineering design, detailed topographic studies	high	Recommended for precision analysis and engineering applications
SRTM	agriculture, regional analysis, spatial planning	Environment	Optimal solution for general studies and large-scale assessments
ASTER	general analyses, exploratory studies, preliminary evaluations	Reduced	limited use, requires additional validation

In the specific conditions of western Romania, characterized by predominantly plain relief, the results indicate that SRTM data offer an optimal compromise between accuracy and accessibility, being more stable than ASTER models in generating contour lines. However, for applications that require a high level of detail, LiDAR data remains the optimal solution, providing the most accurate representation of the land surface.

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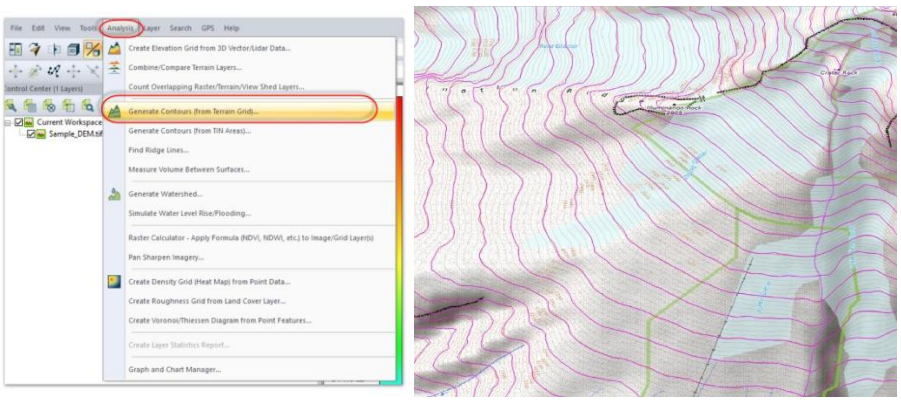


Figure 2. Digital terrain model and contour lines generated based on SRTM and ASTER data

As can be seen in Figure 2, the analysed models show differences in the representation of the contour lines, with the SRTM data providing a more uniform surface compared to the ASTER model.

Following the comparative analysis, the RMSE values calculated between the LiDAR and SRTM data indicated low deviations, while the differences between LiDAR and ASTER were significantly higher, confirming the variability of this type of model.

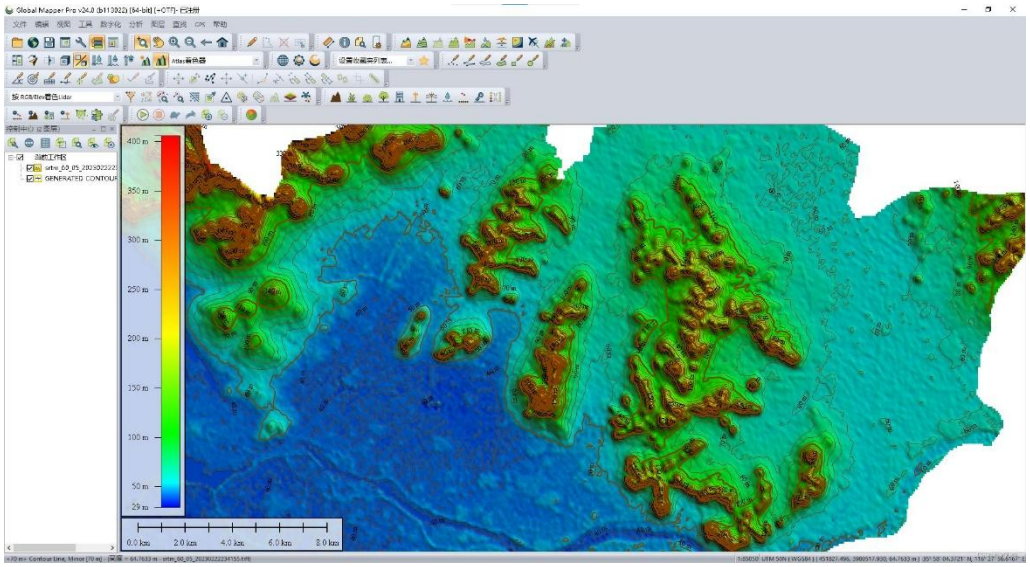


Figure 3. Longitudinal profile of the terrain obtained from the analysed digital models

The digital terrain model generated based on LiDAR data shows the highest level of detail, being able to render fine variations in relief, including microforms and anthropogenic elements. As can be seen in Figure 3, the modelled surface is continuous and free of artifacts, and the contour lines are uniform and correctly distributed. This type of model allows a detailed analysis of the terrain, being suitable for engineering and cadastral applications.

The models generated from SRTM data, illustrated in Figure 2, provide a generalized representation of the terrain, with a lower level of detail compared to LiDAR data. However, the modelled surface is relatively stable with no major artificial variations. The contour lines are continuous, but show a simplification of the landforms, which indicates a loss of detail specific to the lower resolution (FARR et al., 2007; WEHR and LOHR, 1999).

In the case of ASTER GDEM models, a higher variability of the land surface is observed. Irregularities and discontinuities occur in the representation of contour lines, generated by interpolation errors and data noise. These characteristics affect the quality of the model and limit its use in detailed analyses.

To evaluate the differences between the analysed models, altimetric values were extracted from common points, comparing the LiDAR data with those from the SRTM and ASTER models. The analysis revealed smaller deviations between LiDAR and SRTM, while the differences between LiDAR and ASTER were more pronounced, confirming the variability of this type of model.

Mean Square Error (RMSE) values indicate higher accuracy of LiDAR data, followed by SRTM models, while ASTER data shows the largest deviations. This confirms that the accuracy of the model depends directly on the acquisition method and the resolution of the data used.

The RMSE values obtained from the comparison showed differences in the order of meters between the analysed models, with smaller deviations in the case of SRTM data compared to LiDAR and significantly higher values for the ASTER model. These results confirm that global elevation models have limitations in the detailed representation of the relief.

The analysis carried out for the western area of Romania, characterized by predominantly plain relief, highlights the fact that the differences between the models become more evident in the conditions of low altimetric variations. Under these conditions, ASTER models tend to introduce significant errors, while SRTM data provides a more stable representation of the land surface.

The results confirm that SRTM models are an efficient and affordable solution for regional applications, while LiDAR data is required for detailed analysis and precision work.

The results obtained are in line with specialized studies, which highlight the superiority of LiDAR data in detailed relief analysis, but also the usefulness of SRTM models in large-scale applications (FARR et al., 2007; RODRIGUEZ et al., 2006; WEHR and LOHR, 1999).

Overall, the benchmarking highlights that the choice of the digital terrain model must be made according to the purpose of the application, requiring a trade-off between accuracy, resolution and data availability.

CONCLUSIONS

Following the comparative analysis carried out, it can be concluded that the digital terrain models obtained from LiDAR data offer the highest accuracy and the highest level of detail, being suitable for engineering, cadastral and detailed study applications.

SRTM data has proven to be an effective solution for regional-scale analysis, providing an optimal balance between accuracy, spatial coverage, and accessibility. In the conditions specific to western Romania, characterized by predominantly plain relief, these models ensure a stable and coherent representation of the land surface.

In contrast, ASTER models have significant limitations, evidenced by artificial relief variations and local errors, which reduces their applicability in detailed analyses, especially in areas with small elevation differences.

The results obtained are in line with the studies in the literature, which highlight the superiority of LiDAR data in detailed relief analysis, but also the usefulness of SRTM models in large-scale applications. Research in Central and Eastern Europe confirms these trends, especially in regions with poorly fragmented relief, where differences between digital patterns are becoming more evident.

In the context of Romania, the results highlight the fact that for lowland areas, such as the west of the country, the use of SRTM data represents an effective solution for the general analysis of the terrain. However, for applications that require high accuracy, such as cadastral work or engineering projects, the use of LiDAR data is recommended.

The integration of data from multiple sources into the GIS environment makes it possible to obtain reliable digital terrain models that are adaptable to different types of applications. The choice of data source must be made according to the purpose of the analysis, requiring a compromise between accuracy, resolution and data availability.

Based on the results obtained, it is recommended to use the integrated use of several altimeter data sources, as well as their validation by field measurements (GNSS or total station), to increase the accuracy of digital models. For future research, it is proposed to extend the comparative analyses to other global digital models, as well as to evaluate them under various geomorphological conditions.

From a practical perspective, the results of this study emphasize the importance of selecting elevation data according to the spatial scale, accuracy requirements and final purpose of the analysis. The use of the highest-resolution dataset is not necessarily justified for every application. In regional studies, particularly in predominantly low-relief areas such as Western Romania, SRTM data can provide an appropriate basis for preliminary terrain characterization, agricultural planning and environmental assessment, while reducing data acquisition and processing requirements. Conversely, applications involving cadastral surveys, engineering design, detailed drainage analysis or the identification of micro-relief features require higher spatial and vertical accuracy, making LiDAR data more appropriate. The combined use of global elevation models and high-resolution datasets can therefore represent an efficient strategy for adapting the level of detail to the specific requirements of each project.

An important contribution of the proposed approach is the integration of remotely sensed elevation data with field-based geodetic measurements within a common GIS workflow. GNSS and total station measurements can provide an independent reference for evaluating local altimetric differences and identifying possible inconsistencies in digital elevation models. This aspect is particularly relevant in areas with small elevation differences, where relatively limited vertical errors may influence the interpretation of slopes, contour lines, drainage directions and terrain profiles. Consequently, the validation of global elevation models should be considered an important stage when these datasets are used for applications requiring increased positional reliability.

At the same time, the study has several limitations that should be considered when interpreting the results. The comparative assessment was carried out under the specific geomorphological conditions of Western Romania and therefore the behaviour of the analysed datasets may differ in hilly or mountainous regions, where terrain complexity is substantially higher. Future research should extend the analysis to areas with different relief characteristics and should include additional global and regional elevation datasets. A larger number of field control points and a more detailed statistical evaluation of vertical errors could also improve the quantitative assessment of model performance.

Overall, the results demonstrate that there is no single digital elevation data source that can be considered optimal for all geospatial applications. The most appropriate solution depends on the required accuracy, spatial resolution, data availability, processing resources and scale of analysis. The integration of LiDAR, global elevation models and field measurements provides a flexible methodological framework capable of combining regional accessibility with local accuracy. Such an approach can support a wide range of applications in agriculture, environmental monitoring, spatial planning, cadastral surveying and engineering, while providing a more reliable basis for terrain analysis and geospatial decision-making.

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