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Vertical Accuracy Assessment for the Free Digital Elevation Models SRTM and ASTER in Various Sloping Areas

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Keywords
Accuracy assessment, check points, SRTM-1, ASTER 1, root mean square error, outlier.

Abstract: Some free versions of the digital elevation models are available for SRTM and ASTER with the same spatial resolution of 30m, but differences in survey accuracy and techniques used in producing data for each, as well as the impact of terrain slope, lead to differences in their vertical accuracy. On the other hand, the number of check points used in evaluating this accuracy process plays an important role, as the elevation differences of the check points contain outliers that must be removed before completing the vertical accuracy assessment process. The main goal of this research is to evaluate the impact of terrain slope on the vertical accuracy of the SRTM-1 and ASTER A1 models, which have the same spatial resolution. The research applied ASPRS standards to determine the necessary number of check points to evaluate accuracy, with a proposed application of a simple method to identify outliers in elevation differences. Tests were conducted in the Latakia Governorate after dividing it into three areas: a moderate slope area, a moderate steep slope area, and a steep slope area. As for the check points, they were extracted from a topographic map with a scale of 1/25000. The results showed a strong positive correlation between reference elevations and elevations extracted from both the SRTM and ASTER models in all test areas, with a Pearson coefficient value of 0.99. It was also found that the vertical accuracy of the SRTM model is better than that of the ASTER model in the moderate slope area, where this accuracy reached 11.899m. In the case of the moderate steep slope area, the research found that the elevations extracted from the SRTM model are more accurate than those extracted from the ASTER model, with a vertical accuracy value of 21.609m for the SRTM model and 23.145m for the ASTER model. In the case of steep slope area, it was found that the elevations extracted from the ASTER model are more accurate than those extracted from the SRTM model, with a vertical accuracy of 36.770 meters for the ASTER model and 40.538 meters for the SRTM model.

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1. **Introduction**

Digital Elevation Model (DEM) is considered one of the most significant products of remote sensing. This involves the DEM being extracted using various methods with different levels of accuracy and costs. Historically, these models were extracted using aerial stereo images. However, satellite imagery is currently considered the primary source for producing these models [1]. Digital elevation models provide us with information about the Earth's surface and are an important input in the processing and analysis of imagery, such as correcting displacements resulting from changes in terrain elevations in imagery (Ortho-rectification), Contour mapping, deriving three-dimensional images, disaster management (identifying areas prone to landslides, floods, and others) [2 and 3], in addition to many other applications.

Over the past decades, advancements in Earth observation technologies have led to the acquisition of a diverse range of digital elevation models covering vast areas of the Earth (potentially global coverage). This collection includes the well-known Shuttle Radar Topography Mission (SRTM) model [4] and the ASTER Global Digital Elevation Model (ASTER GDEM2) [5]. The global models ASTER GDEM2 were obtained using stereo photogrammetry, while the SRTM model was generated by measuring interference using a synthesized radar called Interferometric Synthetic Aperture Radar (InSAR).

Evaluating the vertical accuracy of open-source global digital elevation models requires a comparison process of the elevations derived from these models to a set of reference points, known as check points, with their elevations measured using more precise techniques such as GPS [6] or derived from accurate reference digital elevation models [7]. In this research, the Root-Mean-Square Error (RMSE) value had been used to estimate the vertical accuracy.

Despite the availability of some versions of the SRTM and ASTER models with the same spatial resolution (SRTM1 and ASTER Level 1A) at 30m, this does not necessarily mean that these versions have the same vertical accuracy due to differences in survey accuracy and the techniques used in producing their data, as well as the impact of terrain slope on this data. The number of check points used in the accuracy assessment process typically plays a crucial role. Additionally, the height differences of the check points contain outliers that need to be removed before completing the vertical accuracy assessment. The basic assumption of outlier detection assumes that the height differences follow a normal distribution can be considered acceptable if there are no significant biases or systematic errors present. However, to ensure the validity of this assumption, it will be tested using statistical methods such as the Kolmogorov-Smirnov test or the Shapiro-Wilk test. These tests will help determine whether the differences between the DEMs genuinely follow a normal distribution, allowing for the reliable use of this assumption in subsequent analyses.

2. Previous Studies

There are many research studies that have dealt with the subject of EDM accuracy assessments. The study by Bildirici, I. O., et. al. (2017) is one of the studies that compared the vertical accuracy of the SRTM and ASTER models with a 30m resolution throughout Turkey by comparing them with a locally produced reference elevation model from national topographic maps at a scale of 1/25000. The results showed that the accuracy of the SRTM model is better than the accuracy of the ASTER model concerning the locally produced reference elevation model, with the ASTER model excelling in some rugged terrain areas in terms of elevation data accuracy [8]. In a study conducted by Fazilova, et. al. (2021), the accuracy of several digital models for the study area was evaluated, and the research concluded that the ASTER GDEM2 model is the most accurate among these models by calculating the root mean square error, mean error, and absolute vertical accuracy at a 90% confidence level using GPS measured check points [9]. In a study conducted by Kovalchuk, et al. (2019), a comparison of the vertical accuracy of SRTM and ASTER GDEM models with a resolution of 90 meters (three arc-seconds) was made using a reference digital elevation model derived from topographic maps with a scale of 1/50000. The study found that the elevation values derived from SRTM and ASTER models correspond to a vertical accuracy of 16 and 17 meters, respectively, which are close values [10]. In a study conducted by Elkhrachy, 2018, the accuracy of the SRTM and ASTER DEM models in the city of Najran in the Kingdom of Saudi Arabia was evaluated using Global Positioning System (GPS) devices and topographic references. The research concluded that the absolute vertical accuracy of the elevations extracted from the two models is two to three times greater than the theoretical absolute value of vertical accuracy for the SRTM model, which is 16 meters [11]. In a study conducted by Florinsky, et al. (2018), the vertical accuracy of three digital elevation models, namely AW3D30 DSM, SRTM1, and ASTER GDEM, was compared. The results showed that the AW3D30 DSM model is the most accurate and capable of representing the actual terrains of the test area, whereas the ASTER GDEM model was the least accurate among the tested models, particularly near the landslide slopes, forest-grass boundaries, and the highway [12].

3. Research objectives and its importance

It is true that, when comparing global free digital elevation models with national elevation models (if available), these global free models tend to have lower vertical accuracy. However, generating accurate digital elevation models at the national level is a costly and challenging process. Therefore, in some cases, global free digital elevation models are used as substitutes for national elevation models. The importance of our research lies in that it seeks to evaluate the accuracy of these models. The research objectives are as follows:

- To compare the vertical accuracy of two models, SRTM and ASTER that have the same spatial resolution, considering the impact of terrain slope on this accuracy.
- Applying clear criteria for selecting the necessary number of check points to evaluate the vertical accuracy of the tested digital elevation models, which has been done in relatively limited previous studies. Where the criteria of the American Society for Photogrammetry and Remote Sensing (ASPRS) had been applied in this research.

- Applying a simple practical method to identify outliers in elevation differences between tested digital elevation models and either GPS measurements or the reference digital elevation model and removing them before conducting the vertical accuracy assessment of the tested models.

3. Study methods and materials.

4.1 Digital Elevation Models SRTM and ASTER

The Shuttle Radar Topography Mission (SRTM) digital elevation model is a product of collaboration between the National Aeronautics and Space Administration (NASA) and the National Geospatial-Intelligence Agency, in addition to the participation of the German and Italian space agencies. The SRTM mission consists of a modified synthetic aperture radar onboard a space shuttle launched in 2000 during an 11-day mission. This model covers approximately 80% of the Earth's surface [13], and the available versions of SRTM are:

- A digital elevation model with a spatial resolution of 30 arc-seconds (1 km x 1 km).
- A digital elevation model with a spatial resolution of 3 arc-seconds (90 m x 90 m).
- A digital elevation model with a spatial resolution of one arc-second (30 m x 30 m), which is the latest version.

SRTM data can be obtained for free through the U.S. Geological Survey (USGS) website. Regarding our research, the latest version of the SRTM model for the study area has been utilized. Regarding the ASTER model, it was created through a collaboration between the Ministry of Economy, Trade, and Industry (METI) in Japan and NASA. This product is known as ASTER Global DEM [5] and was created using data from the Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) onboard the Terra satellite. Version 1 was released in 2009, and Version 2 was released in 2011. The latest version is based on data collected between 2000 and 2010, covering the Earth's surface between 83 degrees north and 83 degrees south latitude, with a horizontal spatial resolution of approximately 30 meters at the equator. Many researchers have compared ASTER in Version 2 using ground control points on different continents and obtained a Root Mean Square Error (RMSE) ranging from 8 to 13 meters [14 and 15].

4.2 Detecting Outliers in Elevation Differences

The vertical accuracy of digital elevation models is evaluated using what is known as ground control points, which are points with known elevations measured with a higher precision technique than the points used to compute the digital elevation model [7]. In this study, the Root-Mean-Square Error (RMSE) value had been used to estimate the vertical accuracy [16]. The following equation (1) demonstrates the value of this measure:

$$\boldsymbol{RMSE = \sqrt{\frac{\sum_{i=1}^{i=n}(\Delta z_i)^2}{n}}} \qquad (1)$$

Where: $\Delta z_i = Z_{reference(i)} - Z_{DEM\,(i)}$ represents the differences between the elevations of the sampled test points from the digital elevation model and their reference elevations. $Z_{reference(i)}$ is the reference elevation for check point i, and $Z_{DEM\,(i)}$ is the elevation of check point i sampled from the digital elevation model. RMSE measures the level of agreement between actual elevations and the surface of the digital elevation model [17]. The accuracy of the topographic products obtainable from the SRTM model is affected by its vertical accuracy, and among these products are contour maps. The number of check points used in the accuracy assessment process typically plays a crucial role. Additionally, the height differences of the check points contain outliers that need to be removed before completing the vertical accuracy assessment. However, elevation differences in check points typically contain outliers that must be removed before completing accuracy assessment operations vertically.

- The First Method: relies on setting a tolerance threshold for accepting or rejecting the measurement (elevation difference) after assuming that the measurements follow a normal distribution and testing this hypothesis. Here, the root mean square error $RMSE$ is calculated from all initial measurements by applying equation (2), and the tolerance threshold $\mp 3 \times RMSE$ value is determined. The problem with this method is that it does not enable the detection of all outlier values [18].
- The Second Method: relies on estimating the estimator of Mean Square Error (MSE) for the Expected height differences, known as the Normalized Median Absolute Deviation (NMAD). This estimator is given by the following equation (2):

$$\boldsymbol{NMAD = 1.4826 \times Median}\ (|\boldsymbol{\Delta Z_i - m_{\Delta Z}}| \tag{2}$$

Where ΔZ_i represents individual measurements and $m_{\Delta Z}$ represents the median of the measurements. In this case, NMAD is considered an estimator of the mean square error$RMSE$, where the tolerance limit $\mp 3 \times RMSE$. A disadvantage of this method is using the median that is not affected by outlier values; thus, it cannot detect all outlier values, especially when these values are numerous [18].

- Third Method: relies on using the Quantile-Quantile (Q-Q) plot, which connects the theoretical values of the normal distribution with the actual values of the distribution of real measurements. This plot allows us to visually judge the presence of outlier values in the measurements [19].

In this study, simple method based on calculating the first quartile Q1 and the third quartile Q3 of a sample of measurements had been applied [20]. Where the quartiles are values that divide the measurements sorted in ascending order into four equal parts in terms of the number. For the first quartile (Q1), one-quarter of the measurements are smaller than it, and three-quarters of the measurements are larger than it. As for the third quartile (Q3), three-quarters of the measurements are smaller than it, and one-quarter is larger than it. To apply this method, first it is necessary to arrange the measurement values in ascending order and then calculate the positions of the first quartile (Q1) and the third quartile (Q3) in the sample of measurements (with a total of n observations), where these positions are determined by the following relationships (3),(4) and (5):

$$K_1 = \frac{n+1}{4} \tag{3}$$

$$K_2 = \frac{2(n+1)}{4} \tag{4}$$

$$K_3 = \frac{3(n+1)}{4} \tag{5}$$

Where: $k_1$is the position of the first quartile (Q1), k_2 is the position of the second quartile (median), and k_3 is the position of the third quartile.
Next, the Interquartile Range (IQR) is calculated as the difference between the third quartile (Q3) and the first quartile (Q1) (6):

$$IQR = Q_3 - Q_1 \tag{6}$$

Then, the Lower Limit (LL) and the Upper Limit (UL) can be calculated, which will contain most of the measurements between them (7) and (8).

$$LL = Q_1 - 1.5 \times IQR \tag{7}$$

$$UL = Q_3 + 1.5 \times IQR \tag{8}$$

Any measurement value falling outside these two ranges is considered an outlier.

4.3 ASPRS Criteria for Determining the Number of Check Points to Assess Vertical Accuracy of Digital Elevation Models

The American Society for Photogrammetry and Remote Sensing (ASPRS) accuracy standards for digital geospatial data include a specific annex regarding vertical accuracy concerning Very Vegetated Areas (VVA) and Non-Vegetated Areas (NVA) [21]. In this appendix, a detailed recommendations regarding the number of check points recommended for assessing the vertical accuracy of digital elevation models, based on the nature of the terrain (in terms of vegetation coverage) and the extent of the study area. This is illustrated in (Table 1).

Table (1). The recommended number of check points varies depending on the area and type of coverage.

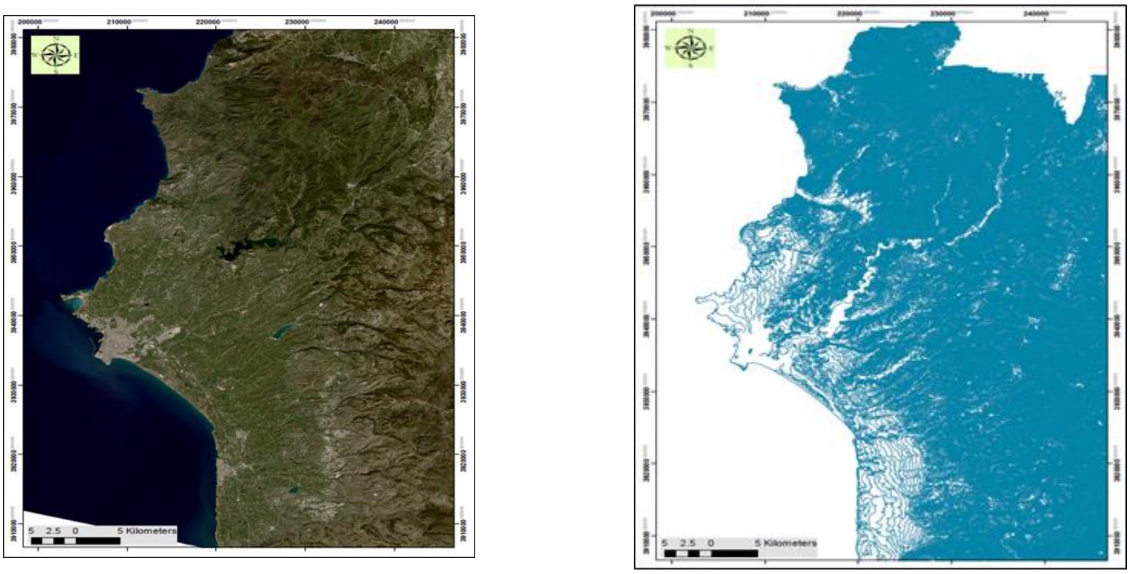
Area of study zone (km^2)	Vertical check		
	Vertical check points, NVA	**Vertical check points, VVA**	**Total number**
≤500	20	0	20
501-750	20	10	30
751-1000	25	15	40
1001-1250	30	20	50
1251-1500	35	25	60
1501-1750	40	30	70
1751-2000	45	35	80

Area of study zone (km^2)	Vertical check		
	Vertical check points, NVA	**Vertical check points, VVA**	**Total number**
2001-2250	50	40	90
2251-2500	55	45	100

4.4 Study Area and Available Data

The study area is Latakia governorate in Syria (Figure 1), located between latitudes 35°56′37.95″ north and 35°15′16.92″ north, and between longitudes 35°43′11.9″ east and 36°14′9.48″ east, with an approximate area of about 2887 square kilometers. The area has a diverse texture in terms of urban areas, open areas, and areas with dense vegetation cover. The area is characterized by uneven slopes.

The study area has a topographic map at a scale of 1:25000 with contour interval of 10 meters (Figure 1), where the minimum and maximum elevations are 0 and 2032.24 meters respectively. The map was obtained from the General Organization for Surveying in Syria and is the result of a photogrammetric survey of the area. This map is defined within the WGS 1984 UTM Zone 37N coordinate system. This map was used in our research to extract the necessary check points for evaluating the accuracy of the SRTM-1 and ASTER digital elevation models covering the study area.



Source: Prepared by the researchers.

Figure (1). The study area boundaries and the contour map at a scale of 1:25,000.

4.5 Research tools and methodology

The following tools were used in this research:

- ArcGIS 10.8 was used to extract elevations of check points from the contour map and determine their corresponding elevations on the digital elevation models SRTM and ASTER.
- 2-NCSS was used for statistical analysis of the results. NCSS is a statistical software used for data analysis, designing statistical studies, and creating graphical presentations. NCSS

enables users to easily and effectively analyze data, conduct statistical tests, and create graphical visualizations, and it is widely used in scientific research, statistical studies, and various data analytics [22].

The methodology applied in this research has gone through the steps illustrated in (Figure 2).

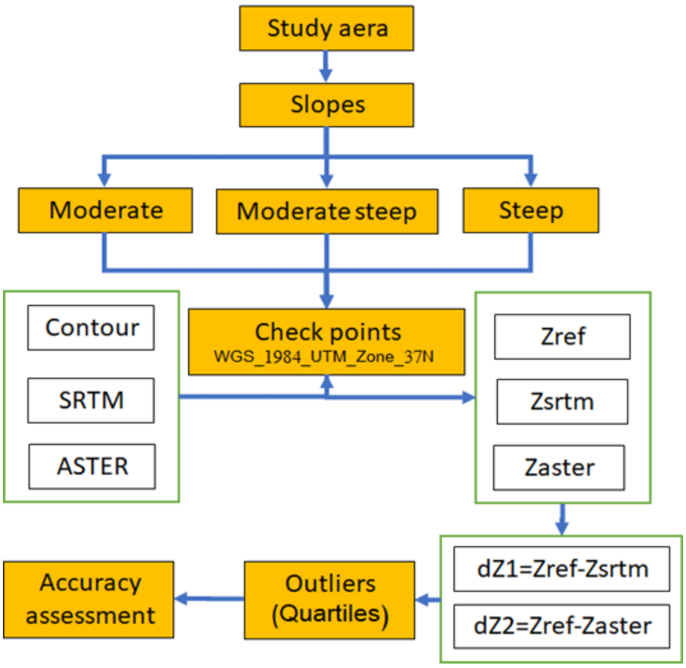


Figure (2). The study methodology

1. Installing the digital models of the SRTM and ASTER elevations for the study area from the website of the United States Geological Survey using USGS Earth Explorer with a spatial resolution of 30m and then clipping the part specific to the study area from these models. The coordinate system of these models was converted to WGS_1984_UTM_Zone_37N, which is the same coordinate system of the 1:25000 topographic map covering the study area. This step was done using ArcGIS 10.8 software. In fact, the models were defined within the geographic coordinate system WGS-84.
2. Deriving the slope map of the study area (Figure 3) using ArcGIS 10.8 software and classifying it into:
    a. An area with moderate slopes where the slopes do not exceed 10%, covering approximately 1321 square kilometers. It is characterized by a mix of built-up areas and sparsely vegetated areas.
    b. An area with moderate steep slopes where the slopes do not exceed 30%, covering approximately 1091 square kilometers. It is characterized by dense vegetation covers in some areas.
    c. An area with steep slopes where the slopes exceed 30%, covering approximately 475 square kilometers. It is characterized by dense vegetation covers in some areas.
3. Extraction of check points elevations from the topographic map with a scale of 1/25000, where ASPRS standards had been applied to determine the number of these

points based on the area and vegetation type. The number of check points for the moderate slope area was 60 points, while the number for the moderate steep slope area was 50 points. In the case of the steep slope area, the number reached 20 points.

4. Extracting the corresponding elevations for the previous check points from the free digital elevation models SRTM and ASTER.
5. Studying the correlation between the reference elevations of the check points and those extracted from the SRTM and ASTER digital elevation models. This correlation will be studied by calculating the Pearson correlation coefficient, which is a measure of the strength of the relationship between two variables and their correlation with each other. It is worth mentioning that the correlation coefficient between variables takes values between -1 and +1, and if there is no relationship or correlation between the variables, the calculated correlation coefficient value equals zero or a value very close to zero [23]. The Pearson correlation coefficient is calculated using the following formula:

$$r = \frac{\sum(h_{i1} - \overline{h_1})(h_{i2} - \overline{h_2})}{\sqrt{\sum(h_{i1} - \overline{h_1})^2 . \sum(h_{i2} - \overline{h_2})^2}} \tag{9}$$

Where:

- h_{i1} and h_{i2} are the individual height differences from each dataset (e.g., ASTER and SRTM).
- $\overline{h_1}$ and $\overline{h_2}$ are the means of the height differences in each dataset.

6. Calculating the differences between the elevations of the check points extracted from the digital elevation models and their reference elevations extracted from the topographic map with a scale of 1/25000, detecting outlier values using the quartile method, and then conducting statistical tests to determine the vertical accuracy of the SRTM and ASTER models concerning the reference elevations.

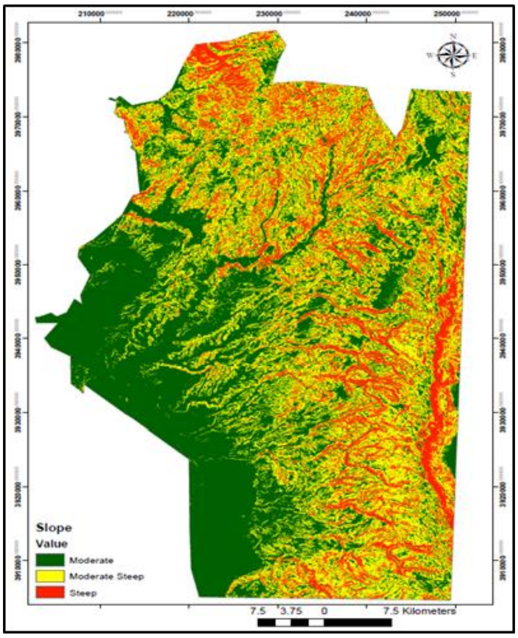


Figure (3). Slope map of the study area.

4. Results and discussion

5.1 Moderate slope Areas

The elevations of 60 check points sampled in the moderate-slope area were uniformly distributed (Figure 4).

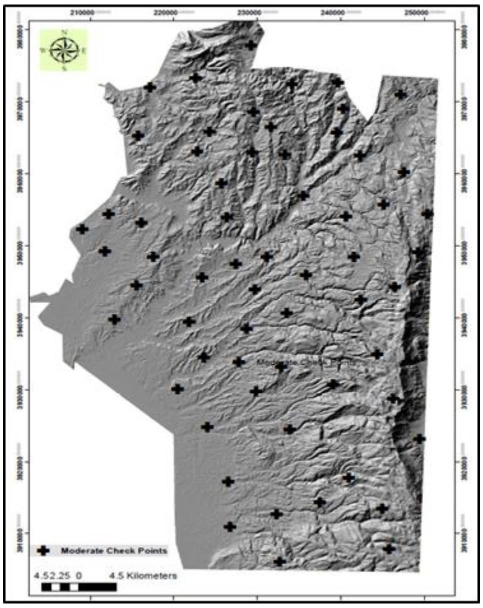


Figure (4). Check points located in the moderate slope areas.

Then the correlation coefficient (Pearson's correlation coefficient) had been calculated between the reference elevations of points and their elevations extracted from the SRTM and ASTER models. Results are illustrated in (Table 2).

Table (2). The Pearson coefficient of correlation of check points heights in case of moderate slope areas.

ASTER	SRTM	
0.99	0.99	Reference

The graphical expression of this correlation is illustrated in (Figure 5).

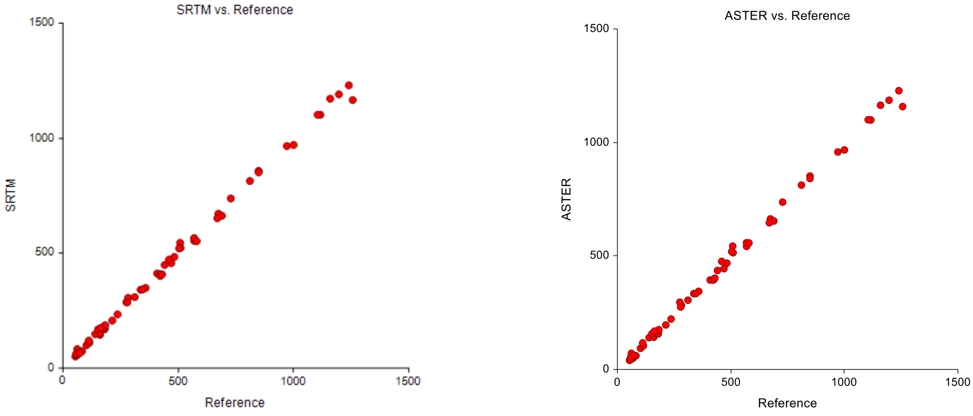


Figure (5). The correlation between reference elevations, SRTM elevations, and ASTER elevations in the case of moderate slope areas.

From (Table 2) and (Figure 5), it was found that there is a strong positive correlation between the reference elevations and the elevations extracted from both SRTM and ASTER.
After that, the elevation differences between the reference elevations of these points and their elevations extracted from the SRTM and ASTER models were calculated. To detect outliers in these differences, the quartiles method had been applied, then the statistical estimators calculated. The results of outlier detection as well as the estimated statistical values calculated using the NCSS software was illustrated in (Table 3).

Table (3). Results of processing elevation differences in case of moderate slope areas.

	RMSE (m)	Q1 (m)	Q3 (m)	IQR (m)	LL (m)	UL (m)	Outlier
dZ_Ref_SRTM	11.899	-7.383	8.548	15.931	-31.279	32.444	5
dZ_Ref_ASTER	12.431	2.169	14.618	12.449	-16.503	33.291	5

From (Table 3), it was found that the elevations extracted from the SRTM model are more accurate than those from the ASTER model in the region with moderate slopes, based on the value of the root mean square error. To confirm this result, (Figure 6) illustrates the graphical relationship between the elevations of the reference check points and the SRTM and ASTER extracted elevations, where the convergence between the reference elevations and SRTM had been observed.

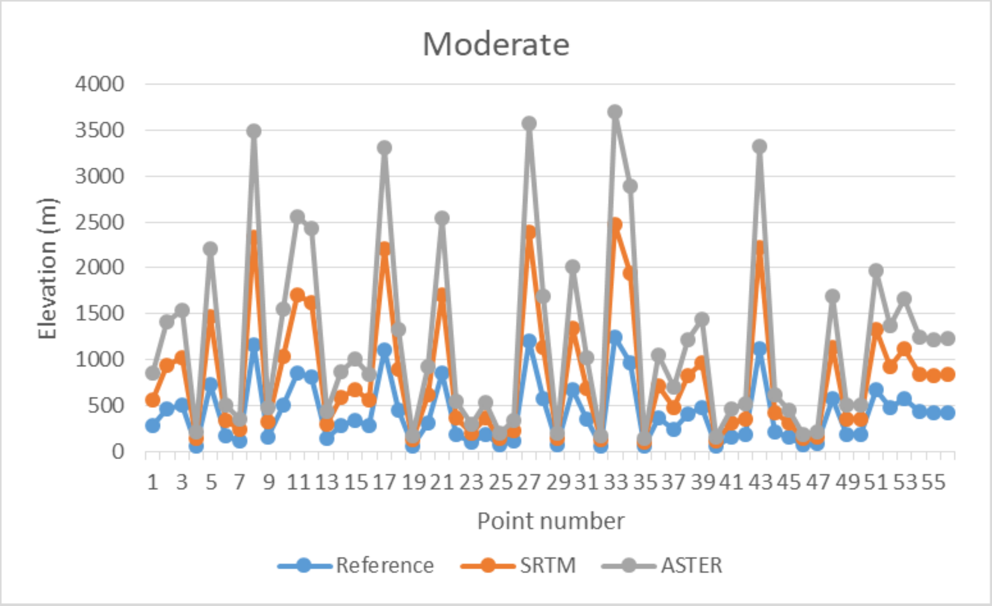


Figure (6). The convergence between the reference elevations and the SRTM elevations in moderate slope areas.

5.2 Moderate-steep slopes Areas

The elevations of 50 check points sampled in the moderate steep-slope area were uniformly distributed (Figure 7). Then the correlation coefficient between the reference elevations of points and their elevations extracted from the SRTM and ASTER models had been calculated. Results are illustrated in (Table 4).

Table (4). The Pearson correlation coefficient values in case of moderate steep slope areas.

ASTER	SRTM	
0.99	0.99	Reference

The graphical expression of this correlation is illustrated in (Figure 8).

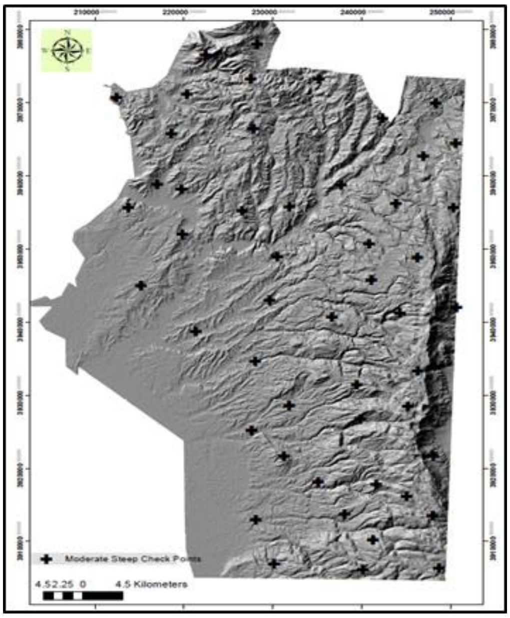


Figure (7). Check points located in the moderate-steep slope areas.

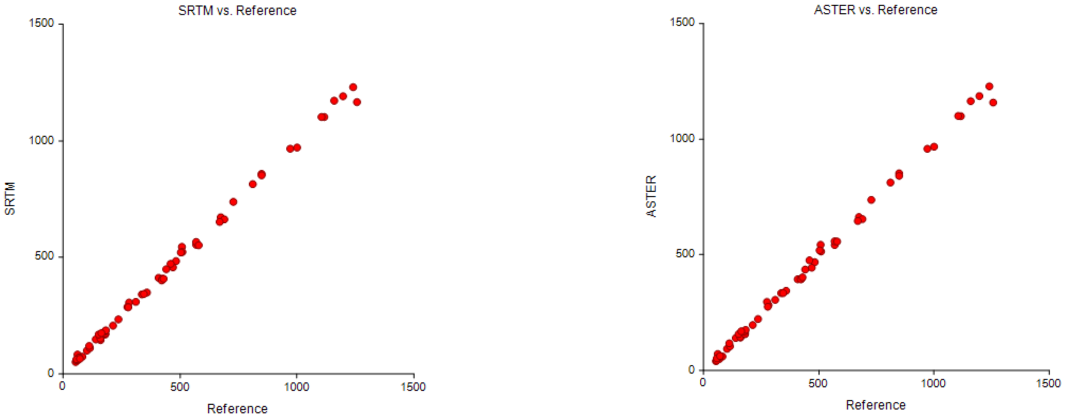


Figure (8). The correlation between reference elevations, SRTM elevations, and ASTER elevations in the case of moderate-steep slope areas.

From (Table 4) and (Figure 8), it was found that there is a strong positive correlation between the reference elevations and those extracted from SRTM and ASTER. The differences between the reference elevations for these points and their elevations extracted from the SRTM and ASTER models had been calculated. The outliers in these differences had been identified using quartiles method. (Table 5) illustrates the results of outlier detection as well as the estimated statistical values.

Table (5). Results of processing elevation differences in case of moderate-steep slope areas.

	RMSE (m)	Q1 (m)	Q3 (m)	IQR (m)	LL (m)	UL (m)	Outlier
dZ_Ref_SRTM	21.609	-12.617	17.122	29.739	-57.226	61.730	1
dZ_Ref_ASTER	23.145	-6.500	21.534	28.034	-48.551	63.585	1

Based on the mean square error value shown in (table 5), it was found that the elevations extracted from the SRTM model are more accurate than those extracted from the ASTER model in the area had moderate steep slope. (Figure 9) illustrates the graphical relationship between the elevations of the reference check points and those extracted from the SRTM and ASTER models, which shows the convergence between the reference elevations and SRTM.

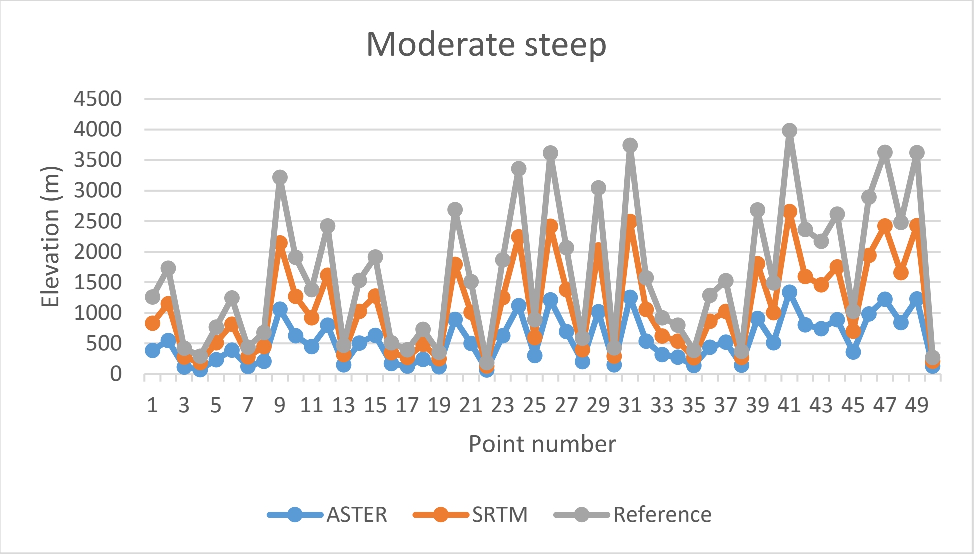


Figure (9). The convergence between the reference elevations and the SRTM elevations in moderate-steep slope areas.

5.3 Steep slopes Areas

The elevations of 20 check points sampled in the steep-slope area were uniformly distributed (Figure 10). Then the correlation coefficient between the reference elevations of check points and their elevations extracted from SRTM and ASTER models had been calculated. Results are illustrated in (Table 6).

Table (6). The Pearson correlation coefficient values in case of steep slope areas.

ASTER	SRTM	
0.99	0.99	Reference

Figure (11) illustrates the graphical expression of this correlation. From (Table 6) and (Figure 11), it was found that there is a strong positive correlation between the reference elevations and those extracted from SRTM and ASTER. The elevation differences between the reference elevations for these points and their elevations extracted from the SRTM and ASTER models had been calculated. Then the outliers in these differences had been calculated using quartiles method. (Table 7) illustrates the results of outlier detection as well as the estimated statistical values.

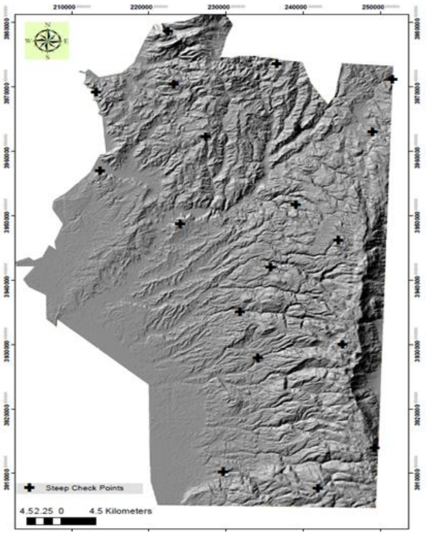


Figure (10). Check points located in steep slope areas.

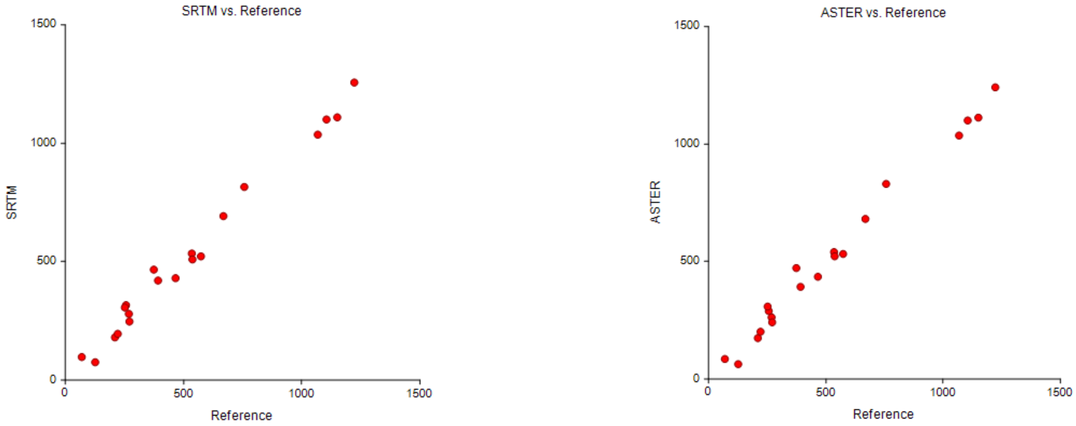


Figure (11). The correlation between reference elevations, SRTM elevations, and ASTER elevations in the case of steep slopes.

Table (7). The Pearson correlation coefficient values in case of steep slope areas.

	RMSE (m)	Q1 (m)	Q3 (m)	IQR (m)	LL (m)	UL (m)	Outlier
dZ_Ref_SRTM	40.538	-39.039	25.456	64.495	-135.782	122.200	0
dZ_Ref_ASTER	36.770	-23.588	31.521	55.108	-106.250	114.184	0

(Table 7) shows that the elevations extracted from the ASTER model are more accurate than those extracted from the SRTM model in case of steep slopes. (Figure 12) illustrates the graphical relationship between the elevations of the reference check points and those extracted from the SRTM and ASTER models, which shows the convergence between the reference elevations and ASTER**.**

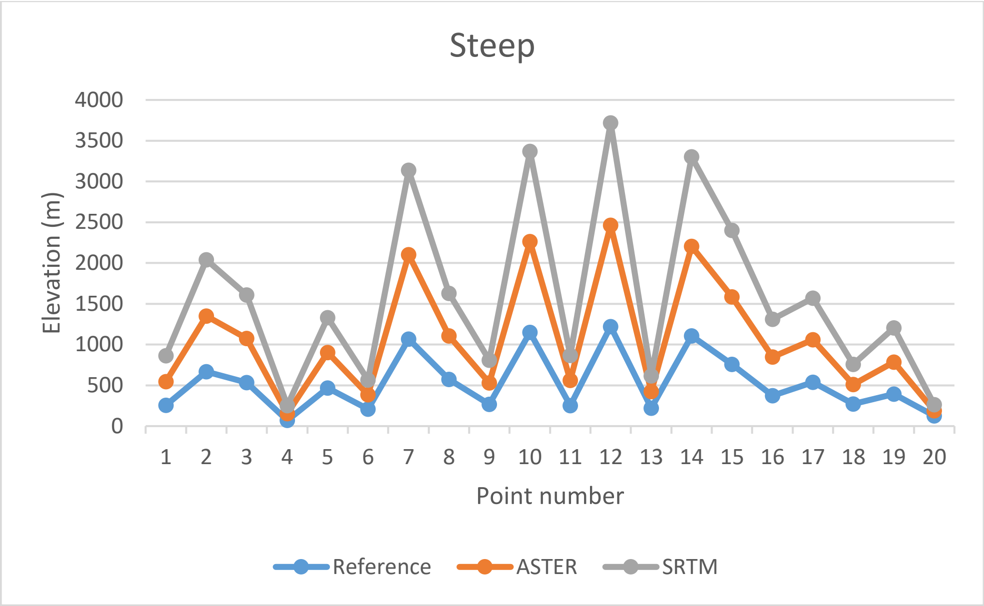
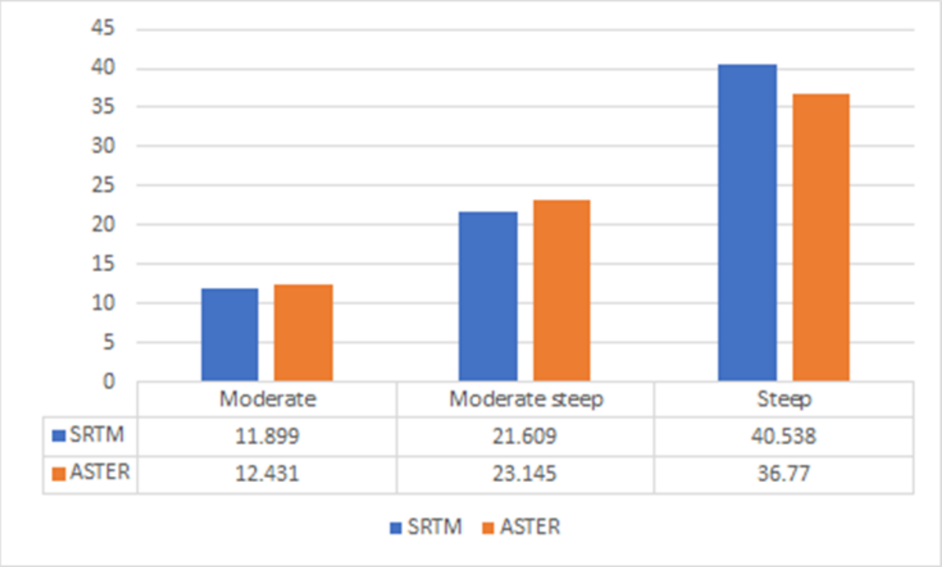


Figure (12). The convergence between the reference elevations and ASTER in steep slope areas.

Based on the research findings, it can be inferred that the precision of the SRTM and ASTER models in vertical measurements, at a spatial resolution of 30 meters, is related to the earth's topography as shown in (Figure 13).



	Moderate	Moderate steep	Steep
■ SRTM	11.899	21.609	40.538
■ ASTER	12.431	23.145	36.77

Figure (13). The vertical accuracy of the SRTM and ASTER models in relation to the earth slope topography.

These results are consistent with the results of the most previous studies conducted in various regions around the world, including [24 and 25], in addition to the studies presented in the context of this research, which have shown that the vertical accuracy of the SRTM model in areas of moderate-to-moderate steep slopes is better than the accuracy of the ASTER model, which excels in case of steep slopes. On the other hand, the research results showed that the vertical accuracy of both SRTM and ASTER models in areas of moderate steep to steep slopes is lower than the theoretical vertical accuracy of the same models ranging from 16 to 17 meters [5, 26 and 27].

6. Conclusion and recommendations

In this study, a comparison was made for the vertical accuracy of the SRTM and ASTER models, both of which have a spatial resolution of 30 meters, based on the slope of the land. This comparison was carried out using selected check points from a topographic map at a scale of 1/25000, according to ASPRS criteria related to the area of the test site and its vegetation cover. On the other hand, a simple method was applied to identify outliers in the elevation differences between the digital elevation models tested and the elevations of reference check points, prior to assessing the vertical accuracy of the tested models. Based on the theoretical and practical study presented here, this research has reached the following conclusions:

1. In all the cases studied, a strong positive correlation between the reference elevations and the extracted elevations from both SRTM and ASTER models had been observed, with a Pearson correlation coefficient value reaching 0.99.
2. In the case of moderate slopes, it was found that the vertical accuracy of both models was better than their theoretical vertical accuracy. Where the elevations extracted from the SRTM model were more accurate than those extracted from the ASTER model in the moderate sloping area, with a root mean square error of 11.899 m on these elevations.
3. In the case of moderate steep slopes, it was found that the SRTM extracted elevations are more accurate than those extracted from the ASTER mode; the vertical accuracy for the SRTM model is 21.609 meters compared with 23.145 meters for the ASTER model.
4. In the case of steep slopes, it was found that the elevations extracted from the ASTER model were more accurate than those extracted from the SRTM model. The vertical accuracy for the SRTM model was 40.538 m, while it was 36.770 m for ASTER.
5. The vertical accuracy of SRTM and ASTER models in moderate steep and steep slope areas is less than the theoretical vertical accuracy of both models, which ranges from 16 to 17 meters.

Finally, we recommend expanding the study to process other freely available digital models with spatial resolutions greater or less than those tested in the research and testing its dependency of their vertical accuracies on the slope of the terrain in order to achieve more comprehensive results.

References

[1] Aghataher, R., Samadi, M., Laliniat, I., & Najafi, I. (2016). Comparative assessment of vertical accuracy of SRTM and ASTER GDEM elevation data.

[2] Gruber, U., & Haefner, H. (1995). Avalanche hazard mapping with satellite data and a digital elevation model. Applied Geography, 15(2), 99-113.

[3] Stucky, J. L. D. (1998). On applying viewshed analysis for determining least-cost paths on digital elevation models. International Journal of Geographical Information Science, 12(8), 891-905.

[4] Farr, T. G., Rosen, P. A., Caro, E., Crippen, R., Duren, R., Hensley, S., ... & Alsdorf, D. (2007). The Shuttle Radar Topography Mission Reviews of Geophysics, Vol. 45. RG2004, 10, 1-13.

[5] Tachikawa, T., Hato, M., Kaku, M., & Iwasaki, A. (2011, July). Characteristics of ASTER GDEM version 2. In 2011 IEEE international geoscience and remote sensing symposium IEEE, pp. 3657–3660.

[6] Satge, F., Denezine, M., Pillco, R., Timouk, F., Pinel, S., Molina, J., ... & Bonnet, M. P. (2016). Absolute and relative height-pixel accuracy of SRTM-GL1 over the South American Andean Plateau. ISPRS journal of photogrammetry and remote sensing, 121, 157-166.

[7] Mukherjee, S., Joshi, P. K., Mukherjee, S., Ghosh, A., Garg, R. D., & Mukhopadhyay, A. (2013). Evaluation of vertical accuracy of open-source Digital Elevation Model (DEM). International Journal of Applied Earth Observation and Geoinformation, 21, 205-217.

[8] Bildirici, I. O., & Abbak, R. A. (2017). Comparison of ASTER and SRTM digital elevation models at one-arc-second resolution over Turkey. Selcuk University Journal of Engineering, Science and Technology,5(1), 16-25.

[9] Fazilova, D., Magdiev, K., & Sichugova, L. (2021). Vertical accuracy assessment of open access digital elevation models using GPS. International journal of Geoinformatics, 17(1), 19-26.

[10] Kovalchuk, I. P., Lukianchuk, K. A., & Bogdanets, V. A. (2019). Assessment of open-source digital elevation models (SRTM-30, ASTER, ALOS) for erosion processes modeling. Journal of geology, geography and geoecology, 28(1), 95-105.

[11] Elkhrachy, I. (2018). Vertical accuracy assessment for SRTM and ASTER Digital Elevation Models: A case study of Najran city, Saudi Arabia. Ain Shams Engineering Journal, 9(4), 1807-1817.

[12] Florinsky, I. V., Skrypitsyna, T. N., & Luschikova, O. S. (2018). Comparative accuracy of the AW3D30 DSM, ASTER GDEM, and SRTM1 DEM: A case study on the Zaoksky testing ground, Central European Russia. Remote Sensing Letters, 9(7), 706-714.

[13] Yang, L., Meng, X., & Zhang, X. (2011). SRTM DEM and its application advances. International Journal of Remote Sensing, 32(14), 3875-3896.

[14] Jing, C., Shortridge, A., Lin, S., & Wu, J. (2014). Comparison and validation of SRTM and ASTER GDEM for a subtropical landscape in Southeastern China. International Journal of Digital Earth, 7(12), 969–992.

[15] Rexer, M., & Hirt, C. (2014). Comparison of free high resolution digital elevation data sets (ASTER GDEM2, SRTM v2.1/v4.1) and validation against accurate heights from the Australian National Gravity Database. Australian Journal of Earth Sciences, 61(2), 213–226.

[16] Zhang, Y., Han, T., Liu, H., Wang, X., & Zhang, E. (2017). Cooperation of the Spatial Interpolation Algorithm for the Contour Map of the Shockwave Overpressure Field. Journal of Engineering Science & Technology Review, 10(6).

[17] Ghilani, C. D. (2017). Adjustment computations: spatial data analysis. John Wiley & Sons.

[18] Baguio, C. B. (2009). Adaptive Robust Estimator of a Location Parameter for Some Symmetric Distributions. In Recent Advances in Technologies. IntechOpen.

[19] Hohle, J., & Hohle, M. (2009). Accuracy assessment of digital elevation models by means of robust statistical methods. ISPRS Journal of Photogrammetry and Remote Sensing, 64(4), 398-406.

[20] Iglewicz, B., & Hoaglin, D. C. (1993). How to detect and handle outliers, Quality Press, Vol.16.

[21] ASPRS Positional Accuracy Standards for Digital Geospatial Data. November 2014, Photogrammetric Engineering & Remote Sensing. 81 (3), 53. (accessed on: 25/6/2023).

[22] NCSS 2021 Statistical Software (2021). NCSS, LLC. Kaysville, Utah, USA, ncss.com/software/ncss.

[23] Hamoudi, S., Sh. (2009). Principles of Statistics and its Applications. Dar Al-Thaqafa for Publishing and Distribution, Oman.

[24] Baral, S. S., Das, J., Saraf, A. K., Borgohain, S., & Singh, G. (2016). Comparison of Cartosat, ASTER and SRTM DEMs of different terrains. Asian Journal of Geoinformatics, 16(1).

[25] Rawat, K. S., Singh, S. K., Singh, M. I., & Garg, B. L. (2019). Comparative evaluation of vertical accuracy of elevated points with ground control points from ASTERDEM and SRTMDEM with respect to CARTOSAT-1DEM. Remote Sensing Applications: Society and Environment, 13, 289-297.

[26] Chang, K., & Tsai, B., 1991. The effect of DEM resolution on slope and aspect mapping. Cartography and Geographic Information Science, 18, 69-77.

[27] Fujisada, H., Bailey, G., Kelly, G., Hara, S., & Abrams, M., 2005. ASTER DEM performance. IEEE Transactions on Geoscience and Remote Sensing, 43(12), 2707-2714.

تقييم الدقة الرأسية للنماذج الارتفاعات الرقمية المجانية SRTM وASTER في مناطق مختلفة الانحدار

ملخص

تتوفر بعض إصدارات النماذج الرقمية المجانية للارتفاعات SRTM وASTER بنفس دقة التمييز المكانية والبالغة 30 m، ولكن الاختلافات في دقة المسح والتقنيات المستخدمة في إنتاج بيانات كل منهما وكذلك تأثير درجة انحدار الأرض تؤدي إلى اختلافات في دقتهما الرأسية. من ناحية أخرى، يلعب عدد نقاط الاختبار المستخدمة في عملية تقييم هذه الدقة دوراً مهماً كما تحتوي فروق الارتفاعات الخاصة بنقاط الاختبار على قيم شاذة Outliers يجب التخلص منها قبل إتمام عمليات تقييم الدقة الرأسية. إن الهدف الرئيسي من هذا البحث هو تقييم تأثير درجة انحدار الأرض على هذه الدقة الشاقولية للنموذجين SRTM-1 وASTER A1 اللذين يملكان نفس دقة التمييز المكانية. تم في البحث تطبيق معايير ASPRS في تحديد عدد نقاط الاختبار اللازمة لتقييم الدقة مع اقتراح تطبيق طريقة عملية بسيطة لتحديد القيم الشاذة في فروق الارتفاعات. تم إجراء الاختبارات على محافظة اللاذقية وذلك بعد تقسيمها إلى ثلاث مناطق: منطقة قليلة الانحدار، منطقة متوسطة الانحدار ومنطقة شديدة الانحدار. أما فيما يخص نقاط الاختبار فقد تم اقتطاعها من خارطة طبوغرافية مقياسها 1/25000.

بينت النتائج وجود ارتباط موجب قوي بين الارتفاعات المرجعية والارتفاعات المقتطعة من كل من النموذجين SRTM وASTER في كل مناطق الاختبار حيث بلغت قيمة معامل بيرسون 0.99. كما وجدنا أن الدقة الرأسية للنموذج SRTM أفضل من الدقة الرأسية للنموذج ASTER في المنطقة قليلة الانحدار حيث بلغت هذه الدقة 11.899 m. أما في حالة الأرض متوسطة الانحدار فقد توصل البحث إلى أن لارتفاعات المقتطعة من النموذج SRTM أدق من تلك المقتطعة من النموذج ASTER حيث بلغت الدقة الرأسية لحالة النموذج SRTM القيمة 21.609 m في حين كانت 23.145 m في حالة النموذج ASTER. وأخيراً، جدنا أنه في حالة الأرض شديدة الانحدار أن الارتفاعات المقتطعة من النموذج ASTER أدق من تلك المقتطعة من النموذج SRTM حيث بلغت الدقة الرأسية لحالة النموذج SRTM القيمة 40.538 m في حين كانت 36.770 m في حالة النموذج ASTER.

كلمات مفتاحية: دقة شاقولية، نقاط اختبار، SRTM-1، ASTER 1، خطأ متوسط التربيع، قيم شاذة.