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Evaluation and Validation of Recent Freely-Available ASTER-GDEM V.2, SRTM V.4.1 and the DEM Derived from Topographical Map over SW Grombalia (Test Area) in North East of Tunisia

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Abstract

Digital Elevation Models (DEMs) provide one of the most useful digital datasets for a wide range of users. Both the Shuttle Radar Topographic Mission (STRM V.4.1) topography and the Advanced Spaceborne Thermal Emission and Reflection Radiometer Global Digital Elevation Model (ASTER-GDEM V.2) have been widely used in geomorphology, hydrology, tectonic, and others since they were made access to the public. The magnitude of vertical errors of two near-global DEMs—SRTM and ASTER-GDEM is compared and validated against a reference DEM which has a relatively high precision of 1:25,000 scale constructed from topographical map. Moreover, the reference DEM, ASTER-GDEM and SRTM were used as basic topographic data to extract some Morphometric index. The parameters like slope and shaded reflectance maps, were derived from the elevation distribution to provide a more sensitive indication of DEM quality. A square area in the North East of Tunisia was selected as a case study to test and evaluate the elevation accuracy of ASTER-GDEM and SRTM. The relative accuracy approach and absolute accuracy were adopted to evaluate global DEMs. The comparisons show that SRTM overestimates and ASTER-GDEM underestimates elevations, both DEMs can be used to extract the elevations of required geometric data, *i.e.* sub watershed boundaries, drainage information and cross sections. However, small errors still exist in. The lower root mean square errors values indicate that SRTM is comparatively more accurate than ASTER-GDEM.

Keywords

Digital Elevation Models (DEMs), Reference DEM, ASTER-GDEM, SRTM, Comparisons,

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Morphometric Index

1. Introduction

A digital elevation model (DEM) is a digital cartographic representation of the elevation of surface. The applications of DEMs include flood risk assessment, landslides modeling, flight planning, rectification of remote sensing imagery, urban planning, military uses, to name only a few [1]-[3].

High quality DEMs are also essential for measuring land deformations. To date, the majority of DEMs are generated using photogrammetric methods. Besides, new remote sensing techniques, such as Interferometry Radar (InSAR), can also be used to generate high quality DEMs [4]-[6]. Photogrammetry is a passive system which detects reflected solar radiation from ground surface and records the returns digitally or on films. The ASTER-GDEM has been produced using this photogrammetry technique. Unlike photogrammetry, radar is an active system that equips its own energy source for illuminating the land. The SRTM DEM has been produced using the Interferometric capabilities of the Radar instrument equipped with two receivers.

The resolution and availability of free worldwide Digital Elevation Models (DEM) increased dramatically in the last 20 years. The ETOPO and GTOPO models, in the beginning of the 90th of the last century, are derived by different free and military elevation sources compiled to a new raster dataset. The quality and accuracy of the models are spatially different because the primary data sources are different. Consequently, regional studies are difficult to perform [7]. Two different systems generate two new models increasing the resolution of worldwide elevation models more than 100 times at the beginning of the 21th century. The first one is the SRTM-model, recorded in 2000 and presented area-wide for the region of 60˚N to 54˚S in 2004 [8]. The second one is the ASTER-GDEM which was released in 2009 by METI (Ministry of Economy, Trade and Industry), Japan and NASA [9].

The main objective of this work is to assess how the elevation data from SRTM ver.4.1 and ASTER GDEM ver.2 do compare in an absolute manner with respect to a contour based elevation model in an absolute comparison. The second objective is to compare and validate the information content of SRTM ver.4.1 and ASTER GDEM ver.2 based on calculation of several geomorphic indices related to stream networks and watersheds boundaries.

The present study was undertaken to assess the vertical accuracy of ASTER GDEM2, SRTM version 4.1 by comparing them to reference DEM derived from 1/25,000-scaled topographic maps. The accuracy of open source DEMs (ASTER and SRTM) was analyzed for a variety of extracted geomorphometric parameters such as watershed and drainage network.

2. Test Site and Datasets

In this work we use three data models as a representation for the topography (**Figure 1**). At first, Reference DEM derived from topographical map, Second, the ASTER Global Digital Elevation Model (GDEM), and third, Shuttle Radar Topography Mission (SRTM).

These three models were used to assess, on the one hand, the quality of the datasets, in particular the difference between the ASTER GDEM and the reference DEM, the difference between the SRTM and the reference DEM and on the other hand a possibility of application for regional studies to using the one of both DEMs.

2.1. Area of Study

The study area is located in North East of Tunisia (**Figure 1**). This site has different elevation ranges and differs in land cover. Elevation range is between 127 m and 754 m. It is fairly flat, with an average slope of 9.9˚. The dominant land cover types are forest (52%) and woodland/shrubland (34%).

2.2. Reference DEM

The reference DEM was generated from contour topographic maps published by the office of Topography and Cartography of Tunisia at a scale of 1:25,000 (**Figure 2(a)**) and originally derived from black-and white aerial

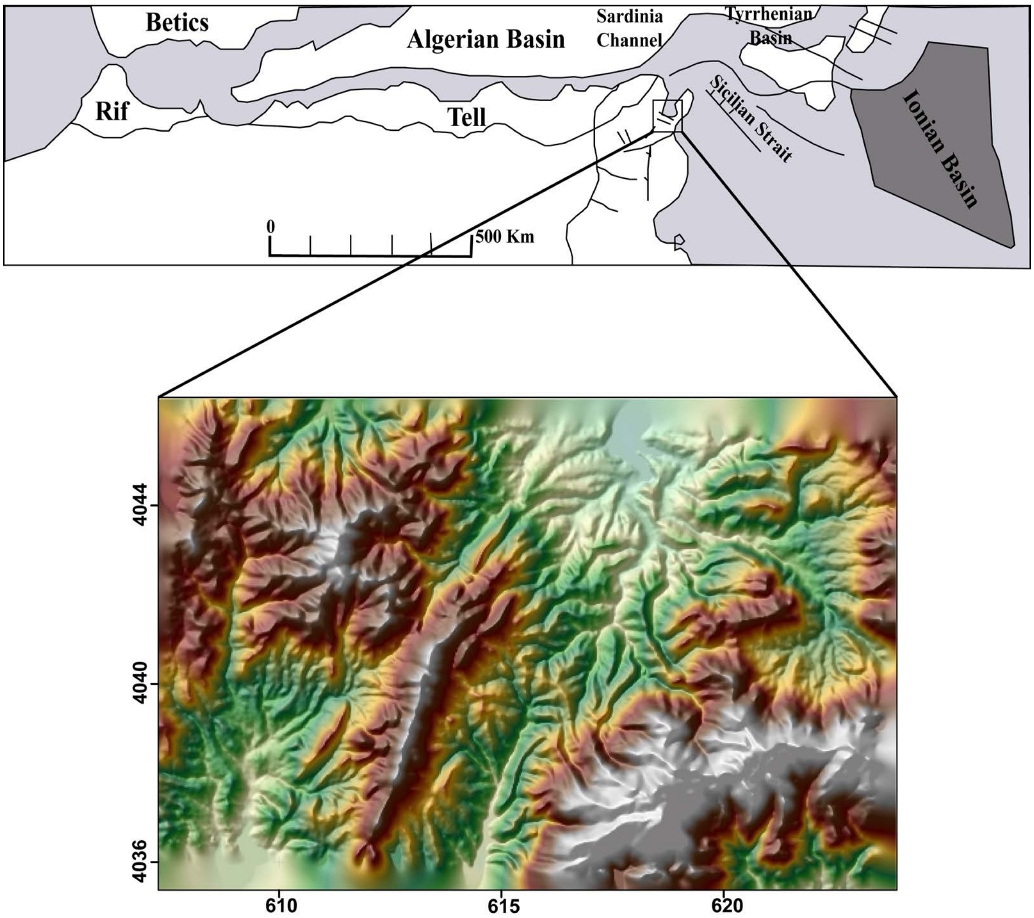


Figure 1. Digital elevation model and location of study area.

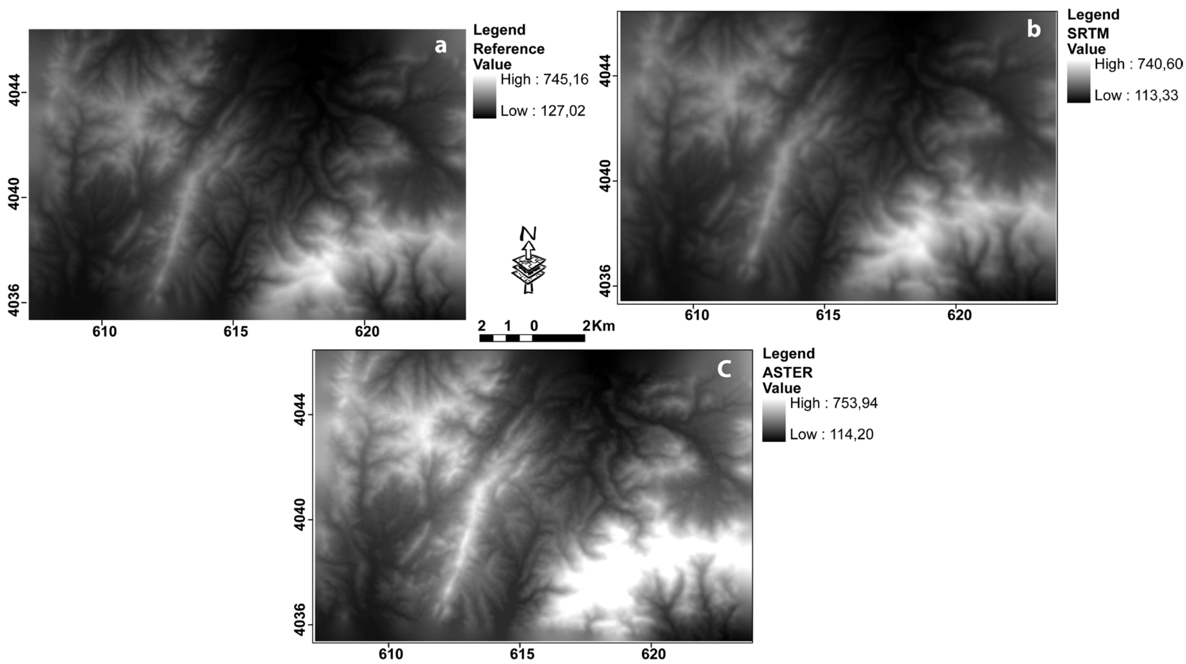


Figure 2. Digital elevation model (DEM) data sets used in the study. (a) Reference DEM; (b) SRTM; (c) ASTER-GDEM.

photos. The topographic maps follow the Lambert conformal conic projection, and the reference ellipsoid is the Clarke 1880 with Carthage as local Datum. The interval between the contours is 10 meters height.

The "Topo to Grid" tool implemented in ArcGIS software was used to interpolate the transformed contour data into a DEM. It is based on the ANUDEM program developed by [10] [11]. A brief summary of ANUDEM and some applications are given in [12]. A cell size of 30 m was chosen for the reference DEM to enable comparison with the other DEMs. Finally, the reference DEM was reprojected into Universal transverse Mercator Zone 32 N system projection. WGS 84 was selected as both datum and spheroid.

2.3. SRTM

The NASA Shuttle Radar Topographic Mission (SRTM) has provided digital elevation data (DEMs) for over 80% of the globe. This data is currently distributed free of charge by USGS and is available for download from the National Map Seamless Data Distribution System, or the USGS ftp site. The SRTM data is available as 3 arc second (approximatly. 90m resolution along equator).

An 11 day space Shuttle Radar Topography Mission (SRTM) was successfully flown in February 2000. This mission used InSAR with C- (5.6 cm) and X- (3 cm) bands of the microwave to create the first DEM of entire earth between the latitudes ranging from 60˚N to 57˚S [13]. SRTM used two antennas, separated 60 m apart, to image the surface instantaneously [8].

The C-band antenna has an imaging swath width of 225 km while the X-band antenna was only limited to a swath of 45 km. Therefore the coverage of X-band is limited and does not provide in global coverage. As the fact that X-band wavelength cannot penetrate the vegetation and C-band wavelength will be reflected at the top of the canopies, the elevation measured by SRTM is also referred to as a digital surface model (DSM) which represents the height of the ground surface objects including vegetations.

SRTM 3" arc pixel size. In order to allow comparison between DEMs, the pixel size was resampled to 30m (using the nearest neighbor interpolation method).

2.4. ASTER-GDEM

The ASTER GDEM is a global elevation data set that was released in 2009 by METI (Ministry of Economy, Trade and Industry), Japan and NASA [9]. The ASTER GDEM is based on optical imagery collected in space with the METI ASTER imaging device that was operated on NASA's Terra satellite. These global DEMs cover land surface between 83˚N and 83˚S with geographic latitude-longitude coordinates at 1arc second, approximately 30 m grid cell size. The vertical and horizontal accuracies of ASTER GDEM are estimated in pre-production level at 95% confidence as 20 m, and 30 m respectively. Prior to releasing the ASTER GDEM data to the global user community in July 2009, an extensive preliminary validation study in cooperation with the US Geological Survey (USGS), ERDAS, and other investigators has been performed [9]. The results of the accuracy assessment by this study prove that the pre-production estimated vertical accuracy of 20 m at 95% confidence is globally correct. The ASTER GDEM ver.2 is an update version of ASTER GDEM that was released in mid-October, 2011 by METI and NASA [14].

3. Methods

3.1. Data Preparation

DEMs of the study site were transformed into the same coordinates reference—Universal Transverse Mercator (UTM) zone 32 north. WGS 1984 was selected as both datum and spheroid. The original 3'' arc resolution of the SRTM was resampled to 30 m to enable comparison with the other DEMs. After resampling, a fill skin was applied to all DEMs to filling local depressions.

In practice, the fill local depressions of DEMs prior to geomorphometry analysis have proved more popular among geomorphometry users. **Table 1** presents general statistics for the different DEMs.

3.2. Comparison of DEMs

Two main approaches were used to compare and validate the elevation products against the reference. These are:

- Quantitative approach—determining the accuracy of the elevation values of the products (absolute accuracy)

Table 1. Summary of general statistics for every DEM.

Dataset	Description	Min	Max	Mean	Standard deviation	Skweness	Kurtosis
Refernce DEM	Elevation	127.03	745.16	302.22	109.17	0.92	3.83
	Slope	0	39.23	9.97	6.23	0.72	3.32
SRTM	Elevation	113.34	740.60	300.68	109.34	0.94	3.86
	Slope	0	36.93	9.15	5.83	0.86	3.49
ASTER-GDEM	Elevation	114.20	753.94	300.13	109.82	0.93	3.87
	Slope	0	44.09	9.92	6.39	0.82	3.47

Determining the accuracy of terrain derivatives of the products (relative accuracy).

- Qualitative approach—The simplest way to compare DEMs of the same area uses visual comparison of shaded reflectance or hill shade maps and slope map.

In this assessment, the three DEMs were first preprocessed to obtain a hydrological consistent elevation model (filling local depressions). Flow direction, next, a common outlet location was used to extract catchments area and the drainage network from the DEMs and the attributes of the derived catchments and drainage network are compared.

3.2.1. Accuracy of Elevation Values

This was achieved by performing visual comparisons, DEM differencing and profiling.

- The simplest way to compare DEMs of the same area uses visual comparison of shaded reflectance or hillshade maps. A second visual technique superimposes topographic profiles from each of the DEMs. This shows the relative relationships of the different DEMs.

While visual comparisons are important, because DEMs provide a valuable base map, quantitative measures should back up the qualitative visual assessments. This study looked at both elevation and slope distributions.

- DEM differencing: This was performed to derive elevation error maps. Root mean square error (RMSE), a common measure of quantifying vertical accuracy in DEMs, was calculated for each error map or residual error map. DEM differencing was calculated by applying subtraction operation of pixel by pixel such as ASTER-GDEM minus Reference DEM and SRTM minus Reference DEM. In addition, skewness and kurtosis [15] was calculated for each error map. Skewness is a unitless measure of asymmetry in a distribution [16]. Let a Gaussian distribution with the mean and standard deviation that have been observed, a negative skewness indicates a balancing on the right of the observed histogram with regard to the reference Gaussian distribution and often a longer tail to the left, while positive skewness indicates a balancing on the left and often a longer tail to the right. Excess kurtosis is a unitless measure of how sharp the data peak of the observed histogram is with regard to its reference Gaussian distribution. A value of the kutosis larger than zero (0) indicates a peaked distribution, while a value less than zero (0) indicates a flat distribution. Percen- tage of pixels falling within different error ranges was also determined.

Profiling: Horizontal profiles were created on the DEMs and compared. Two profiles were elaborated then a graph of elevation against distance was produced for comparison. Profile lengths were 35 km and 45 km for P1 profile and P2 profile respectively.

3.2.2. Accuracy of Terrain Derivatives (Relative Accuracy)

In this assessment, the three DEMs were first preprocessed (filling local depressions). Flow direction, using a deterministic-8 flow direction algorithm, flow accumulation and drainage maps were subsequently generated.

Next, a common outlet location was used to extract an upstream catchment area from the DEMs and the attributes of the derived watershed compared.

Sub-watershed boundaries extracted from the three different DEMs exhibit a high degree of congruency especially in upstream areas. In these areas, SRTM exhibits lower root mean square errors (RMSEs) than the ASTER-GDEM.

4. Results

4.1. Accuracy of Elevation Values

4.1.1. Visual Comparisons

Visual comparison of shaded reflectance or hills hade maps and slope map (**Figure 3** and **Figure 4**) shows two such comparisons. In both **Figure 3** and **Figure 4**, the ASTER-GDEM shows less detail than any of the other data sets. In **Table 1** we presented a summary statistics of DEMs analyzed for three DEMs.

4.1.2. DEM Differencing

Table 2 presents the statistics of the error maps obtained for both DEM, whereas **Figure 5** shows the spatial distribution of the errors and the percentage of pixels that falls in different error ranges. It is quite evident that better results were obtained for SRTM than ASTER-GDEM. This is manifested in the RMSEs obtained for SRTM. Although all RMSEs fall within predefined vertical accuracy specification [17] [18], results for the two DEM (SRTM and ASTER-GDEM) shows that in flat terrain with a small slope (less complex terrain), the distribution of the errors is less than on hilly and mountainous terrain.

Table 2 further reveals that, compared to the reference DEM, SRTM has a better vertical accuracy than the ASTER GDEM. A smaller RMSE was obtained for SRTM than ASTER GDEM. This finding is in line with the pre-launch vertical accuracy of 16 m for SRTM [18] and 20 m for ASTER GDEM [18] [19].

Figure 5 shows the spatial distribution of errors in the ASTER-GDEM and in SRTM. The graphs indicate that ASTER-GDEM elevations are generally lower, compared to the reference DEM. In other words, the ASTER GDEM underestimates elevation. Statistics from error maps indicate that about 80% of pixels fall below zero (0) this underestimation is more pronounced on flat and less complex terrains than in hilly and complex terrains.

Figure 5 shows that SRTM have the directly opposite characteristic (overestimates elevation). Elevation differences are positively biased, resulting in majority of pixels being greater than zero (0). Statistics indicate

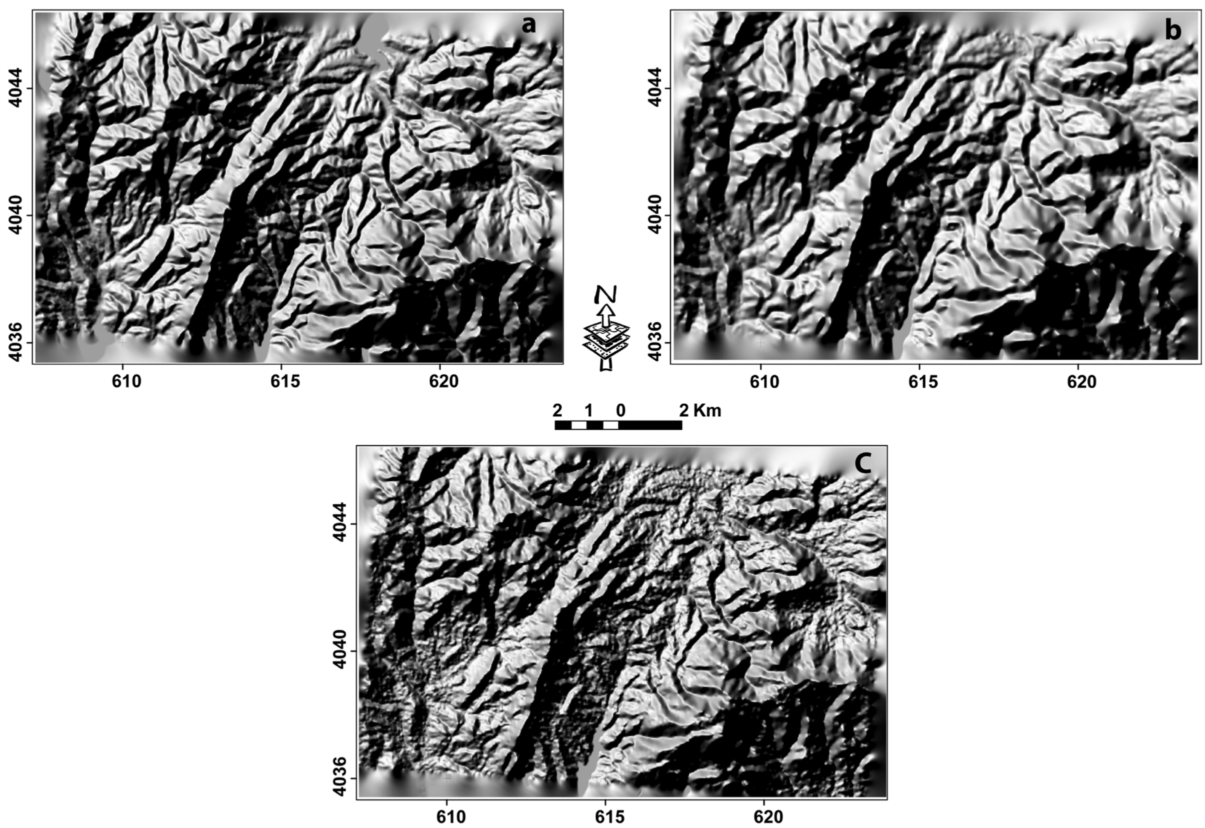


Figure 3. Hillshade maps of three DEMs in SW of Grombalia. (a) Reference DEM; (b) SRTM; (c) ASTER-GDEM.

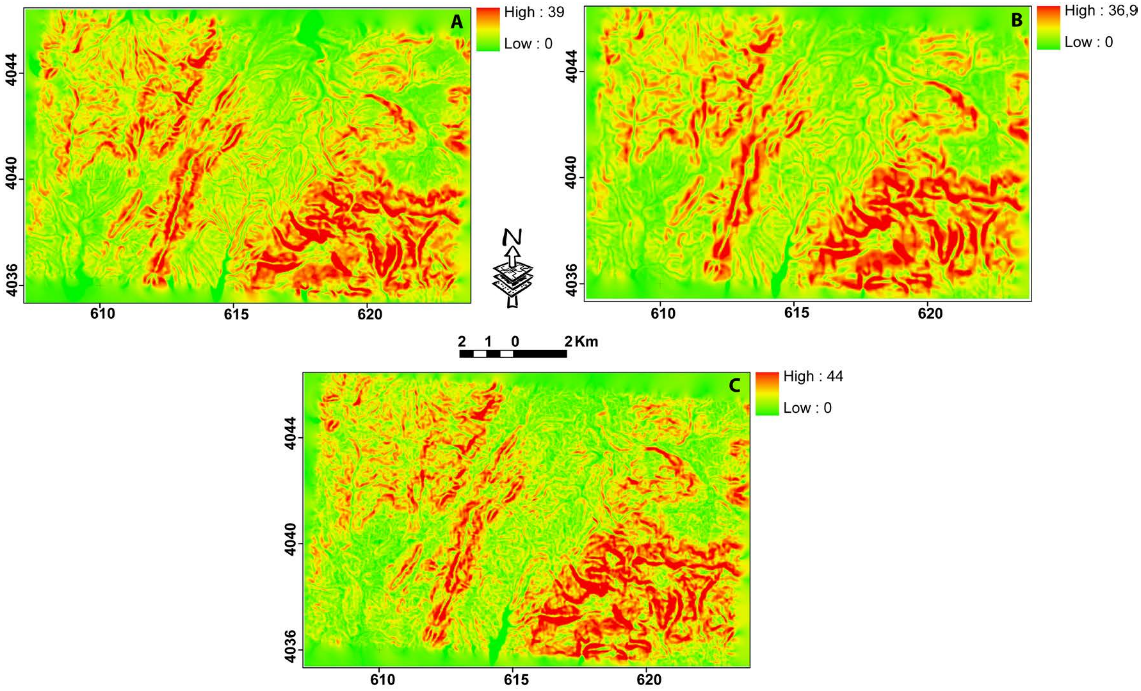


Figure 4. Slope maps of 3 DEMs in SW of Grombalia. (A) Reference DEM; (B) SRTM; (C) ASTER-GDEM.

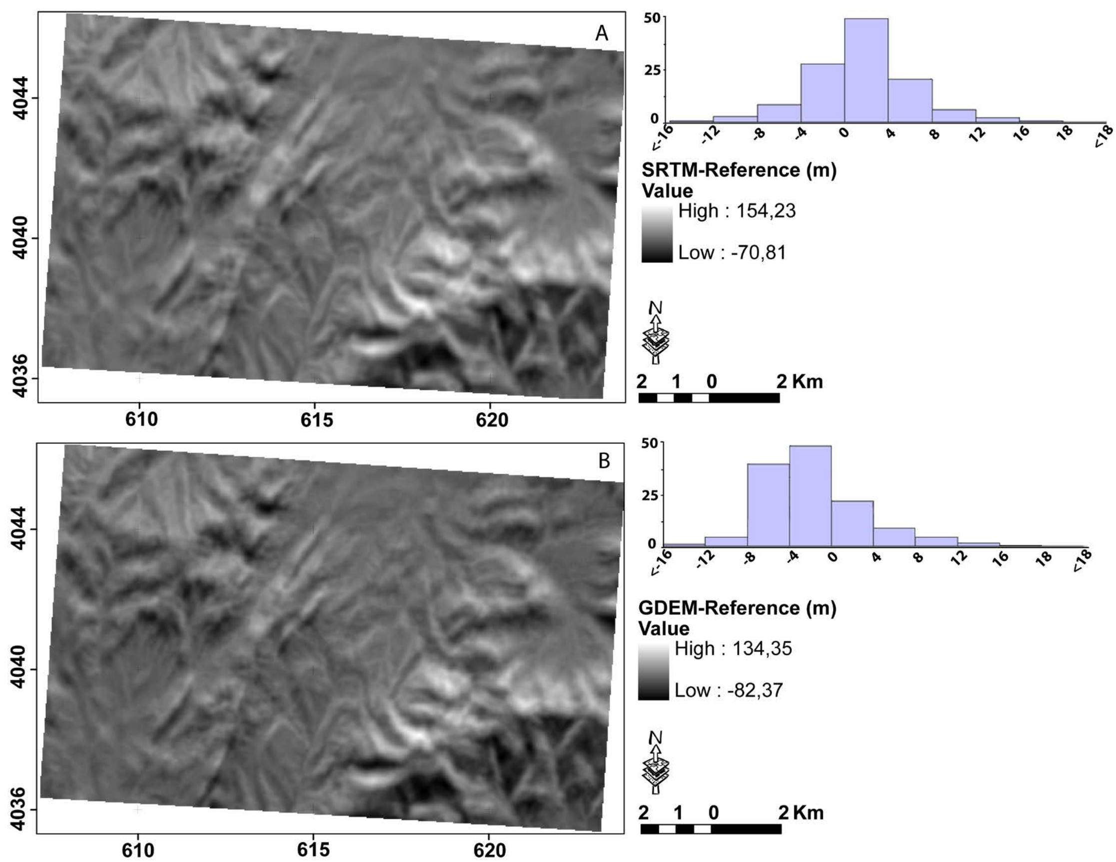


Figure 5. Difference maps computed for the study region. (A) SRTM minus Reference DEM; (B) ASTER minus Reference DEM.

Table 2. Statistics of the absolute elevation error map.

Difference Map	Min	Max	Mean	Standard Deviation	RMSE	Skewness	Kurtosis
SRTM-Reference	−70.81	154.23	0.76	47.46	7.62	0.15	4.33
ASTER-Reference	−82.37	134.35	0.54	47.24	10.53	0.20	4.47

that about 70% of pixels were greater than zero (0). This overestimation may be partly due to the fact that SRTM records the reflective surface and, thus, may be positively biased with respect to the bare Earth when foliage is present. This under- and overestimation of ASTER GDEM and SRTM respectively has been noted in previous studies [19].

4.1.3. Profiling

Apart from generating error maps, vertical profiles were created on the DEMs using the 3-D analyst extension in ArcGIS, and the data exported to MS Excel for comparison. **Figure 6** shows the comparison between the three DEMs. The results obtained in this section further confirm the earlier finding that ASTER-GDEM underestimates elevation whereas SRTM overestimates.

Figure 6 clearly shows how bad ASTER-GDEM performs on lowlands—its profile line is consistently below that of SRTM and the reference DEM. A visual inspection of **Figure 6** reveals that, the magnitude of overestimation of SRTM is less than the magnitude of underestimation of ASTER-GDEM. In other words, SRTM is “closer” to the reference than ASTER-GDEM. This further confirms that SRTM has an accuracy superior to ASTER.

4.2. Accuracy of Terrain Derivatives (Relative Accuracy)

Results of the hydro-processing to extract watershed and drainage information, using a common outlet, from the three DEMs are shown in **Figures 7(a)-(c)**.

Visually, there are small differences between the extract watershed from Reference DEM and the SRTM-based boundaries (**Figure 8**), the same ascertainment is available for the drainage network (**Figure 9**), while the ASTER-based boundary varies from the extract watershed from Reference DEM one, especially in some places (a, b, c and d) the biggest difference in x coordinates between the ASTER-based and extract watershed from Reference DEM, located in (d) site, is 1045,34 m while the difference between the SRTM-based and reference DEM-based boundary at the same place is 134,67 m. The area of some watershed extract watershed from Reference DEM, the SRTM-based watershed area and the ASTER-based watershed area is shown in **Table 3**.

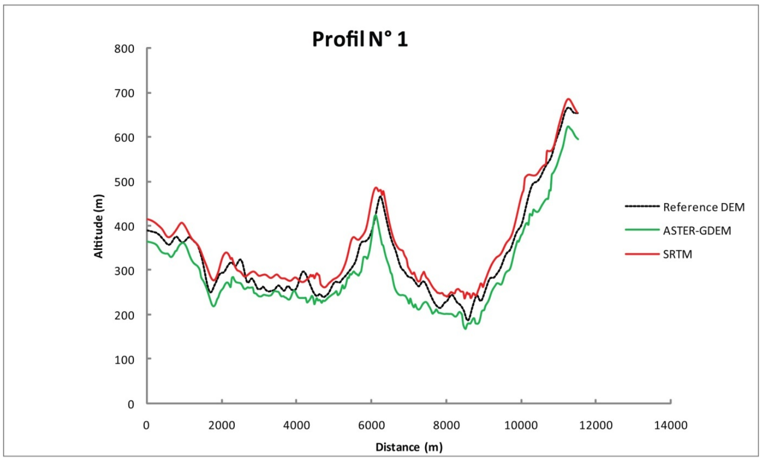
The regression analyses, as indicated in **Figure 10**, show that SRTM is more correlated than ASTER-GDEM. The coefficient of correlation is respectively comparing area of 8 watersheds yielded an R2 of 0.993 between the SRTM and extract watershed from Reference DEM; the R2 for the comparison between the ASTER and the extract catchments from Reference DEM was 0.971 (**Figure 10**).

4.3. Horton Statistics

In hydrology, the geomorphology of the watershed, or quantitative study of the surface landform, is used to arrive at measures of geometric similarity among watersheds, especially among their stream network. The quantitative study of stream networks was originated by Horton. Horton’s original stream ordering was slightly modified by Strahler, and Schumm added the law of stream areas. Number of streams of successive order, the stream length of successive order and the catchment area of successive order is found to be relatively constant from one order to another.

Horton statistics were computed using the extracted drainage data from the three DEMs (**Figure 9**). The statistical values are shown in **Table 4**.

SRTM and ASTER have a larger number of drainage lines per Strahler order, especially for the lower order streams and therefore the stream length per order is less for SRTM and ASTER compared to the Reference DEM. The stream area shows a similar tendency. The stream lengths for the fifth and sixth order are the main deviating phenomena; smaller and larger for the Reference DEM, compared to ASTER and SRTM respectively. The Horton ratio’s, calculated from the lowest and highest stream orders, shows that SRTM and ASTER have



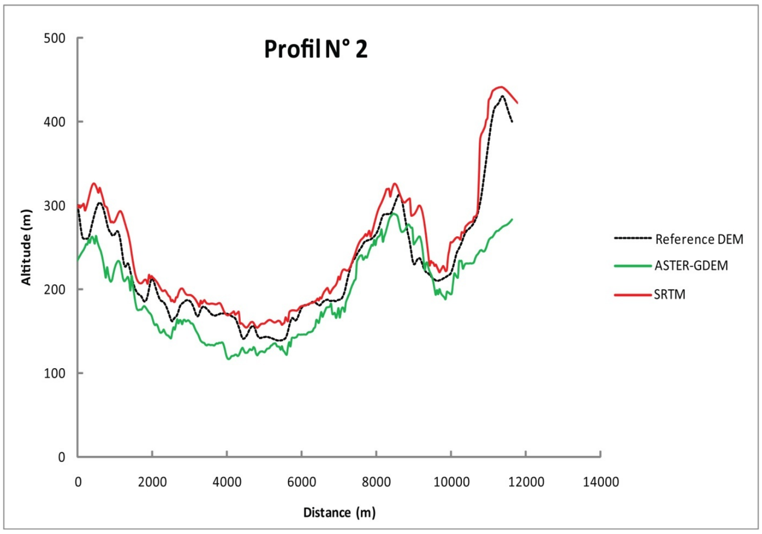


Figure 6. Comparison of profile lines derived from all DEMs for SW of Grombalia.

Table 3. Area values for some extracted watershed.

	Area (Km^2)		
ID	**From Topo DEM**	**From SRTM**	**From ASTER-GDEM**
1	6.8	6.77	6.7
2	1.27	1.29	1.43
3	3.65	3.7	4.17
4	4.17	4.21	4.11
5	3.44	3.45	3.45
6	4.24	4.27	4
7	3.58	3.61	3.51
8	4.56	4.23	4.21
Mean	3.96375	3.94125	3.9475
Sd	1.52573109	1.49780256	1.43927313

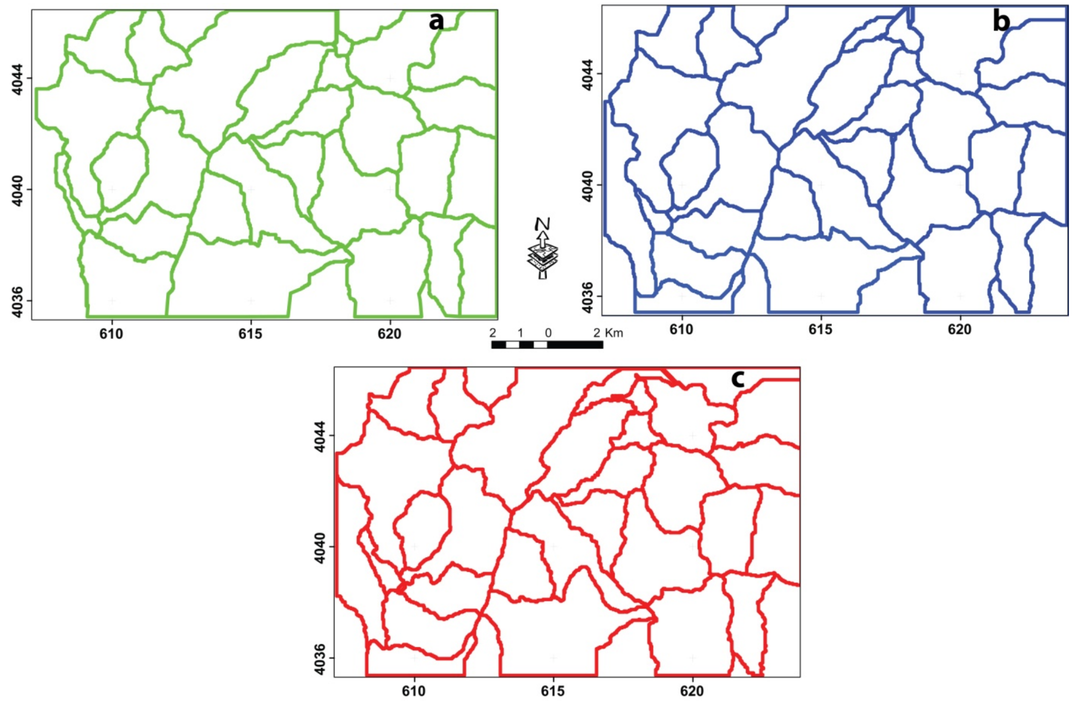


Figure 7. Watershed derived from: (a) Reference DEM, (b) SRTM and (c) ASTER-GDEM.

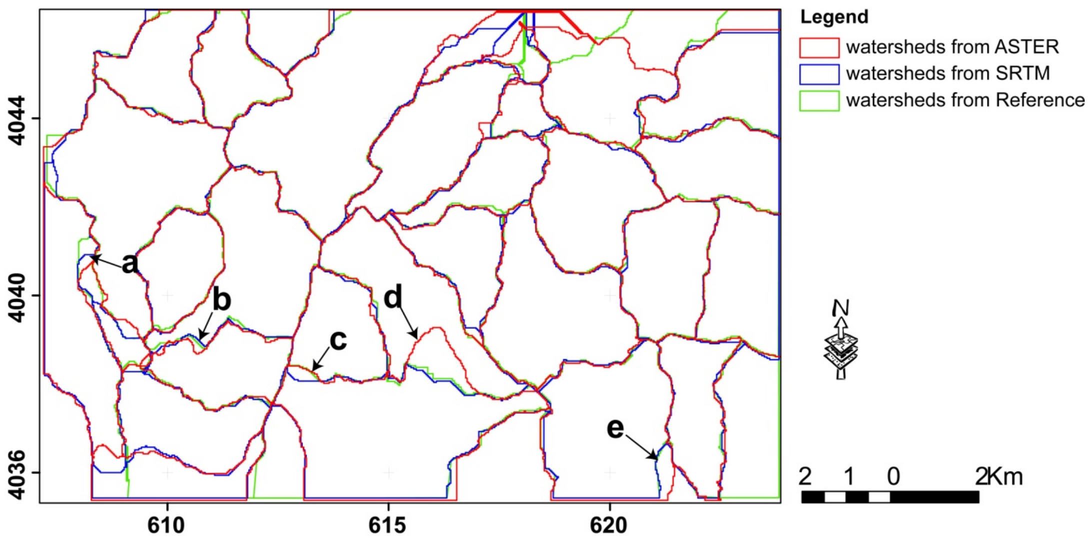


Figure 8. Watershed boundaries comparison.

slightly higher ratio values compared to the one derived from the Reference DEM.

The Correlation coefficients between two terrain attributes (length and Ratio bifurcation) derived from the different models are shown in **Figure 11**. All the DEMs were linearly correlated with the Reference DEM, presenting in all cases high values for the correlation coefficient.

The resulting graphs showed important discrepancies between terrain attributes derived from reference DEM and those derived from the other DEMs.

5. Conclusions

In this study, two near-global DEMs, SRTM and ASTER-GDEM, are compared and validated against a refer-

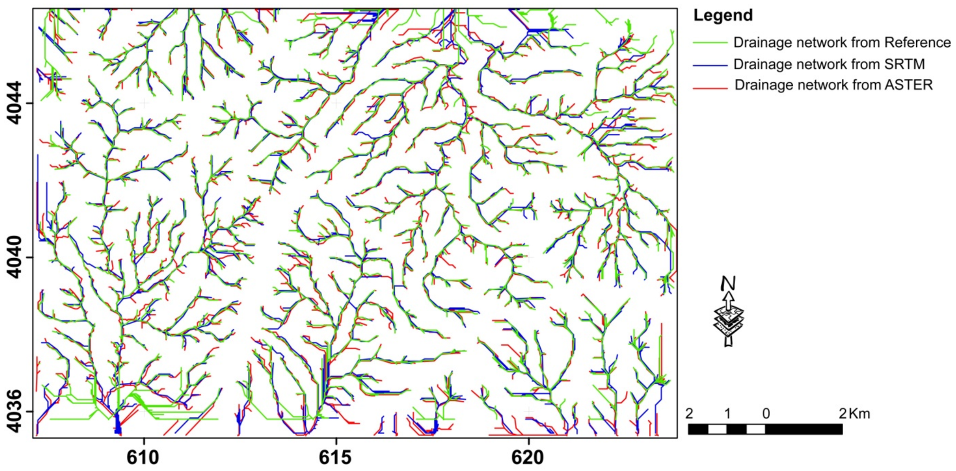


Figure 9. Stream networks derived from Topo DEM, ASTER GDEM, and SRTM. Stream networks superposed in top for each other: green, blue, and red colors indicate respectively streams extracted from Reference DEM, SRTM and ASTER GDEM.

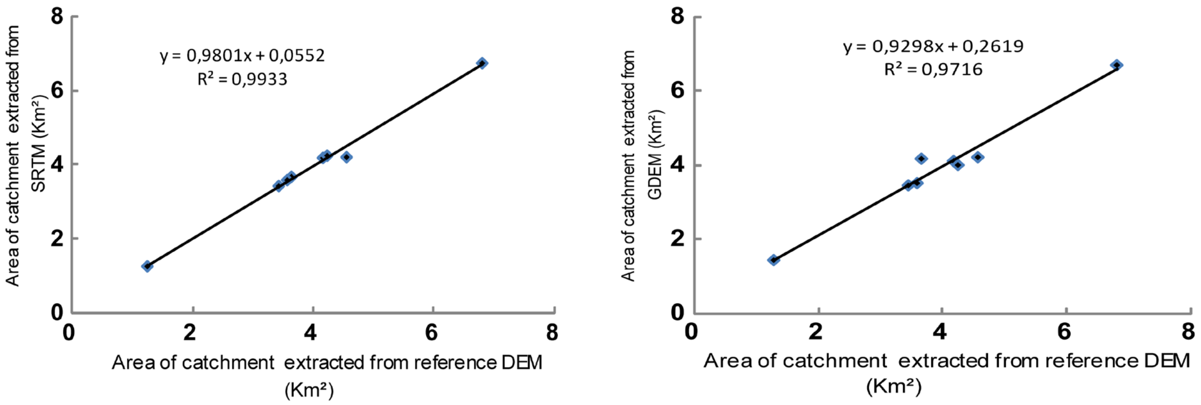


Figure 10. Correlation plot: (a) SRTM versus Reference DEM and (b) ASTER GDEM versus Reference DEM.

ence DEM applied on SW of Grombalia in North East of Tunisia. The reference DEM has been generated from a 1:25,000 topographical map produced by the Office of Topography and Cartography of Tunisia. DEM differencing, profiling, correlation plots, extraction of catchment area and drainage network and computation of Horton statistics are some of the methods employed in the comparison.

Results obtained indicate that, for the site selected, both SRTM and ASTER-GDEM show that SRTM has a higher vertical accuracy (in terms of RMSE) than ASTER-GDEM. RMSEs ranged between 7.62 and 10.53 for SRTM and ASTER respectively. The vertical accuracy of both products, thus, increases on flat and less complex terrain. Analyses conducted revealed that ASTER-GDEM underestimates elevation (*i.e.* negatively biased), SRTM, on the other hand, overestimates elevation, which may be partly due to the fact that SRTM records the reflective surface. The underestimation of ASTER-GDEM is more pronounced on flat and less complex terrain, and of a greater magnitude than the overestimation of SRTM.

Results of horizontal profiling showed that the elevation of ASTER-GDEM is consistently lower than that of the other two.

The methodology described in this paper enables the assessment of the watershed delineation and drainage network extraction on DEMs of different sources. The accuracy of the watershed delineation and drainage information is highly dependent on the accuracy and good quality of the Digital Elevation Model. In this study SRTM proved a higher accuracy with reference DEM than ASTER-GDEM.

In summary, the study has revealed that SRTM is "closer" to the Reference DEM than ASTER, although both products are useful and can be a replacement for local 1:25,000 topographical map data both in absolute and

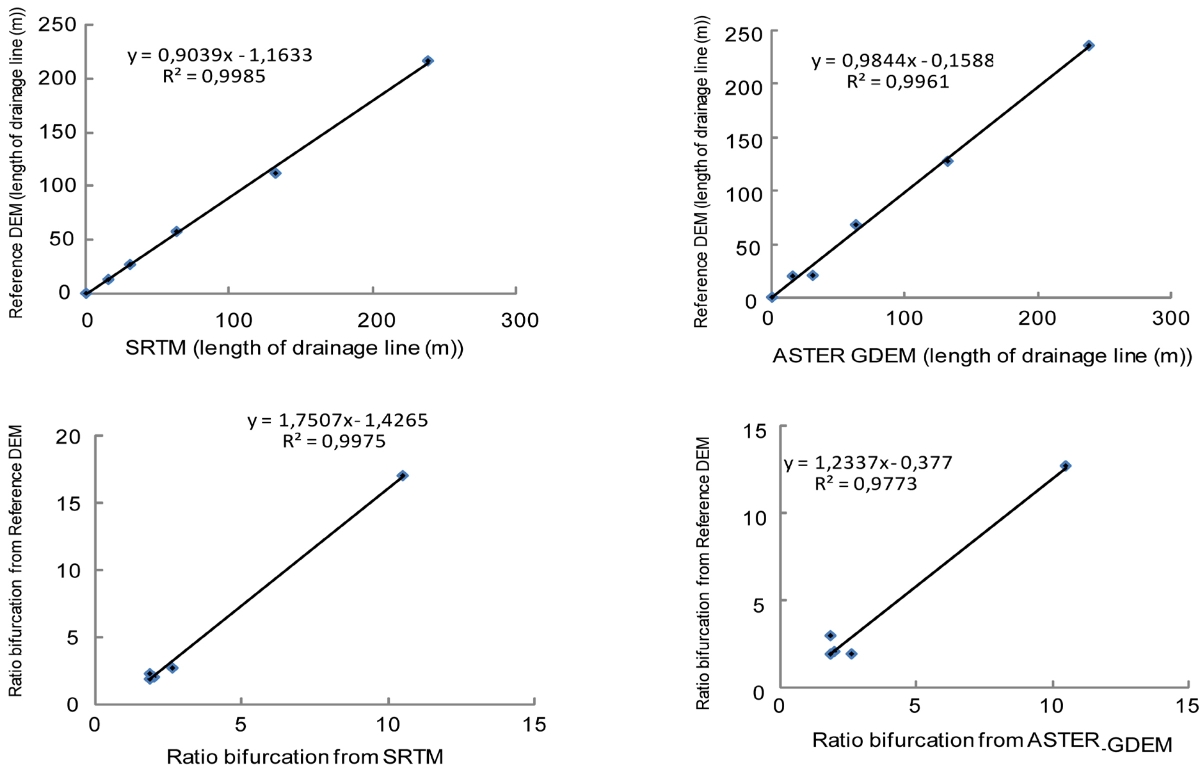


Figure 11. Correlation coefficients between two terrain attributes (length and Rb) derived from the different models.

Table 4. Horton statistics.

Reference DEM (Length of drainage line)					
Order1	Order2	Order3	Order4	Order5	Order6
238.47	132.19	63.15	30.69	15.57	0.05
ASTER-GDEM (Length of drainage line)					
Order1	Order2	Order3	Order4	Order5	Order6
235.37	127.35	67.96	20.68	20.04	0.06
SRTM (Length of drainage line)					
ORDER1	ORDER2	ORDER3	ORDER4	ORDER5	ORDER6
217.24	112.2	57.77	26.9	12.87	0 .03
Reference DEM (Number of drainage line)					
Order1	Order2	Order3	Order4	Order5	Order6
746	375	203	110	42	4
Reference DEM (Ratio bifurcation)					
Rb1/2	Rb2/3	Rb3/4	Rb4/5	Rb5/6	
1.99	1.85	1.85	2.62	10.50	
ASTER-GDEM (Number of drainage line)					
Order1	Order2	Order3	Order4	Order5	Order6
770	384	207	71	38	3

Continued

ASTER-GDEM (Ratio bifurcation)					
Rb1/2	Rb2/3	Rb3/4	Rb4/5	Rb5/6	
2.01	1.86	2.92	1.87	12.67	
SRTM (Number of drainage line)					
Order1	Order2	Order3	Order4	Order5	Order6
760	380	205	91	34	2
SRTM (Ratio bifurcation)					
Rb1/2	Rb2/3	Rb3/4	Rb4/5	Rb5/6	
2	1.85	2.25	2.68	17	

relative terms. The relative assessment further confirms that various surface processes can be appropriately studied when using these global elevation data sets, which is a great asset to geomorphologists. Here the relative assessment conducted is more focused to hydrological processes, and one of the terrain processes important in geomomorpholgy.

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