International Journal of Innovation and Applied Studies
ISSN 2028-9324 Vol. 15 No. 3 Apr. 2016, pp. 618-628

http://www.ijias.issr-journals.org/

Vertical accuracy assessment of Open source Digital Elevation Model (a case study from northern Morocco)

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ABSTRACT: Digital elevation models (DEMs), as its name suggests, is a digital representation of ground in terms of altitude. It provides information not only on landforms but also on their geolocation; this is why it is considered one of the most useful digital data sets for a wide range of users. Various field, remote, and laboratory techniques can generate DEMs. Some of the DEMs such as ASTER, SRTM, and GTOPO30 are freely available open source products; however, the accuracy of these data sets is often unknown and is uneven within each dataset due to radar characteristics, type of topography, and physical properties of the surface. In this study, we evaluate open source DEMs (ASTER and SRTM) and their derived attributes using a reference DEM produced by contours maps interpolation and ground control points. In fact, the quality of derived attributes of DEMs such as slopes and drainage network is closely linked to accuracy of DEMs. While Open source DEMs partially show low accuracy in high elevation terrain and forest areas, it can be concluded that the quality of the datasets is sufficient in large scale studies.

KEYWORDS: Digital elevation models, ASTER, SRTM, Topography, Accuracy.

1 INTRODUCTION

Digital Elevation Models (DEMs) can be defined as a set of altimetry data describing the shape of the ground surface [2] , From which are derived, digital models of slope gradient, horizontal curvatures, catchment area, and other topographic attributes [4].

The knowledge of the surface topography is of major importance to Earth sciences. It is essential in any discipline concerned with process modeling like hydrology, climatology, geomorphology and ecology [6].

DEMs can be generated by Conventional topographic surveys, Kinematic GPS surveys, Analogue and digital photogrammetric approaches, Radar techniques, Laser surveys, Shipboard echo sounding, Airborne optical sensing, Satellite radar altimetry, Airborne ice-penetrating radar techniques and Digitizing of contours [4].

The need for global coverage with a medium scale DEM (1-3 arcs second, or 30-100 m post spacing) led to the Shuttle Radar Topography Mission (SRTM) [1], and the recent release of the ASTER GDEM [12]. These DEMs have different data spacing (3" for SRTM and 1" for ASTER), with ASTER GDEM having near global coverage (N83° to S83°) [12] while the SRTM is limited to latitudes from N60º to S56º [7].

Small scale DEM representation is required for global and regional scale simulation studies, but the feasibility of application depends on vertical accuracy [2]. To assess the accuracy of DEM many attempts have been made, yet there is enough scope to evaluate the open source DEMs because ASTER GDEM Version2 was released on October17,2011. In addition, testing of DEM accuracy in Morocco's landscape especially in Mediterranean are very limited.

Elevation profiling, image subtraction and ground control points are used to assess data quality. This paper examines also the relationship between the DEMs elevation error and terrain morphology, slope and land cover.

2 STUDY AREA

The study area is located in northern Morocco, geographically situated between 494600 (-004°46'13.32") and 502400 (-004°55'20.18") (Easting) and 557300 (035°03'01.87") and 543438 (35°07'17.59") (Northing) for Lambert Coordinate system (Zone 1) and WGS 1984 respectively. The test site has a area of 55 km2 with elevation differences of approximately 1000 m. The relief of the test site is highly rugged and a dense network of small creeks. Land cover is reasonably homogeneous; with 50% of open fields, 35% of forest areas and 11 % as urban areas.

The results of the investigations are only valid for the limited set of environments represented by the test site. Further studies are necessary to proof the validity of the conclusions drawn from this evaluation for other surface types.

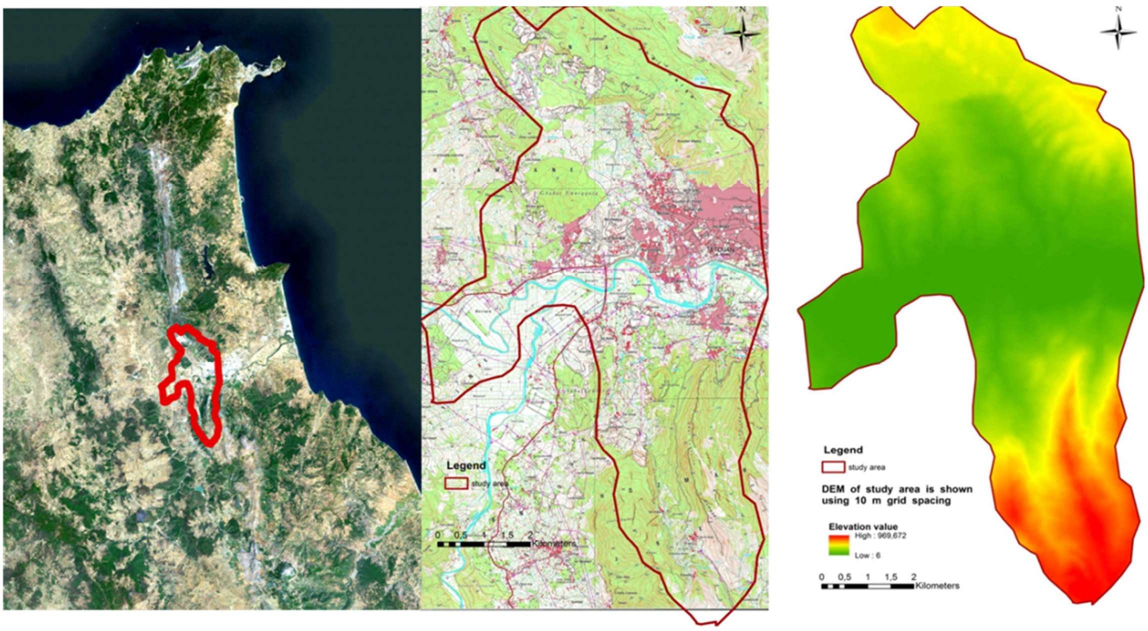


Fig. 1. Delimitation of the study area

3 DATA

In this study, three DEMs are used.

The first DEM is the Shuttle Radar Topography Mission (SRTM): considered as one of the most complete, highest resolution digital elevation model of the Earth. The project was a joint effort of NASA (the National Geospatial-Intelligence Agency), the German and Italian Space Agencies in February 2000. It used dual radar antennas to acquire interferometric radar data, processed to digital topographic data [9].

The second DEM is Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) derived from optical portion of electromagnetic spectrum and the microwave based Shuttle Radar Topography Mission [12].

The "version 1" of (ASTER) Global Digital Elevation Model (GDEM) was released on June 29, 2009 by NASA and the Ministry of Economy, Trade and Industry (METI) of Japan. It was compiled from over 1.2 million scene based DEMs covering land surfaces between 83°N and 83°S latitudes [12].

NASA and METI released a second version of the ASTER GDEM (GDEM2) in October, 2011. Improvements in the GDEM2 resulted from acquiring 260,000 additional scenes to improve coverage, and improved water masking [12].

Table 1. The product specification of the ASTER and SRTM elevation models

	SRTM 3	ASTER GDEM 2
Data supplier	NASA / NGA / DLR/ASI	METI / NASA
Period of collection	11 days in 2000	2000 - 2010
Grid spacing	3"x3" longitude and latitude	1"x1" longitude and latitude
Datum (horizontal)	WGS84	WGS84
Datum (vertical)	WGS84 or MSL (optional)	WGS84 or MSL (optional)
Data format	DTED 16-bit signed integer	GeoTIFF, signed 16-bit, in units of vertical meters
Horizontal precision (absolute)	±20m 90% circular error	±20m 95% circular error
Vertical precision (absolute)	±16m 90% vertical error	±17m 95% vertical error

The third is reference DEM, data reference acquisition is a critical step in the process of developing these models since it has a direct influence on the degree of precision to achieve [2].

The selection of a technique to produce a DEM for soil and geological research depends on several factors, such as the size of the study area, required accuracy and resolution of the DEM, accuracy and resolution of other maps and materials as well as the cost of the DEM generation [4].

Topographic maps of various scales are digitized to produce DEMs. In digitizing, one may use ancillary cartographic information, such as elevation values for mountain summits and depression bottoms, and structural lines. However, Isobaths maps are the most used to create DEMs [5].

In this study, a reference DEM produced by digitizing of contours from topographic map at a scale of 1:25000 is used. The horizontal accuracy is given as less than 5 m and the vertical accuracy as 2–3m (ground control points from general leveling of Morocco).

4 METHODOLOGY

4.1 GENERATION OF DEM FOR REFERENCE DATA

Creation of a DEM from a topographic map requires that the elevation map contours should be converted to raster DEM. This was done using a multi-step process.

To generate the reference DEM, topographic maps of Tetouan_alazhar and Oued_lakhmis at a scale of 1:25000 are used. The topographic map had scanned and geo-referenced. Then contour, spot elevations, coastlines and water bodies extracted and converted to digital vectors. Each vector contour had tagged with their corresponding elevation value. At last a reference DEM at 10 m grid size was generated based on those vector features. The reference DEM has the same coordinate system of topographic maps; Lambert conic conform projection -Morocco zone 1- as horizontal datum and vertical datum were considered as Mean Sea Level (MSL).

4.2 DATUM MATCHING

The vertical datum of reference DEM is MSL, while the elevation value in SRTM and ASTER data is given as height above EGM96 1996 Earth Gravitational Model in optional way [12] [8]Which is closely comparable with MSL. Therefore, matching datum is not necessary.

When open source DEMs are downloaded in WGS84 as vertical datum, several processing steps are necessary to transform the open source data into a product comparable to the reference DEM.

The fact that SRTM AND ASTER DEM have WWGS84 as horizontal datum, they are then projected to a Lambert conic conform projection (zone 1, Morocco) to make them comparable to the reference DEM. In order to introduce the least possible geometric error in this processing step, cubic convolution is used as a resampling method.

The associated smoothing is a minor obstacle and the error margin related to this process can be specified to be below 1 m in order to match the same vertical and horizontal datum.

5 VALIDATION AND DISCUSSION

5.1 VISUAL AND STATISTIC VALIDATION

5.1.1 ELEVATION PROFILES

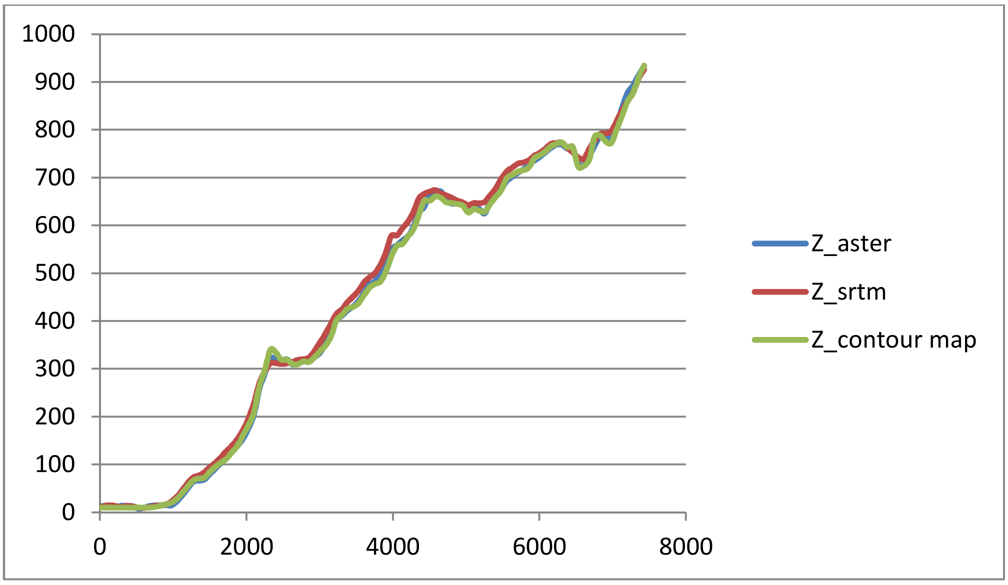


Fig. 2. Terrain profile derived from three DEMs along the section line

Elevation profiles are effective ways to illustrate differences between Digital Elevation Models. Fig. 2 compares a subset of an elevation profile for each the SRTM; ASTER DEM and the reference DEM.

It is clear from the chart that while over most of the curve the SRTM elevation value does not deviate from the reference DEM by more than approximately 10 m. In high elevations; up to 400 m the curve shows much more severe deviations from the reference.

At the same time we see that the deviations from the reference are much less in the case of ASTER elevations compared to SRTM elevations.

5.1.2 DIFFERENCE IMAGES

Difference images are widely used to visualize the spatial distribution of error between a DEM and a particular reference. In effect, computing a difference image removes the topography from the DEM and only shows the true deviation in elevation from the reference.

In this case, the SRTM DEM and ASTER DEM were subtracted from the reference DEM to obtain positive numbers for cases in which the SRTM or ASTER underestimates the elevation and negative numbers for those cases in which it overestimates the elevation; $\Delta z = Zref - ZSRTM/ASTER$

Where **Δ**z is the elevation error, zSRTM/aster is the elevation of the SRTM or ASTER DEM and zref the elevation of the reference DEM at a particular location.

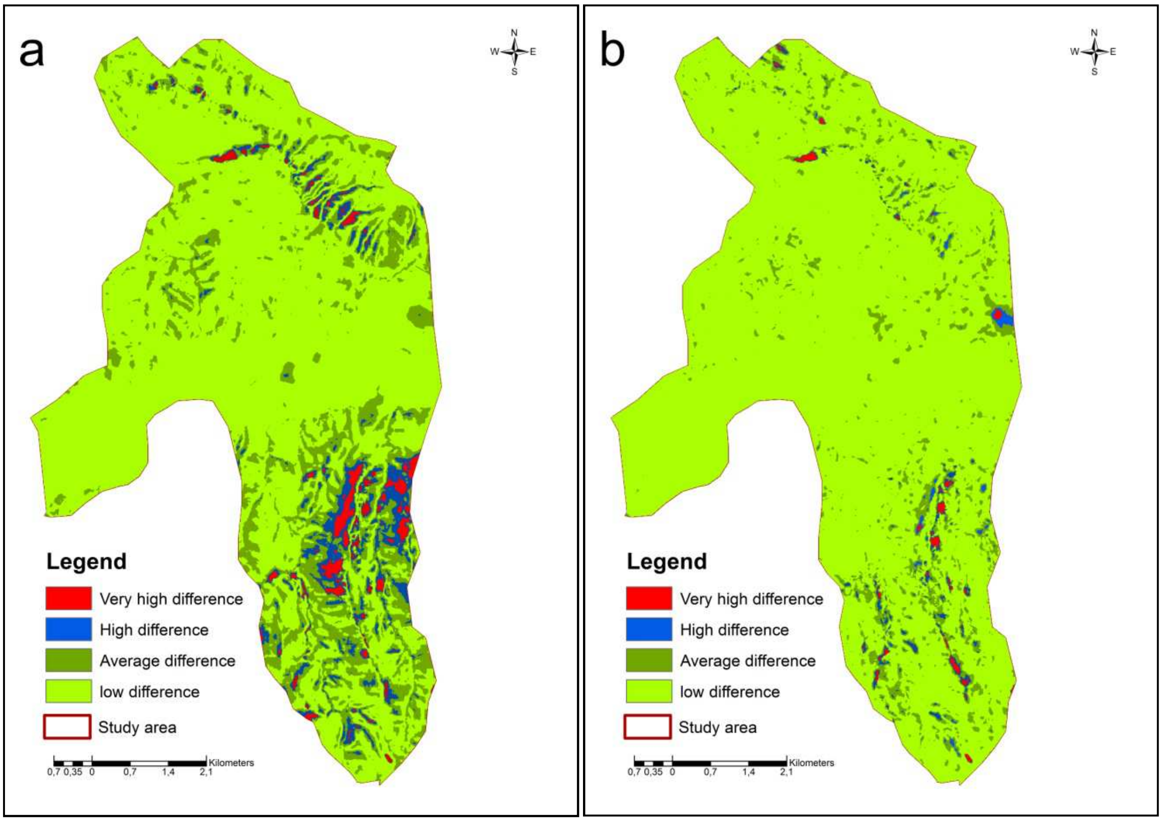


Fig. 3. Difference image between: a) the SRTM DEM and the reference DEM b) the ASTER DEM and the reference DEM.

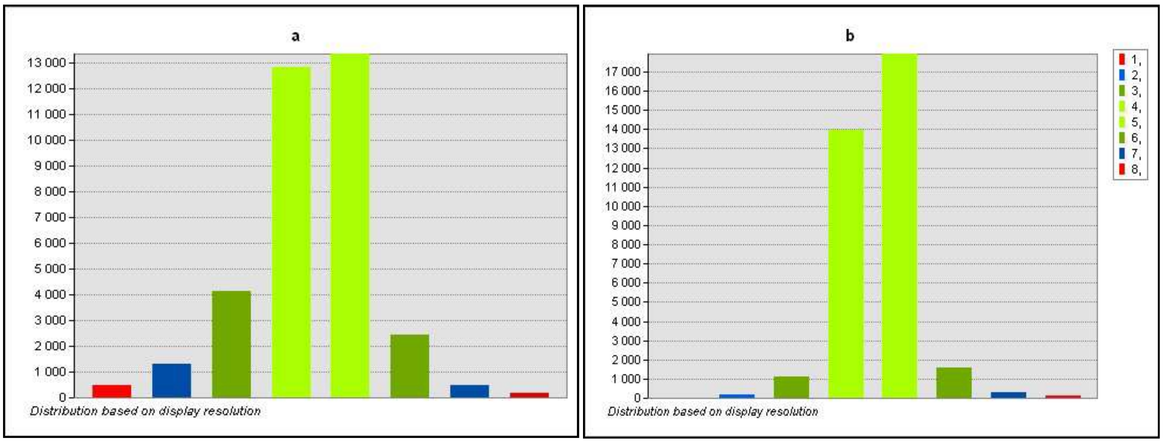


Fig. 4. Histogram of difference image between: a) the SRTM DEM and the reference DEM b) the ASTER DEM and the reference DEM

The altitude differences were classified into 4 classes (very high difference> 30m, high difference between 20 and 30 m, average difference between 10 and 20 and low difference<10m). Fig. 2 shows the corresponding difference image, Areas at very high errors are wider in the case of SRTM DEM than Aster DEM. This shows that aster DEM is closer to reference than SRTM DEM; this is due in part to the resolution of SRTM data that is 3 * 3 arcs while 1 * 1 arcs for ASTER.

We can also observe in Fig. 2 that flat areas only show errors of ±10 m and High differences are concentrated in the mountainous and hilly areas, which is proving that slope and surface objects play an important role in the accuracy of elevations values.

The histogram of the difference image set is shown in Fig. 3,The altitude differences were classified into 8 classes (class 1 > -30m; -30<class 2<-20; -20 <class 3<-10; -10 <class 4<0;0 <class 5<10;10 <class 6<20;20 <class 7<30;class 8 >30).

It is clear that the percentage of high error is very important in SRTM DEM; 90% of differences in ASTER DEM are less than +/-10 m compared to74% in SRTM DEM.

Furthermore, within average and high differences, the negative ones are more current in the first histogram and positives are more current in the second, which means that SRTM DEM underestimates the elevation value and ASTER DEM overestimates it. Nevertheless, in low differences both ASTER and SRTM DEM underestimate elevation value; the overestimation and underestimation are extremely linked to the land cover. This relationship will be treated in the chapter 5.2.2.

5.1.3 VALIDATION USING SURVEYING POINTS

The reference DEM used for this study provides a reliable and homogeneous source of spatially distributed elevation data, however it has a potential 2–3m vertical error. The next step in this study was therefore to validate the SRTM and ASTER using surveying with very high accuracy in position as well as elevation.

A number of 161 evenly distributed surveying points were available for validating the open source DEMs. For each point, the elevation value of the surveying point was subtracted from the corresponding open source DEM pixel value to calculate the error.

It must be noted that the comparison of a pixel value as the spatial mean of a 30 × 30 m area to a point value is problematic, as some of the deviation is certainly attributed to these different scales of observation. A quantification of this effect is beyond the scope of this paper, thus compensation within the samples was assumed.

Table 2. Basic statistic of ASTER and SRTM DEMs errors

	ASTER elevation	SRTM elevation
Mean	1,083	-13,660
Standard error	0,844	1,179
median	-1,826	-17,475
Standard deviation	10,705	14,964
Minimum	-16,132	-34,470
Maximum	41,960	44,889
sum	174,306	-2199,334
Number of samples	161	161
Confidence interval (95,0%)	1,666	2,329

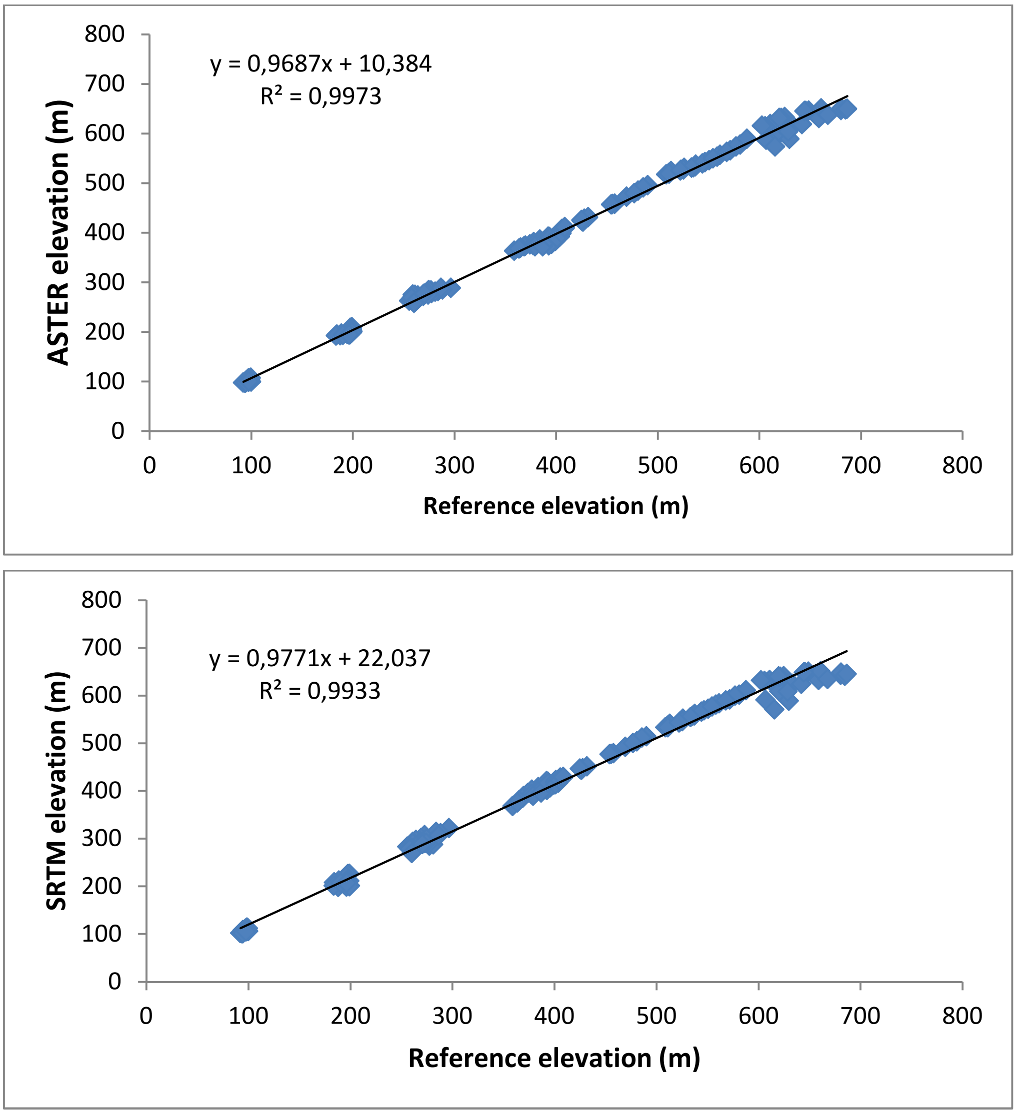


Fig. 5. Deviations of the SRTM and ASTER elevations from the reference at the surveying points

The basic statistics for this analysis show that elevations values from ASTER are more accurate and homogeneous compared to SRTM elevations. In fact the mean error, standard deviation, median, standard error and Confidence interval are higher in ASTER than SRTM.

Fig.4: shows that The level of agreements (R2) between reference elevation is 0.997 for ASTER and 0.993 SRTM thus correlation between ASTER and reference height is which signifies that accuracy of ASTER is better compared to SRTM.

5.2 Factors influencing elevation errors

5.2.1 Effect of terrain morphology and slope in DEM accuracy

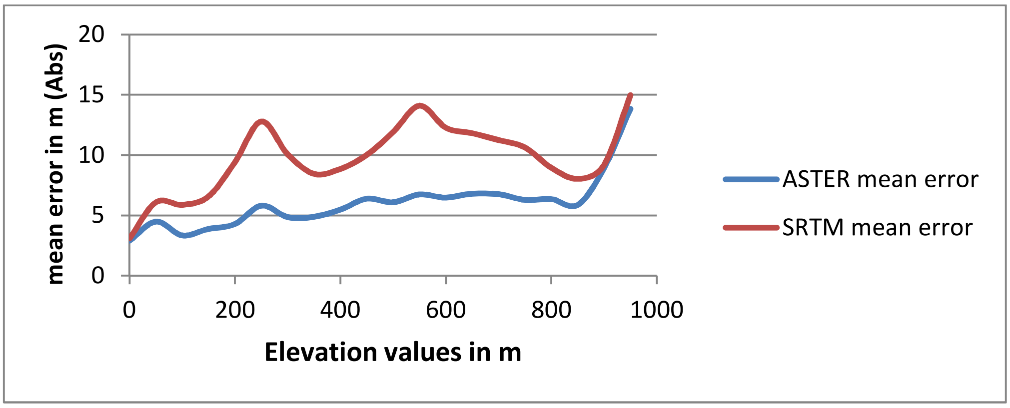
Terrain morphology is one of the major influencing factors for vertical accuracy of DEM. In order to evaluate this influence, reference DEM is divided into 7 altitudinal zones and slope was derived from each DEM.

Table 3. Statistical characteristics slope derived from ASTER and SRTM elevation data

Statistics of ASTER DEM derived slope			
Altitudinal zone	MAX	MEAN	STD
<300	57,51	9,94	7,20
301-400	65,44	14,94	9,85
401-500	59,00	16,37	9,40
501-600	60,30	22,30	11,22
601-700	57,41	24,13	9,25
701-800	53,42	22,03	8,40
>800	54,21	18,55	8,66

Statistics of SRTM DEM derived slope			
Altitudinal zone	MAX	MEAN	STD
<300	46,77	8,75	6,42
301-400	59,63	13,23	9,06
401-500	59,73	14,63	8,69
501-600	59,51	21,09	10,80
601-700	58,12	23,01	8,07
701-800	46,20	20,63	7,33
>800	41,77	17, 08	8,01

The statistical characteristics of the slope maps calculated from ASTER and SRTM for each altitudinal zone are given in Table 2. Maximum, mean and standard deviation of slope are lower when calculated from SRTM. This could be explained by the effect of generalization due to coarse posting (30m in ASTER and 90 in SRTM).



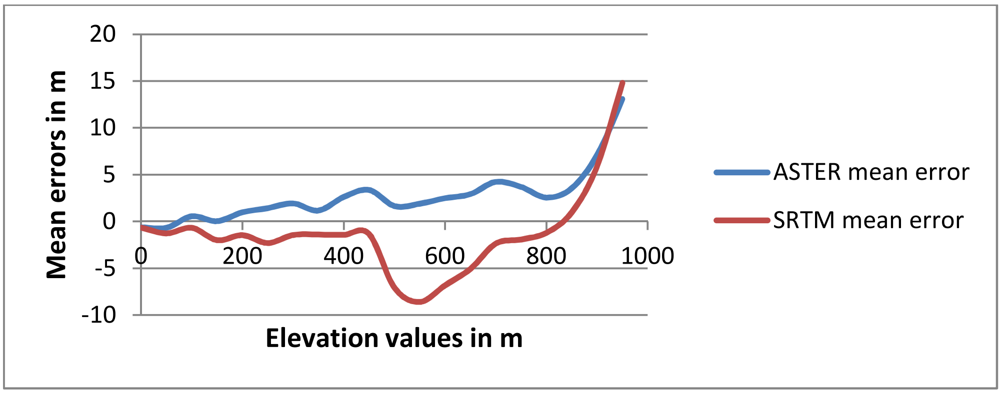
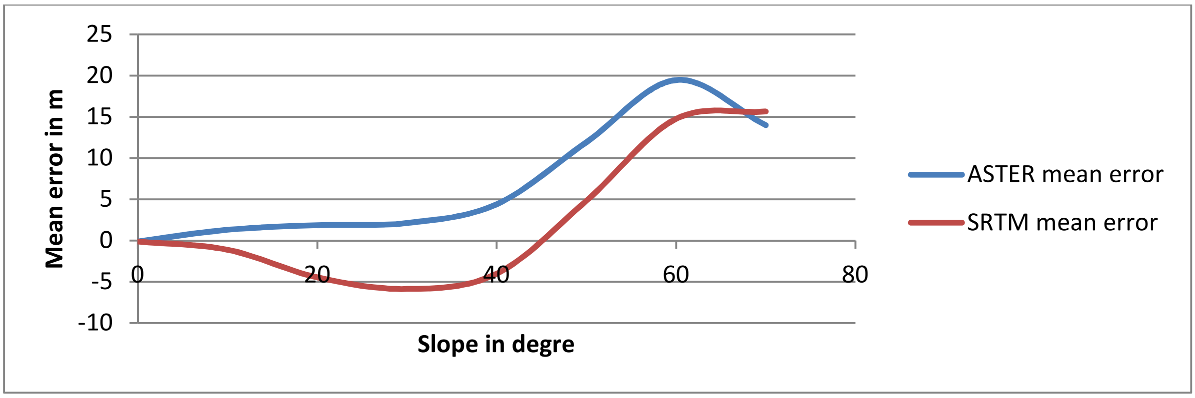


Fig. 6. Vertical accuracy of ASTER and SRTM relative to terrain morphology

The mean error of elevation value of ASTER and SRTM within each zone is calculated from differenced surfaces.(Fig.5) shows the effect of terrain topography on DEM accuracy. The DEM surface in both cases is more erroneous in high altitudinal zone where terrain is rugged; The mean error curve shows an increasing trend in high altitudinal zone indicating that relief increases the uncertainty of height measurement. The mean error curve show negative SRTM errors while ASTER errors are always positives witch prove again that SRTM data overestimate elevation value and ASTER data underestimate them. In absolute value the mean curve shows that the mean error of SRTM is always higher than aster mean error proving that ASTER surface provide more accuracy compared to SRTM surface.



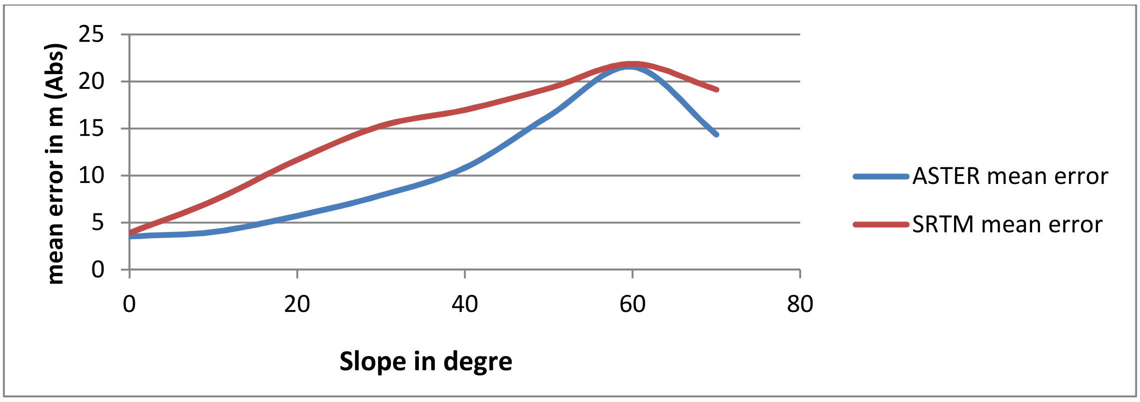


Fig. 7. Vertical accuracy of ASTER and SRTM relative to slope of the reference

The effect of slope on the height accuracy is shown in Fig. 6. It indicates that in relatively flat areas (slope less than 20◦), the accuracy of DEMs is less than 10 m. The error increases rapidly when the slope value is greater than 20◦. It also reveals the effect of relief on DEM accuracy. The ASTER mean errors are always less than SRTM errors witch prove another time that the ASTER surface provides a better accuracy compared to SRTM.

5.2.2 RELATIONSHIP BETWEEN SRTM AND ASTER ELEVATION ERROR AND LAND COVER

As SRTM and ASTER is a radar-based method, the quality of the reflected signal is dependent on the properties of the scattering object on Earth surface. In addition to topography, the accuracy of the SRTM and ASTER DEM was also expected to show some variation with land cover.

To analyze any potential relationship between SRTM and ASTER elevation error and land cover, the land cover (forest map of Tetouan) data set was used. Land cover map is organized into 8 classes (urban areas, matorral, Open forest, low-density forest, average -density forest, dense forest, open space and wetlands).

Table 4. Basic statistics of the ASTER and SRTM mean error for the land-cover classes

Land useclass	AREA m2	ASTER mean error	SRTM mean error
Urban areas	5932600	-3,34	-0,93
Open space	28375300	0,94	-1,39
Matorral	13627200	3,41	-0,40
Field with small plantation	1073800	1,35	-0,81
low-density forest	2315900	2,69	-4,45
average -density forest	667000	-0,33	-8,94
dense forest	3078100	-2,34	-6,65
wetlands	400400	0,03	1,16

Basic statistics were computed from the difference image (fig.2) for each land-cover class. Table 3 shows the results with the mean error being the most interesting parameter.

The Open space, and wetlands classes show only very low (less than a meter) absolute deviations from the reference, while the absolute errors for the Urban areas and forest are the largest.

Minor deviations were detected in the localization of sub watershed and in the spatial pattern of river segments, which can be particularly related to the different technique of DEM generation in terms of the true object surface detection by interferometry.

Dense forests, urban areas and matorral show the highest mean (absolute value) elevation errors. While the high mean error for forest and urban areas was to be expected due to the different representation of topography in the SRTM and ASTER DEM and the reference DEM, the high mean error for the matorral and Field with small plantation was more surprising. However, further analysis showed that areas of matorral and Field with small plantation were almost exclusively located at higher elevations in regions of steep slopes. Thus, this effect can be attributed to the dependence of SRTM and ASTER DEM accuracy on slope.

As expected forests and urban areas show a negative value because ASTER and SRTM DEM overestimate elevation value in that area due to radar technology used to produce DEM. furthermore SRTM shows overestimation of heights in all type of area, while ASTER tends to overestimate elevations only in urban and forest area.

The fact that these values are close to the accuracy of the reference DEM, these deviations may not be significant after all.

6 CONCLUSION

The vertical accuracy of ASTER GDEM Version 2 and SRTM elevation model was tested in the present study. The validation was performed based on two reference data; surveying control points and high posting DEM derived from map contour. The accuracy of ASTER and SRTM DEM was evaluated using visual, profile and statistical methods. The effect of terrain morphological characteristic and slope was also analyzed.

Interestingly, the accuracy of ASTER and SRTM heights exceeds the mission specification when compared with surveying control points and high posting DEM derived from map contour, although ASTER surface provides a better accuracy compared to SRTM.

The vertical accuracy of the DEMs is affected by the terrain morphological characteristics and terrain roughness negatively influences vertical accuracy. In the higher altitude (>400 m) where the variance of elevation is high, the error of elevation is also increased. The slope characteristic of the terrain has significant impact on ASTER and SRTM accuracy where terrain slope is above 20◦. The high mean errors are associated with rugged and steep terrain.

The results show that although the SRTM, ASTER data and the reference DEM have different representations of surface objects, the data have a high vertical accuracy in smooth, hilly terrain with a mean error of less than 1 meter.

The study recommends that the elevation models can be very useful for small scale regional level study where the inaccuracies in the SRTM and ASTER data have only a minor impact on the model results.

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