

Accuracy Assessment of Open Source Digital Elevation Models

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Abstract

Digital Elevation Model is a three-dimensional representation of the earth's surface, which is essential for Geoscience and hydrological implementations. DEM can be created utilizing Photogrammetry techniques, radar interferometry, laser scanning and land surveying. There are some world agencies provide open source digital elevation models which are freely available for all users, such as the National Aeronautics and Space Administration (NASA), Japan Aerospace Exploration Agency's (JAXA) and others. ALOS, SRTM and ASTER are satellite based DEMs which are open source products. The technologies that are used for obtaining raw data and the methods used for its processing and on the other hand the characteristics of natural land and land cover type, these and other factors are the cause of implied errors produced in the digital elevation model which can't be avoided. In this paper, ground control points observed by the differential global positioning system DGPS were used to compare the validation and performance of different satellite based digital elevation models. For validation, standard statistical tests were applied such as Mean Error (ME) and Root Mean Square Error (RMSE) which showed ALOS DEM had ME and RMSE are -1.262m and 1.988m, while SRTM DEM had ME of -0.782m with RMSE of 2.276m and ASTER DEM had 4.437m and 6.241m, respectively. These outcomes can be very helpful for analysts utilizing such models in different areas of work.

Keywords: terrain analysis, open source, modelling, stereoscopic viewing.

الخلاصة

نموذج الارتفاع الرقمي هو تمثيل ثلاثي الأبعاد لسطح الأرض، وهو أمر ضروري لتطبيقات علوم الأرض والهيدرولوجيا. يمكن إنشاء نموذج ارتفاع رقمي باستخدام تقنيات المسح التصويري، والمسح الراداري، والمسح بالليزر والمسح الأرضي. هناك بعض الوكالات العالمية توفر نماذج للارتفاعات الرقمية مفتوحة المصدر متاحة لجميع المستخدمين بصورة مجانية، مثل الإدارة الوطنية للملاحة الجوية والفضاء (ناسا)، والوكالة اليابانية لاستكشاف الفضاء الجوي (جاكسا) و ALOS و SRTM و ASTER هي نماذج ارتفاعات رقمية تعتمد على الأقمار الصناعية وهي بيانات مفتوحة المصدر. إن التقنيات المستخدمة للحصول على البيانات الأولية والأساليب المستخدمة في معالجتها ومن ناحية أخرى خصائص الأرض الطبيعية ونوع الغطاء الأرضي، هذه العوامل وغيرها هي سبب الأخطاء الضمنية المتولدة في نموذج الارتفاع الرقمي والتي لا يمكن تجنبها. في هذا البحث، استخدمت نقاط الضبط الأرضي المرصودة باستخدام نظام تحديد المواقع العالمية التفاضلي للتحقق من كفاءة وأداء نماذج الارتفاعات الرقمية لأقمار صناعية مختلفة. وللتحقق من كفاءتها، تم تطبيق اختبارات إحصائية قياسية مثل الجذر التربيعي لمعدل الخطأ (RMSE) ومتوسط الخطأ (ME) والتي أظهرت الجذر التربيعي لمعدل الخطأ لـ ALOS كان بمقدار 1.988m أما معدل الخطأ فكان -1.262m، بينما لـ SRTM فكان RMSE و ME 2.276m و -0.782m على التوالي أما لـ ASTER فكان 4.437m و 6.241m. ويمكن أن تكون هذه النتائج مفيدة جدا للمحللين الذين يستخدمون هذه النماذج في مجالات عمل مختلفة.

الكلمات المفتاحية: تحليل التضاريس، مصدر مفتوح، نمذجة، منظور مجسم .

Introduction

DEM is a stereoscopic representation of the earth's surface which is giving essential information about the elevations of terrain. DEM might be considered the best way of terrain modelling. It is a grid based matrix structure, which illustrates topological relations between data points implicitly (Guth, 2006). Important parameters which are derived from DEM such as aspect, topographic index, slope, drainage area and network, and so on are used for extracting spatial information from terrain analysis. These are essential in various applications, for example, modelling water stream, runoff estimation, inundation simulation and administration, landform investigation, the making of relief maps, volcanic dangers, territory representation and

mapping, weather and meteorological investigations. The results of the models rely on the accuracy of the DEM (Mukherjee *et.al.*,2013).

The techniques of Photogrammetry, airborne laser scanning, radar interferometry and topographic surveys are used to create DEMs. Like any spatial dataset, DEM is encounter to various sorts of errors, for example, gross error when collecting data, the insufficient orientation of stereo images with photogrammetrically determined elevation values and obscure blends of errors (Blunders) which are the inevitable errors. These errors difference geographically relying upon the status of the terrain (Mukherjee *et.al.*,2011). Other matters are concerned to DEM accuracies such as the grid spacing and interpolation modes (Patel *et.al.*, 2016).

The obtaining of DEM over expansive zone is a challenging assignment in view of the complex generation operation. The accessible open source DEMs, for example, SRTM 1 arc second, ALOS 1 arc second, ASTER 30 m, and numerous others have a coarser resolution. The feasibility of usage of DEM relies on vertical accuracy. Endeavors have been made to look at the vertical exactness of DEM (Frey and Paul, 2012).

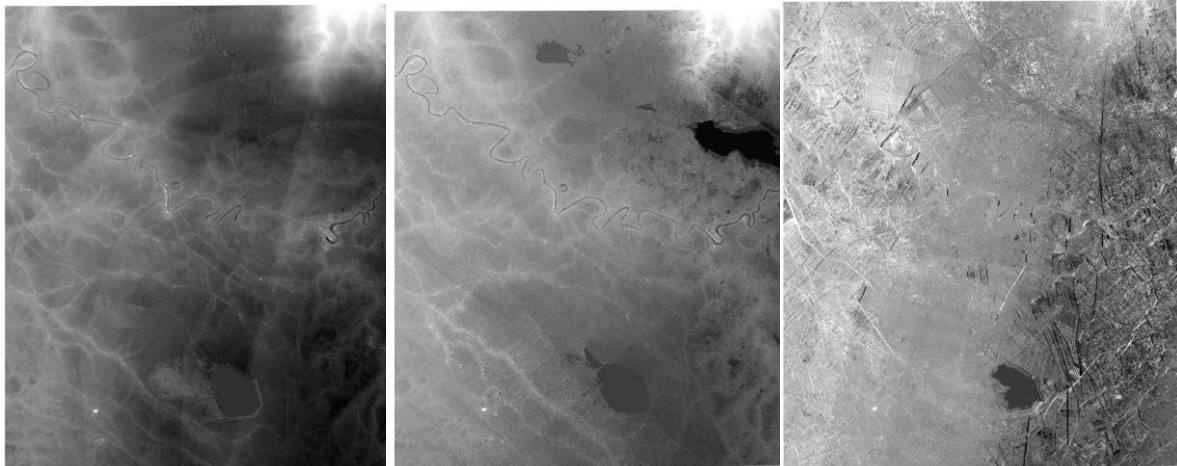
Shuttle Radar Topography Mission (SRTM) was a joint mission by National Imagery and Mapping Agency (NIMA) and NASA to collect global elevation data set (Rabus *et.al.*, 2002). STRM gives highest resolution accessible DEM of the Earth. It relies on the standard of interferometry Synthetic Aperture Radar SAR or Interferometric Synthetic Aperture Radar InSAR, which utilizes phase-difference estimations got from two radar images. In quantitative terms, the cartographic items got from the SRTM information are examined over a framework of roughly 30 m * 30 m. The product comprises of consistent raster information, which is provided according to a user specified region of coverage. The SRTM information meets the absolute horizontal accuracy of 20 m and vertical accuracy of 16 m at 90% confidence level, as determined by the mission. The vertical accuracy is altogether superior to the 16 m. It is nearer to ± 10 m. Its application is the concern of different monographs which were directed on geomorphology, topography, vegetation cover topics, tidal appraisal and urban investigations. SRTM data check was performed utilizing different altimetry information and DEMs (Patel *et al.*, 2016). For this study, SRTM data were downloaded from <http://srtm.csi.cgiar.org>.

The Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) was produced by the METI (Ministry of Economy, Trade, and Industry) of Japan and the NASA of United States. It has an along-track stereoscopic ability utilizing its near infrared spectral band to gain stereo image. The spatial resolution is 15 m and created DEM is 30 m. It covers regions between of 83°N and 83°S. The absolute vertical accuracy of ASTER is 20 m at 95% confidence level. The enhanced vertical accuracy of ASTER, launched on October 17, 2011, is 8.86 m (Mukherjee *et.al.*,2013). For this study, ASTER data were downloaded from <http://demex.cr.usgs.gov/DEMEX/>.

JAXA created the worldwide digital elevation model DEM and ortho-rectified image (ORI) utilizing the archived information about the Panchromatic Remote Sensing Instrument for Stereo Mapping (PRISM) installed the Advanced Land Observing Satellite ALOS, which was worked from 2006. PRISM comprised of three panchromatic radiometers that procured along track stereo images. It had a spatial resolution of 2.5 m in the nadir-looking radiometer and accomplished worldwide coverage, making it an appropriate potential candidate for exact worldwide DEM and ORI generation. In the last 10 years or so, JAXA has conducted the calibration of the system corrected standard results of PRISM with a specific end goal to enhance

absolute accuracies and to validate the high-level products, for example, DEM and ORI (Tadono *et.al.*, 2014). For this study, the dataset download site is <http://www.eorc.jaxa.jp/ALOS/en/aw3d30/data/index.htm>

The present investigation is to assess the accuracy of the DEM in analyzing the magnitude of the vertical blunder of SRTM, ASTER and ALOS utilizing GCPs collected from the field. The Consider DEMs ALOS, SRTM and ASTER of the area of study appear in Fig.1.



ALOS

SRTM

ASTER

Fig.1: DEMs of the study area

Motivation

This paper aims at utilizing concepts of global navigation satellite system to assess the accuracy of free available data, which requires to analyzing remote sensing data to prove that the open source DEM offers a significant potential for performing the measurements and analyses of spatial data for topographic and geomorphologic purposes.

Study area and data resources

The study is done in the southeast segment of Iraq, geographically located between 31° 59' 37.19" N to 32° 59' 31.64"N and 45° 05' 09.81"E to 45° 59' 08.22"E as illustrated in Fig.2. The region of study includes some portion of Al-Kut, Al-Hayy, Badra, Nu'maniyah and Zubaydiyah districts of Wasit Governorate. The area of study is a varying area in terms of terrain. Geomorphological, the eastern region of the study is characterized by adjacent to the mountain range, which represents the Iraqi-Iranian border and thus it is a high area fairly. The southern part of the study area is a flat area with little variation in elevations, but is lower than the northern part of it. The Tigris river runs through the region, extending from north to south-east from it.

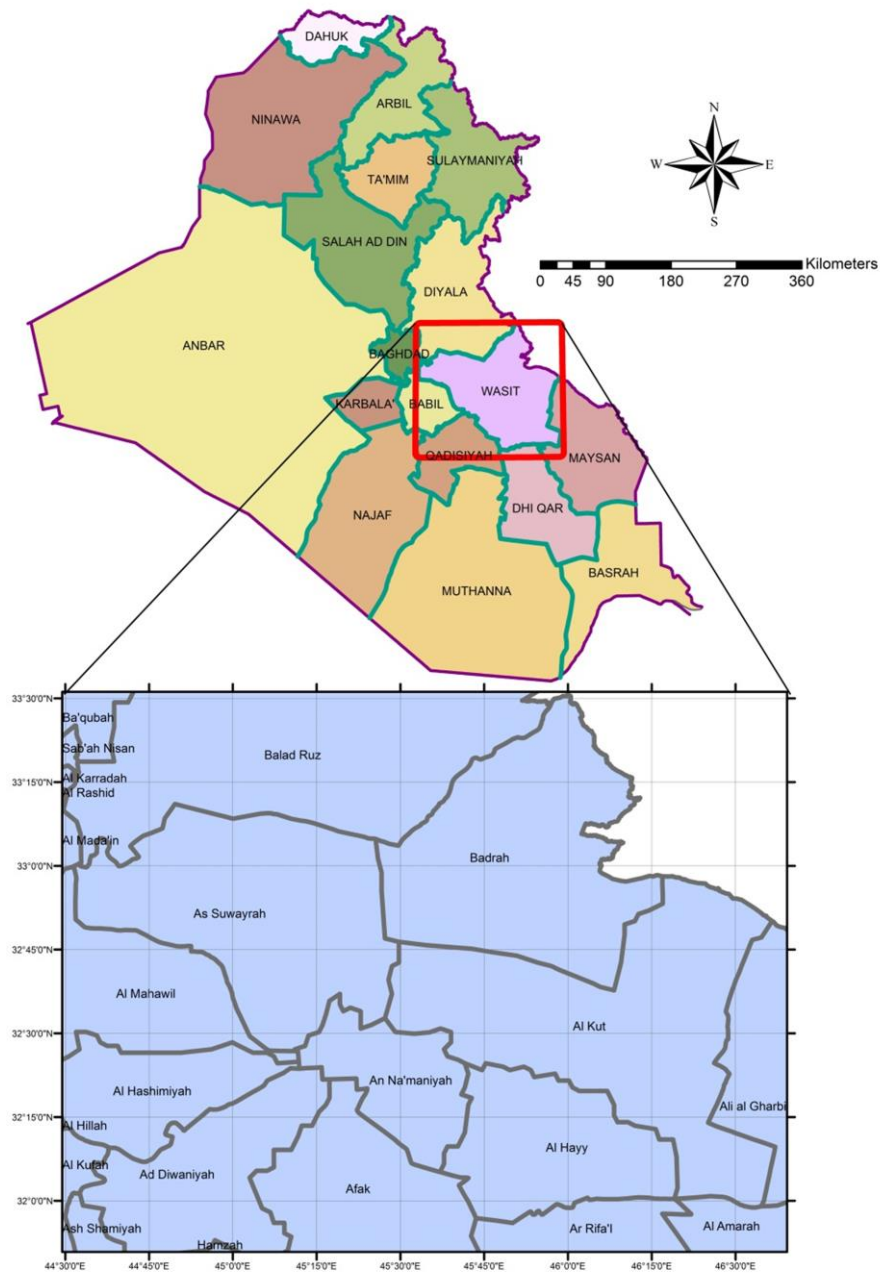


Fig.2: Location of study area

Horizontal and vertical datum's of all DEM are WGS84 and EGM successively. Where the world geodetic system 1984 (WGS84) is typified by the form of the ellipsoid and was computed relying on the hypothetical equipotential gravitational surface of the earth. Be that as it may, the vertical datum is indicated to mean sea level (MSL) as an orthometric height, which is determined by the earth gravity model (EGM) as a geoid model. A huge difference exists between this mathematical ellipsoid model and the geoid model. Mathematically complicated geoid can only approximate the existing shape of the earth. When this ellipsoid vertical datum is utilized, height over the ellipsoid won't be the equal to MSL and direct elevation readings for most areas will be embarrassingly off. The surface of worldwide undulations was computed relying on altimetry observations and very exact (up to two

centimetres) measurements taken from the TOPEX/POSEIDON satellite. This information is illustrated in the EGM, which is additionally alluded to as the spherical harmonic model of the earth's gravitational potential. The Geoid surface is an equipotential or a consistent Geopotential surface which agrees with MSL (local Datum). Fig.3 appear relationship between ellipsoid, geoid and topographic surfaces, and described to in Eq.1 (Mukherjee *et.al.*, 2013).

$$h = H + N \dots\dots\dots(1)$$

where:

h: vertical height of topographic surface from ellipsoid

H: vertical height of topographic surface from geoid

N: difference in height between ellipsoid and geoid

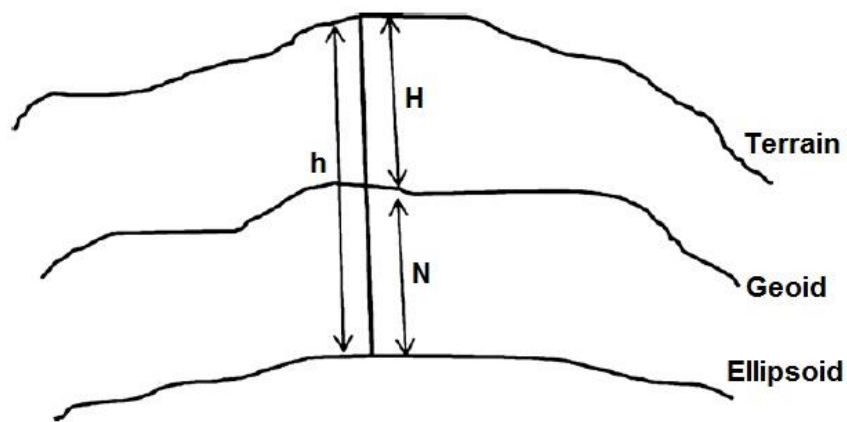


Fig.3: Relation between ellipsoid, geoid and topographic surfaces

Methodology

Commonly used approaches have been evaluated from satellite based DEM with reference to the area of study and the adopted methodology is illustrated below:

- I took 257 ground control points GCPs observed by using dual frequency DGPS utilizes the static observation technique with a horizontal accuracy of 0.012m+ 2.5ppm and a vertical accuracy of 0.015m+ 2.5ppm, then data are processed in GNSS solution after post-processing. These points were obtained from the field surveys carried out by the researcher as well as the points obtained through the topographical survey of the oil and gas companies operating in the district of Badra, Al-kut, Zubeidiya, Nu'maniyah and Al-Hay districts of Wasit Governorate.
- SRTM, ALOS and ASTER DEMs were downloaded from the above-mentioned website. Sub setting interested area of DEMs and the ground control points are illustrated in Fig.4.
- Calculate the elevations of points mentioned above in each DEM by using bilinear interpolation BI which is resampling technique that estimates a new pixel value by using the four closest pixel values. It utilizes the spatial autocorrelation or spatial reliance which measures the level of relationship/reliance amongst close and far targets. (Lillesand *et.al.*, 2004).
- The closeness between the observed and true values called Accuracy. The exactness of ALOS, SRTM and ASTER DEMs is evaluated by comparing with the elevation of GCPs. The validation was performed as far as the root mean square error (RMSE) and mean error (ME). RMSE displays the variation between

observed and true values. ME lets us know whether the set of measurements higher or lower than the true values. The RMSE is a unique value describing error surface, and ME reflects the inclination of the error surface. RMSE and ME may be estimated by the following equations (Patel *et.al.*, 2016):

$$ME = \frac{1}{n} \sum_{i=1}^n (E_o - E_m) \dots\dots\dots(2)$$

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^n (E_o - E_m)^2} \dots\dots\dots(3)$$

where:

E_o : Observed elevation

E_m : Modeled elevation

n: number of tested points

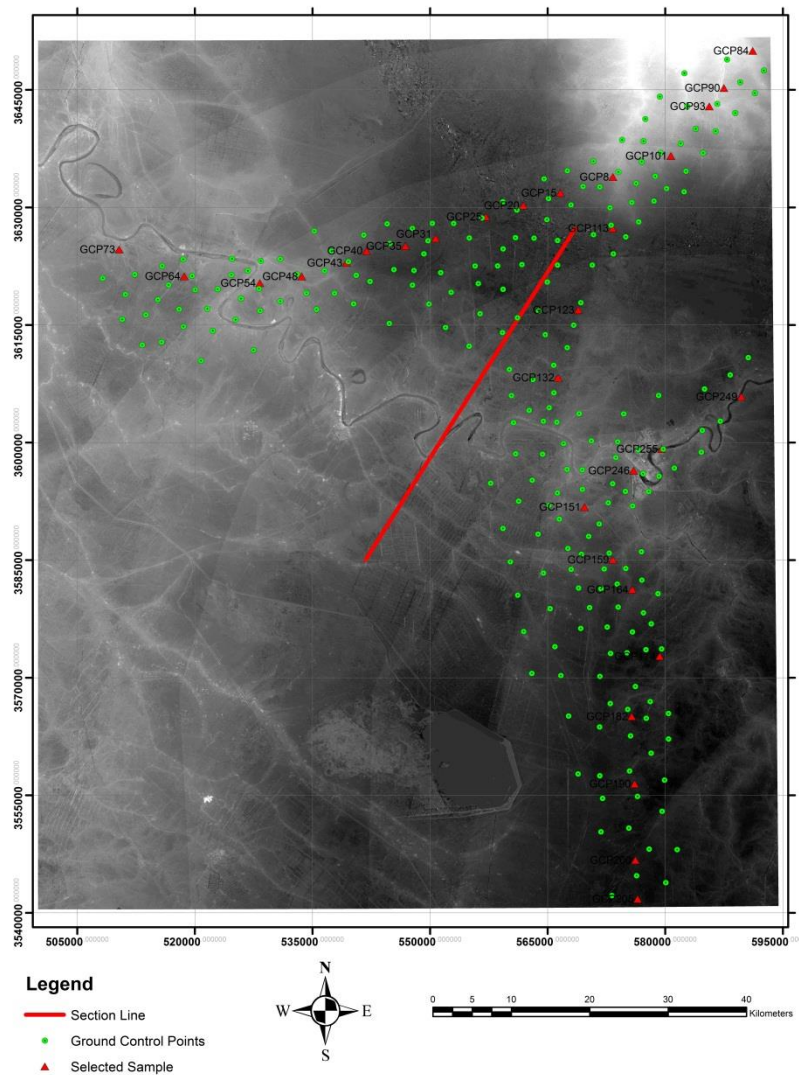


Fig.4: Area of study and GCPs be superposed on satellite based DEM

Results and Discussion

- The horizontal and vertical coordinates which computed by using DGPS and elevations based DEM were calculated by using a bilinear interpolation approach in ArcGIS Spatial analyst tool. Table 1 shows coordinates and elevation of a sample of 30 points.

Table 1: Sample of 30 points with its coordinates

Name	Coordinates based DGPS			Elevations based DEM		
	Easting	Northing	Elevation	SRTM	ALOS	ASTER
GCP8	573327.227	3633894.225	24.443	22	24	15
GCP15	566632.103	3631858.493	18.399	18	19	12
GCP20	561897.535	3630240.719	17.340	20	18	14
GCP25	557105.779	3628811.085	17.070	18	17	15
GCP31	550703.391	3626054.239	17.913	18	17	16
GCP35	546854.287	3625070.975	18.056	20	19	15
GCP40	541901.666	3624456.723	18.006	19	19	15
GCP43	539320.048	3622935.887	19.093	21	20	14
GCP48	533634.328	3621199.580	21.580	23	23	13
GCP54	528295.453	3620355.347	21.937	23	25	11
GCP64	518653.124	3621230.279	21.476	23	23	15
GCP73	510336.541	3624646.741	24.664	27	27	18
GCP84	591165.785	3649983.454	33.380	31	33	21
GCP90	587495.857	3645236.998	32.383	30	31	19
GCP93	585619.330	3642892.654	31.087	27	31	18
GCP101	580723.656	3636570.516	24.130	23	24	16
GCP113	573285.992	3627344.775	16.864	11	18	13
GCP123	568902.482	3616927.199	15.529	19	15	12
GCP132	566335.649	3608287.799	17.280	19	19	11
GCP151	569696.481	3591779.784	17.332	20	21	16
GCP159	573322.066	3585056.713	15.799	18	18	17
GCP164	575807.613	3581245.772	14.781	17	16	15
GCP174	579291.386	3572736.879	12.702	15	14	12
GCP182	575728.436	3565055.584	12.011	13	14	16
GCP190	576098.170	3556458.592	12.357	15	15	13
GCP200	576205.760	3546731.478	11.358	15	13	10
GCP205	576477.127	3541783.061	11.989	12	13	10
GCP246	575965.559	3596426.859	20.446	23	24	16
GCP249	589705.438	3605857.450	14.870	14	15	11
GCP255	579560.389	3599183.789	13.945	14	17	17

The RMSE and ME that were calculated for each satellite based DEM, were shown in Table 2.

Table 2: Comparative analysis of DEMs with bilinear interpolation

	ALOS	SRTM	ASTER
RMSE	1.988m	2.276m	6.241m
ME	-1.262m	-0.782m	4.437m

The straight line that appeared in the Fig.4 is used to generate a profile line based each DEM to show the variation of heights as shown in Fig.5. There is a high variation of ASTER as compared to ALOS and SRTM DEMs which approximately have the same variation of height as shown in Fig.5. additional comparison of variation of elevations is accomplished by considering statistical parameters of satellite DEMs and considering DGPS data with centimetre level exactness as appeared in Table 3. In both cases ALOS and SRTM data have less variation in the maximum, minimum, mean height and standard deviation as shown in Table 3. It has been revealed that statistical parameters in ALOS and SRTM as compared to DGPS point to a data variation in ΔH_{\max} , ΔH_{\min} and $\Delta \text{Std.dev}$ as shown in Table 4 which is less compared to ASTER DEM.

Table 3: Height variation in satellite DEM's and DGPS.

Height	ALOS	SRTM	ASTER	DGPS
Maximum	33m	32m	21m	33.87m
Minimum	12m	11m	9m	11.03m
Mean	19.96m	19.48m	14.26m	18.70m
Standard deviation	4.79m	4.55m	6.62m	4.10m

Table 4: Shows differences in height variation with respect to DGPS.

Height variation	ALOS	SRTM	ASTER
ΔH_{\max}	-0.87m	-1.87m	-12.87m
ΔH_{\min}	0.97m	-0.03m	-2.03m
ΔH_{mean}	1.26m	0.78m	-4.44m
$\Delta \text{Std.dev}$	0.69m	0.45m	2.52m

Where

ΔH_{\max} = maximum height in DEM - maximum height in DGPS.

ΔH_{\min} = minimum height in DEM - minimum height in DGPS.

ΔH_{mean} = mean height in DEM - mean height in DGPS

$\Delta \text{Std.dev}$ = Standard deviation in DEM - standard deviation in DGPS

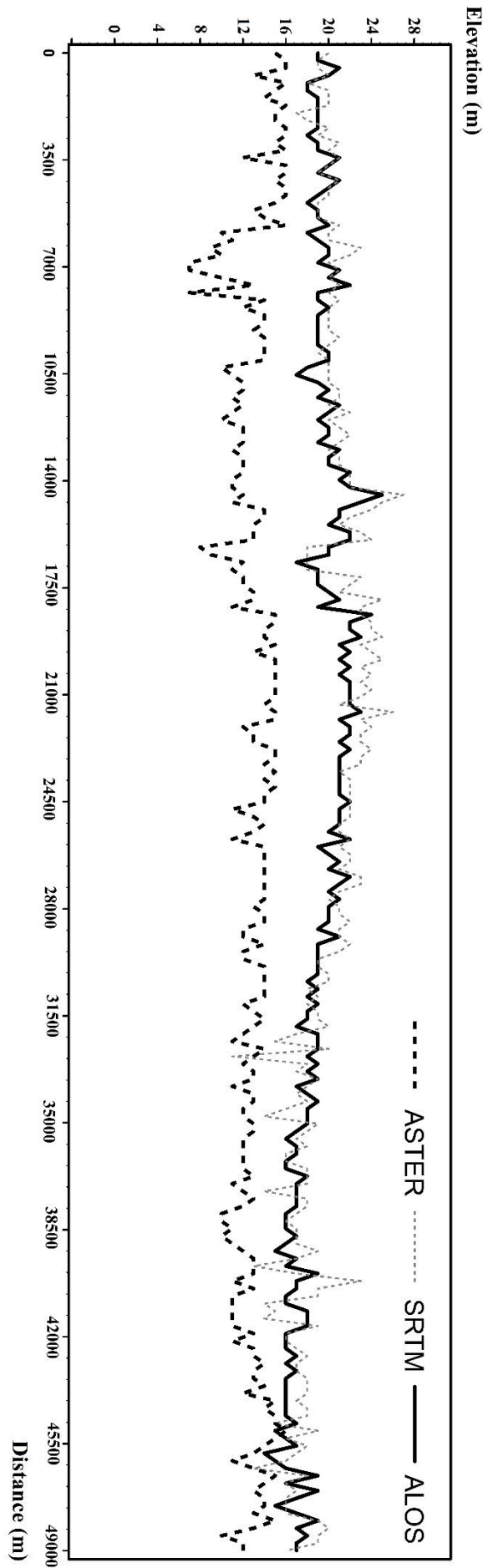


Fig.5: The variation of elevations in three DEMs along the sectional line

Conclusion

The error in the DEM generated surface relies on the many factors, for example, the nature of the region, the sample density of raw data, image resolution and interpolation types. A Comparative analysis was made upon open source DEM such ALOS, SRTM and ASTER for performance and validation evaluation. The following conclusions can be drawn from the present investigation:

- From the analysis, it is clear that ALOS DEM which is 1arc sec resolution is better than SRTM and ASTER DEM. It had produced the lowest RMSE of 1.988m with an ME of -1.262m by using BI techniques.
- Considering DGPS data with centimetre level accuracy. Height deviation comparison of satellite DEMs and DGPS is done. SRTM DEM has produced less deviation in statistical parameters such as ΔH_{\max} , ΔH_{\min} and $\Delta \text{Std.dev}$; as compared to ALOS and Aster DEM's.
- In general, the results showed that the accuracy of the digital elevation model of ALOS and SRTM is higher compared to ASTER. This is due to the technology used to obtain that digital model. Where the active remote sensing technique is used to generate SRTM by utilizing Synthetic Aperture Radar, therefore, leads to high accuracy data, and ALOS is based on passive remote sensing technology by comprising of three panchromatic radiometers that procured along track stereo images to validate the high-level DEM, in contrast to the ASTER which is based on thermal emissions from the surfaces. Thus, the accuracy of the data is inversely proportional to the wavelength of radiation.
- Finally, analysis of the results showed that the open source DEMs are very suitable for surveying, topographic and hydrological implementations, which do not require high accuracy such as computing the quantities for cut and fill works, as well as drawing the profile line for constructions of roads, railways, irrigation and drainage channels, which extends far distances and the computation of the volumes of water bodies and the amounts of floods. All this and more are made freely without the need for field works, but only the use of specialized analytical programs.

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