Accuracy Assessment of the Digital Elevation Model, Digital Terrain Model (DTM) from Aerial Stereo Pairs and Contour Maps for Hydrological Parameters

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Abstract In this study, some of the widely used data for elevation models were compared based on hydrological parameters such as slope, aspect, flow direction, and slope length and steepness factor (LS factor). The study considers the comparison among ASTER GDEM, SRTM DEM, topographic maps, and aerial photography at 430239 predetermined tests points. Bilinear interpolation technique was used to interpolate the data at these testing points. The result shows the digital elevation model (DEM) from topographic maps has relatively higher vertical accuracy (RMSE = 5.40 m), compared to ASTER GDEM (7.10 m) and SRTM DEM (15.07 m), while comparing with digital surface model (DSM) from stereo pairs. For validation, we used 47 ground control points (GCPs) using GPS. The results show the vertical accuracy are relatively higher for DSM (RMSE = 1.11 m), followed by DEMs from topographic maps (4.10 m), ASTER GDEM (7.36 m), and SRTM DEM (12.22 m). The DSM matches closely with the result of topographic DEM in case of slope, LS factor curves, aspect, and flow direction. The result with ASTER DEM matches better than results with SRTM data in all the parameters but both of them show poor match with the results from DSM data.

Keywords Digital elevation model · Hydrological parameters · Aerial photography · Accuracy assessment

1 Introduction

Nowadays, DEM has a major role in various field of study including geography, geology, and environment sciences. The quality or accuracy of DEM is considered as the main factor for application in a particular field depending on required parameters. There are various methods to produce DEM from satellite images, field survey (for

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small area), LiDAR technology, Aerial photos, and RADAR. Depending on the data used, the accuracy also varies significantly.

The scientific community is facing issues in determining the optimum spatial resolution of DEM as a part in decision making in hydrological problems and its analysis [1]. Hydrological parameters such as slope, aspect, flow direction, drainage network, and watershed can be derived by automated techniques from DEMs [1, 2]. Sometimes in hydrological studies, high accuracy in absolute elevations may not be required, instead the accuracies in slope, drainage network, aspect, etc., are required. Previous researchers suggested to use multiple DEMs for all hydrological problems based on their studies on the relation of DEMs spatial resolution (cell size) with the accuracy of hydrological analysis [1–3]. The errors in DEMs will affect the modeling of natural parameters and processes [4, 5]. Wu et al. [6] and Vaze et al. [7] reported that DEM has significant implications on hydrological parameters and error in watershed area and slope increases with coarser resolution [4–7].

At present, many tools and softwares are available to extract the topographic and hydrological parameters from DEM. A variety of freely available DEMs data with variable spatial resolution, e.g., Geographical Survey Institute (GSI) of Japan (GSI-DEM) with 10 m, Advanced Space-Borne Thermal Emission and Reflection Radiometer Global Digital Elevation Model (ASTER GDEM) with 30 m, Shuttle Radar Topographic Mission (SRTM) with 30 arc second (resampled to 3 arc second) are suitable to model the terrain of earth in worldwide very accurately [8]. However, the verification of these data is required by comparing between DEM at multiple reference points with measured in situ high precision data [8–14].

In this present study, comparison among SRTM, ASTER DEM and DEM derived from topographic map with reference DSM derived from stereo pair aerial photos, and validate the results with ground control points (GCPs) collected using differential global positioning system (DGPS).

2　Materials and Methods

2.1　Study Area

Humrat Es-Sahen is extended from the western part of As-salt city near Kufur Huda to King Abdullah Channel (KAC) in the Jordan valley (35° 36.8′–35° 42.2′ E and 32° 4.7′–32° 7.5′ N). Topographically, the basin is of concave shape and it is topographically known as the Humrat Es-Sahen Depression. The elevation ranges from 1300 m above mean sea level (AMSL) eastern of salt city, to a low of 200 m under mean sea level (UMSL), which constitutes the lowest point. The topography of the study area varies from nearly flat area to the mountainous regions with steep slopes. This variation of elevation made the area attract attention from various researchers from different scientific disciplines. The streams have flow directions mainly from east to west due to the topography (Fig. 1).
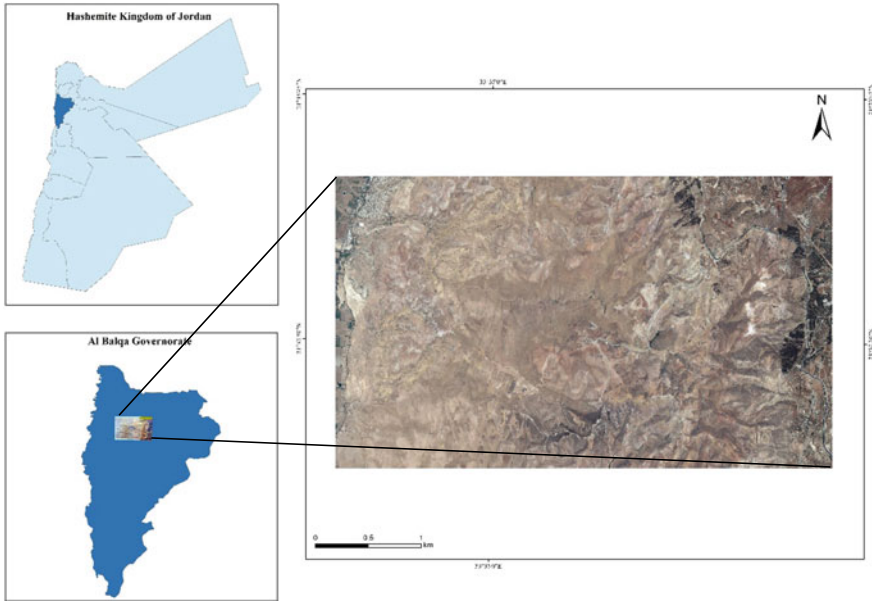
Fig. 1 Location of study area

2.2 Digital Elevations

The DSM from stereo pair aerial photos has compared with three different digital elevation models with different spatial resolutions. The available DEMs were collected from open sources such as SRTM DEM and ASTER GDEM, and paid sources for topographic maps. The topographic maps were digitized from contour lines with contour interval of 20 m with scale 1:50,000 by Royal Jordanian Geographical Center (RJGC). The contour lines were manually digitized and the DEM was generated using ArcGIS 10.2.

The SRTM data is available as 3 arc second (~90 m resolution) DEMs [1]. The area coverage of DEM data is available as (5° × 5°). The ASTER GDEM (Ver. 2) shows significant improvements over the previous release. Though, most of users have advised that the data contains glitches and artifacts which that will be effectiveness for use in certain applications. NASA nor METI/Japan Space Systems (J-space systems) are provided DEM data, where it won't be responsible for any misuse of the data. The area coverage of DEM data is available as 1° × 1° with 30-m ground resolution [2].

The digital surface model (DSM) has been developed using stereo pairs of color aerial photos. These were collected from the archives of aerial photos at the Jordanian Royal Geographical Jordanian Centre (JRGC). These photos were collected using a Leica RC 30 Aerial Camera Systems (ACS) with focal length of 153.28 mm and scale of 1:25,000 along two strips with an approximate 60% overlap and 20% side

lap in flight. The photos had scanned with a photogrammetric precision scanner with 20 μm resolution, which approximately 0.50 m of ground pixel resolution. The basic processes for DEM generation from aerial photos using stereo correlation are based on the interior and exterior orientation [3].

The validation of these data was carried out using predetermined 47 GCPs collected using DGPS (with <5 mm accuracy). The analysis was carried out after reprojecting the DEMs using UTM projection system (zone 36 N), with datum as WGS84 [5].

3 Methodology

The point-to-point comparisons were conducted by extracting points (x, y) locations and (z) altitude from DSM and examining these points with the corresponding points from topographic DEM, SRTM, and ASTER GDEM data. The bilinear interpolation method was used for data extracting from DEMs files using DSM points [4].

The accuracy of each DEM has been examined depend on the reference DSM from aerial photos, the DEM has been calculated the differences with the same location in DSM using Eq. (1).

$$\text{Elev}_{\text{Error}} = \text{Elev}_{\text{examined}} - \text{Elev}_{\text{Reference}} \tag{1}$$

where $Elev_{examined}$ refers to the examined point from DEM, $Elev_{Reference}$ is the checked point from DSM, and $Elev_{Error}$ is the difference in elevation or error. The positive values represent the elevation in particular location of the DEM source is under the reference DSM at the same location, and the negative means the DEM source is above the reference DSM at the same location. The statistical parameters such as mean error, standard deviation error (*STD*), Sample Variance (σ^2), and root mean square error (*RMSE*) values were calculated for vertical accuracy.

3.1 *Hydrological Parameters Analysis*

DEM is a vital source of topographic data and its various derivatives provide substantial information regarding the terrain characteristics [6]. Several hydrological parameters were estimated such as slope, aspect, curvature, flow direction and slope length, and steepness (LS) factor using ArcGIS 10.2 software.

3.2 Slope, Aspect, and Flow Direction

The slope, aspect and flow direction are the primary derivatives of DEM. Slope (i.e., rate of change of elevation) influences the velocity of surface and subsurface flow, soil water content, erosion potential, soil formation. and several other earth surface processes [6], and thereby an important component in various environmental applications such as land capability classification, vegetation mapping, hazard zonation, etc. [7].

Aspect (or slope azimuth; the orientation of the line of steepest descent) is also an important parameter, controlling the availability of incident solar radiation and it is used to explain various environmental factors, such as potential evapotranspiration [8].

Flow direction is the method which calculates the flow for single cell depends on its steepest downslope neighbor and gives eight possibilities for directional flows. The flow direction as algorithm done using ArcGIS 10.2, Table 1 summarizes these directions.

3.3 Curvature

In the terrain parameters, the curvature one of the important parameters used with slope and aspect, the profile (rate of change of slope down a flow line), and plane (rate of change of aspect along a contour) curvature are most commonly used in different environment aspects.

Profile curvature gives an indication on the flow acceleration, zones of enhanced erosion, and deposition and sediment transport processes, whereas plan curvature has significant implications on flow convergence and divergence as well as soil water properties [7].

Table 1 Summarize the aspect and flow directions classes

Class	Flow direction	Aspect
1	–	Flat
2	1	North
3	2	Northeast
4	4	East
5	8	Southeast
6	16	South
7	32	Southwest
8	64	West
9	128	Northwest

3.4 LS Factor

In empirical models like Universal Soil Loss Equation (USLE) and its modified and revised forms, the topographic control on soil loss is elucidated by introducing LS factor (also known as topographic factor) indicating the length (L) and steepness (S) of terrain [8]. It calculates a spatially distributed sediment transport capacity that has significant implications in landscape assessment because it explicitly accounts for flow convergence and divergence [9].

4   Results and Discussion

4.1 Accuracy Assessment of DEMs

The vertical accuracy of DEM derived from topographic map, SRTM DEM and ASTER GDEM, were evaluated and compared with DSM derived from stereo pair aerial photos. According to the National Mapping Program Standards and Specifications [10] for the collection, processing and quality control of DEMs, minimum number of 28 test points per DEM is required (20 interior points and 8 edge points) to verify the accuracy.

The results of accuracy assessment for each DEMs with respect to the DSM as a reference elevation are shown in Table 2. The distribution of the residuals or errors for each DEMs (as point-to-point evaluation) shows linearly relation Fig. 2.

Among these DEMs sources, the errors of DEM which derived from topographic maps were very small and nearly zero. The ASTER GDEM has variation in elevation errors between 0 and 60 m, whereas SRTM DEM has the high error between -10 and 80 m. However, the DEM derived from topographic maps has relatively low RMSE (5.396 m), the ASTER GDEM very close RMSE (7.103 m) and SRTM DEM has higher RMSE (15.074 m).

Table 2   The residual among different DEMs with DSM

Residual	Sample points	Mean error	RMSE
Topo-DSM	430,239	0.36	5.40
ASTER-DSM	430,239	25.85	7.10
SRTM-DSM	430,239	20.84	15.07
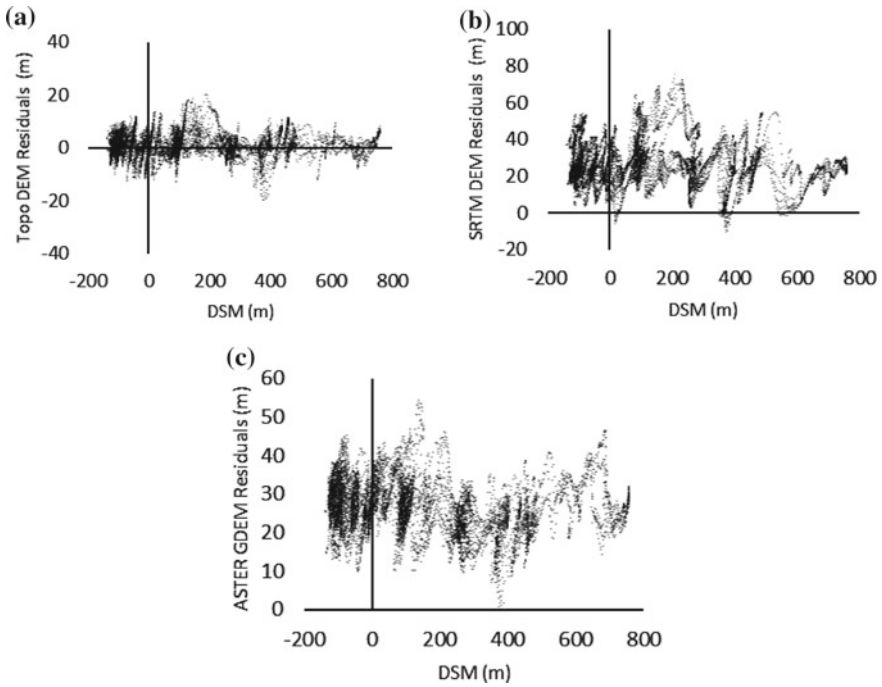
Fig. 2 The residuals of **a** Topo DEM. **b** SRTM DEM and **c** ASTER GDEM variation with DSM
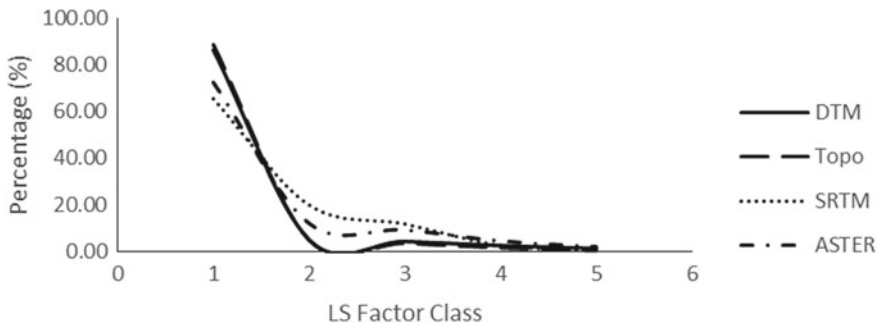

Fig. 3 The scatter plot of GCPs with **a** DSM. **b** Topo DEM. **c** SRTM DEM and **d** ASTER GDEM

4.2 Comparison of Hydrological Parameters

The estimated hydrological parameters were compared to evaluate the ability and the impact of spatial resolution of using different DEM sources in hydrological applications.

The analysis of different DEMs sources has been used in comparing according to the reference DSM. Figure 3 shows the difference among the slope data while

Table 3 Summarized of slope classes for DEMs

Slope	DSM	Topographic DEM	SRTM	ASTER
<5°	6.27	12.23	10.45	7.25
5°–15°	38.19	40.23	61.31	45.98
15°–25°	36.14	36.65	24.83	32.62
25°–35°	14.29	10.44	3.41	10.35
35°–45°	4.99	0.45	0.00	3.74
>45°	0.12	0.00	0.00	0.06

Table 3 summarizes the results of analysis the percentage cumulative and shows the relative relation among the DEMs used with respect to the DSM.

The main difference between aspect and flow direction is that the aspect identify the downslope direction of the change rate in each cell, and the flow direction identifies the flow path from each cell to its steepest downslope.

The analysis shows a significant variation in LS factor in between 2 and 3, however, these difference decreases after 4 and become almost negligible (Fig. 4).
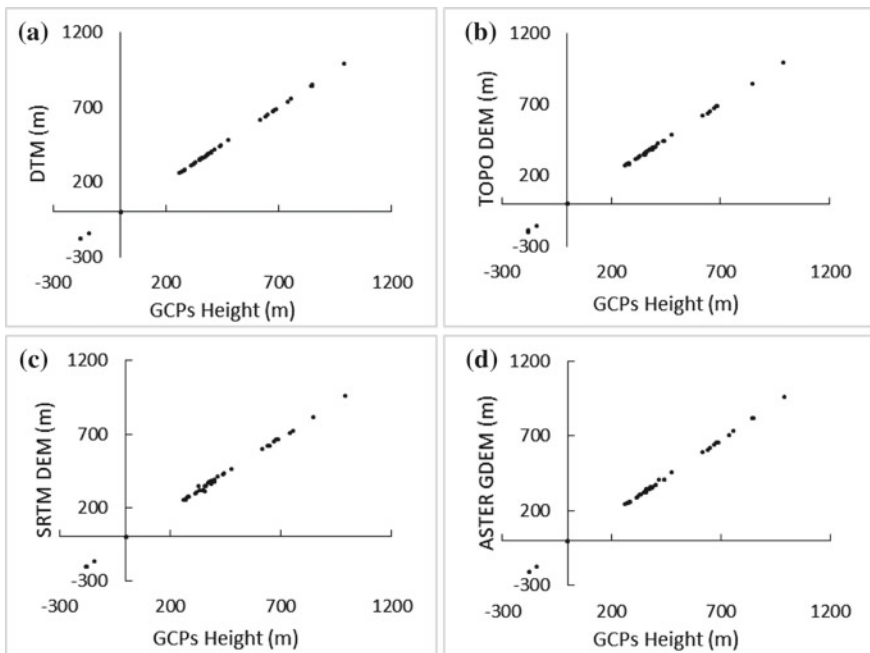

Fig. 4 The percentage of LS factor for different DEMs

Table 4 The basic statistical characteristics of 47 GCPs and DEMs

Parameters	GCPs	DTM	Topo	SRTM	ASTER
Max	989.48	989.48	842.60	962.25	959.18
Min	−179.12	−181.33	0.00	−203.45	−207.87
Mean	398.11	403.57	308.38	329.00	373.68
SD	282.83	273.68	226.56	268.84	280.59

4.3 Validation

The 47 GCPs used for validation was distributed randomly in the study area, and used to calculate the RMSE for each DEM. Results indicate that the DSM has the most accurate DEM and it can used as a reference for further studies. Topo DEM shows better elevation data, and ASTER GDEM is found to give the closest match with GCPs. Table 4 summarizes the statistical estimations with the characteristics of these DEMs and GCPs.

In Fig. 4 shows the relationship between the different DEMs with GCPs. A linear relation was appeared in all cases. In DSM and SRTM DEM, the linear relationship was better than Topo DEM and ASTER GDEM shows variation in few points.

The residual errors of the elevation are shown that, the residual errors in DSM are lying near zero (6 to −3 m), Topo DEM shows the errors are in a range between 15 and −10 m, ASTER GDEM has the errors between 0 and 35 m), and SRTM DEM has the errors between 50 and −20 m

5 Conclusion

This study compared four different DEMs, DSM from aerial photos, Topo DEM from topographic maps, SRTM DEM, and ASTER GDEM. The vertical accuracies were examined to find the most accurate DEM and these are validated with 47 GCPs collected using DGPS with vertical accuracies less than 10 cm. The statistical analysis of these errors shows that the DEM from topographic map is the best. However, as open source, ASTER GDEM gives better accuracy. On the other hand, hydrological parameters analysis show the Topo DEM from topographic maps has the closest match among other DEMs (SRTM and ASTER).

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