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Impact of DEM resolution and accuracy on remote sensing and topographic DEM derived topographic attributes and drainage pattern

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Abstract

Digital Elevation Model (DEM) presents the digital representation of surface topography. DEMs can be derived from satellite remote sensing or conventional techniques of surveying. However, inherent errors in a remote sensing based DEMs can lead to uncertainty in the elevation data and computed topographic attributes. This study evaluates accuracy of remote sensing derived SRTM and ASTER DEMs and physical survey derived Topographic maps. For accuracy assessment of the ASTER and SRTM ASTER DEMs, spot elevation were extracted from the toposheet as a reference data. Acccuracy assessment results reveals that the SRTM DEM shows RMSE of ±27 m and ASTER DEM shows RMSE of ±20 m in the study area. The impact of random errors in the ASTER and SRTM DEMs on the derived topographic attributes (aspect and slope) is evaluated through the Monte Carlo Simulation (MCS). Derived results show higher uncertainty in topographical attributes (aspect and slope) derived from the ASTER DEM than from the SRTM DEM. Results derived from the ASTER DEM shows that mean of slope can deviate 1.2° whereas, SRTM DEM shows it can deviate 0.8°. Aspect derived from the ASTER DEM can deviate up to 31.2° whereas, aspect computed from the SRTM DEM can deviate up to 29.8°. The drainage networks computed from the ASTER, SRTM DEMs and Toposheet are also compared. The analysis revealed that the drainage network extracted from the SRTM DEM, ASTER DEM and Toposheet are matching.

Keywords: DEM; Monte Carlo simulation; Hydrological modeling; Accuracy assessment.

1. Introduction

Digital Elevation Models (DEMs) have been frequently and effectively utilized as one of the crucial databases in many GIS applications (Zhou and Liu, 2004). DEMs provide continuous representation of the earth's topography with varying resolutions and accuracies (Wechsler, 2007). DEMs are frequently used to derive topographic attributes, including aspect, slope, curvature etc. Often, DEMs are perceived as a true representation of the earth's surface, however, like many other spatial data, they are also prone to inherent errors. The inherent errors in a DEM are subsequently propagated in the computed topographic attributes. The influence of DEM errors on elevation and computed topographic attributes are often ignored and therefore might cause uncertainty in the decision making process (Wechsler, 2003).

Errors in a DEM are classified as general and specific errors. General errors are related to the technical problems during the DEM production. Specific errors are inherent errors in a DEM that cannot be removed and is publicized before systems launching and data provision (Wechsler, 2007). General errors include: systematic errors, blunders and random errors. Systematic errors are associated with the procedures followed for the DEM generation and follow fixed patterns that can cause uncertainty in final result. Blunders are vertical errors, associated with data collection process and can be generally identified and removed before the data is released. Random errors are spatially uncorrelated and remain in the data after blunders and systematic errors are rectified. Random errors result from accidental or unknown combination of inaccuracies and identification of these errors are beyond the control of the users. These errors leads to uncertainty and are mentioned as root mean square error (RMSE) of the DEM. RMSE defines the vertical accuracy of the DEM (Rodríguez et al., 2013) and is influenced by the nature of terrain, with higher RMSE in rugged terrain and lower in relatively flat terrain (Raaflaub and Collins, 2006). Therefore, it is crucial to evaluate the accuracy of remote sensing derived DEMs, specifically in a rugged topography.

Accuracy of a DEM can be evaluated by comparing DEM derived elevation values with actual elevation values, called as refrence data that can be acquired with high precision field survey or a secondary source (Castrignanò et al., 2006). The aim of this study is to evaluate the accuracy in the remote sensing derived SRTM, ASTER and Topographic DEMs and to evaluate the impact of these errors on the computed topographic attributes, including aspect and slope. Moreover, the influence of DEM resolution on the derived drainage network is also evaluated in the study.

2. Study area

The study area selected for this study is comprised of districts Karak, Kohat and Hangu (Fig. 1). The selected area covers 698 km^2 and has a moderate topography with elevation values ranges from 400 m to 1520 m above sea level (ASL). It is located in a semi-arid climatic region having extreme temperature in both summer and winter. Temperatures in summer reaches up to 48°C whereas, in winter the temperature drops to 10°C.

3. Methodology

3.1. Data used

3.1.1.Advanced space borne thermal emission and reflection radiometer (ASTER)

Advanced Space borne Thermal Emission and Reflection Radiometer of the study area was acquired from the USGS website (http://gdem.ersdac.jspacesystems.or.jp/) (Fig. 2a). ASTER DEM was jointly released by the Ministry of Economy, Trade, and Industry (METI) of Japan and the NASA, USA in June 2009. The VNIR bands of the ASTER Imagery are consist of two telescopes, one nadir viewing with a three-band detector (3N) and the other backward viewing (3B) (27.7° off-nadir) with a single band detector are used to generate DEM (Nikolakopoulos et al., 2006).

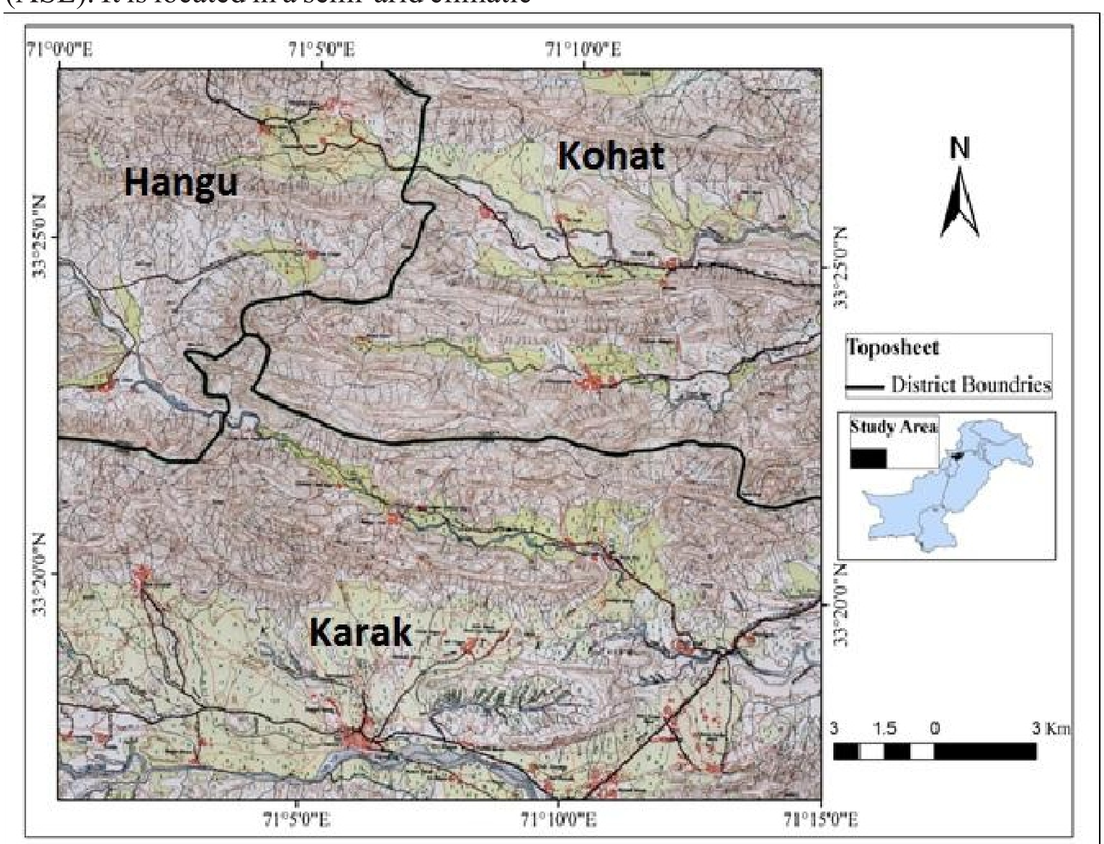

Fig. 1. Location map for study area.

3.1.2. Shuttle radar topography mission (SRTM)

Shuttle Radar Topography Mission (SRTM) DEM of the study area was acquired from the Consortium for Spatial Information (CSI) of the Consultative Group for International Agricultural Research (CGIAR) GeoPortal website http://srtm.csi.cgiar.org/ (Fig. 2). SRTM has created an unparalleled data set of global elevations and is freely available for modeling and environmental applications with spatial resolution of 90 m. SRTM provides the first single-pass, space-borne Interferometric Synthetic Aperture Radar (InSAR) and records data over 80% of Earth's landmass from 60° N to 56° S latitude (Nikolakopoulos et al., 2006). The collected data is being processed by the Jet Propulsion Laboratory (JPL) having horizontal and vertical accuracy about ±16 m (Smith and Sandwell, 2003).

3.1.3.Toposheet

The topographic sheet of the study area at a scale of 1:50000 is acquired, which is developed by the Survey of Pakistan in 1998-99. Toposheet was subsequently used to digitize contours and streams as shown in Figure 3. Digitized contours were then interpolated to generate a DEM and was resampled to spatial resolution of 30 m.

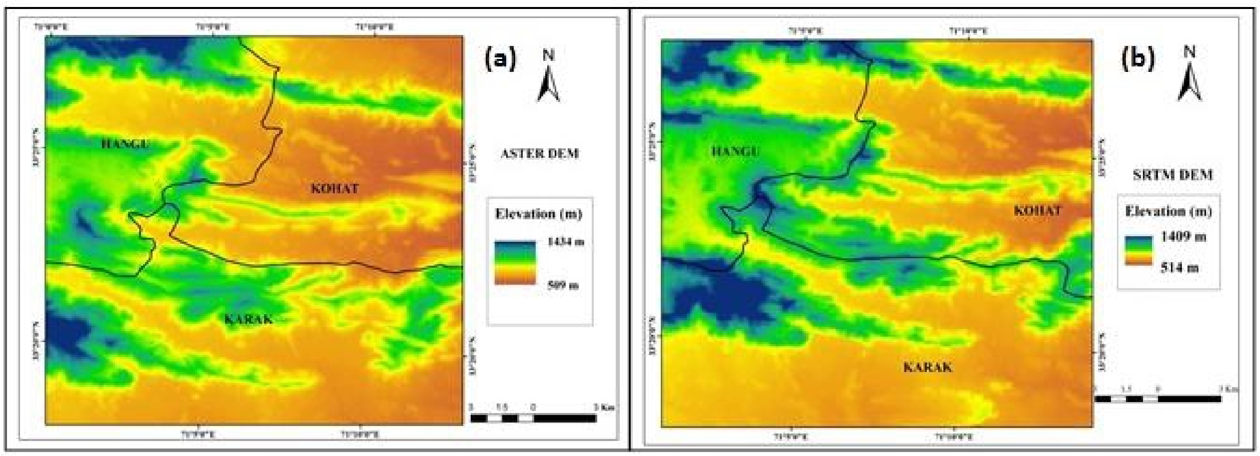

Fig. 2. (a) ASTER DEM (b) and SRTM DEM of the study area.

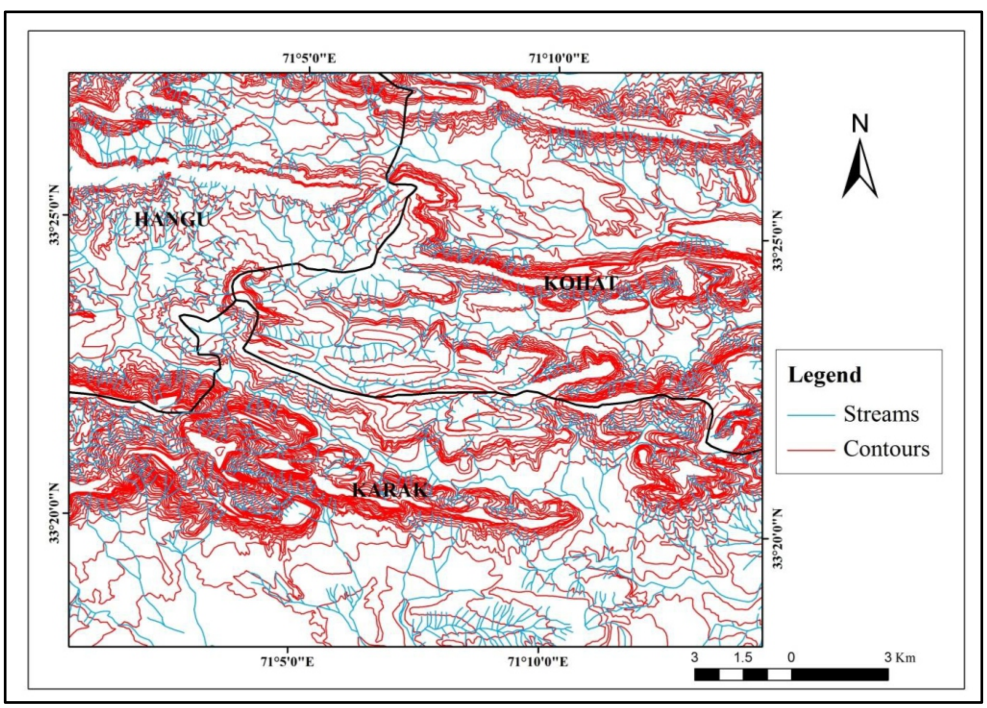

Fig. 3. Digitized streams and contours from the topographic sheet.

3.2. Accuracy assessment of SRS DEM

The accuracy of a DEM is a mainly determined by precision of the source data (such as GPS, digitization of contour maps, automated or manual photogrammetric sampling), terrain nature, and the techqnique used for generation of the DEM surface (Gong et al., 2000). In this study, spot elevation extracted from the toposheet were used as a reference elevation data to evaluate accuracy of the SRTM and ASTER DEMs. The elevation for the same locations was also extracted from the ASTER and SRTM DEMs and analysed to calculated RMSE. RMSE of the DEMs were calculated using Equation 1.

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{n}(x_i - \bar{x_i})^2} \quad \text{Equation 1}$$

Where N is the number of 35 sampled points that were distributed throughout the area and assumed to be the representation of terrain, xi is the spot height elevation and xi is the extracted point elevation data from ASTER and SRTM DEM. The RMSE derived from the accuracy assessment of the DEMs is subsequently used in the Monte Carlo Simulation to evaluate their impact on the computed topographic attributes.

3.3. Monte carlo simulation

Monte Carlo Simulation (MCS) is a stochastic technique and frequnetly used to evaluate the impact of errors in DEMs on computed topographic attributes (Shafique and van der Meijde, 2015). To apply MCS, elevation values of the DEM is assumed as one of the possible values of the accurate elevation. Many simulations were generated to evalute uncertainties in the DEM-computed topographic attributes through statistical evaluation of the distribution of realizations. MCS assumes that errors in a DEM are normally distributed with mean equal "0" and standard deviation equal to "RMSE" of DEM. Elevation errors are assumed to be spatially auto-correlated (Wechsler and Kroll, 2006). Spatially auto-correlated field is created by passing low pass 3×3 filters over random error map. Each pixel in the random error map is replaced by the mean of the surrounding eight pixels (Shafique, 2008). By applying filter, spatial autocorrelation increases and standard deviation decreases. Error DEM is created by adding the random error map to thhe low pass filtered error map. This process is repeated 40 times to generate error DEMs. A new original DEM is generated from previous step. This DEM was used to generate topographic attributes such as slope and aspect from the SRTM and ASTER DEMs. Thus, from each simulation, a new DEM derived topographic attribute map is created. In order to quantify the uncertainity of each DEM, the random error topographic attribute map is subtracted from original topographic attribute map to evaluate the impact of DEM inherent errors on computed topographic attributes of slope and aspect.

4. Drainage pattern

Digital Elevation Models are often used to derive drainage network. Arc Hydro Tool, an extension of the ArcGIS software is used to extract drainage and watershed from the ASTER, SRTM and Toposheet derived DEMs. Sinks are the naturally occurring artifacts in a DEM and must be removed before the drainage extraction (Borough and MacDonnell, 1998). Subsequently, flow direction is computed which indicate the direction of the steepest descent from the processing cell. It has 8 distinct values; each value indicates the steepest downslope surrounding eight neighbors also known as D8 algorithm or D∞. It shows overall drainage pattern of study area.
Subsequent to flow direction, the flow accumulation map is computed showing the number of pixels contributing flow in each pixel. Pixels with zero accumulation are considered mountain, ridges or steep slope and pixels with higher accumulation are regarded as stream (Shafique et al., 2014). Flow accumulation map is used as an input for extracting stream network. Denser stream network can be obtained by lowering the threshold value (Gopinath et al., 2014). The extracted streams are further classified according to the Strahler classification scheme. These drainage network is computed from SRTM, ASTER, and Topographic DEM and the impact of DEM resolution and accuracy on the derived drainage network is evaluated.

5. Results and discussion

5.1. Accuracy assessment

Accuracy assessment of the ASTER DEM shows RMSE of ±20 m and the SRTM DEM shows RMSE of ± 27 m. This shows that RMSE of the ASTER DEM falls within the predefined vertical accuracy, whereas, the accuracy of SRTM is higher than the global assessment that is ± 16 m.

5.2. Uncertainty from DEM-derived topographic attributes

Uncertainty in the slope and aspect computed from the ASTER and SRTM DEMs is evaluated using MCS (Table 1) . Terrain slope computed from the ASTER DEM can deviate 1.2° and aspect can deviate up to 31.2° (Fig. 4). Results derived from the SRTM DEM shows that slope can deviate 0.8° and aspect can deviate up to 29.8° (Fig. 5). Therefore, the SRTM DEM was found to be more consistent in computaion of topographic attributes.

Table 1. MCS derived uncertainty in slope and aspect computed from the ASTER and SRTM DEMs.

DEM	Topographic attribute	Minimum	Mean	Maximum	Standard Deviation
ASTER	Slope	0.09	1.2	2.33	0.2
	Aspect	0.3	31.2	179	45.7
SRTM	Slope	0.30	0.8	2.45	0.10
	Aspect	0.6	29.8	179.1	42.8

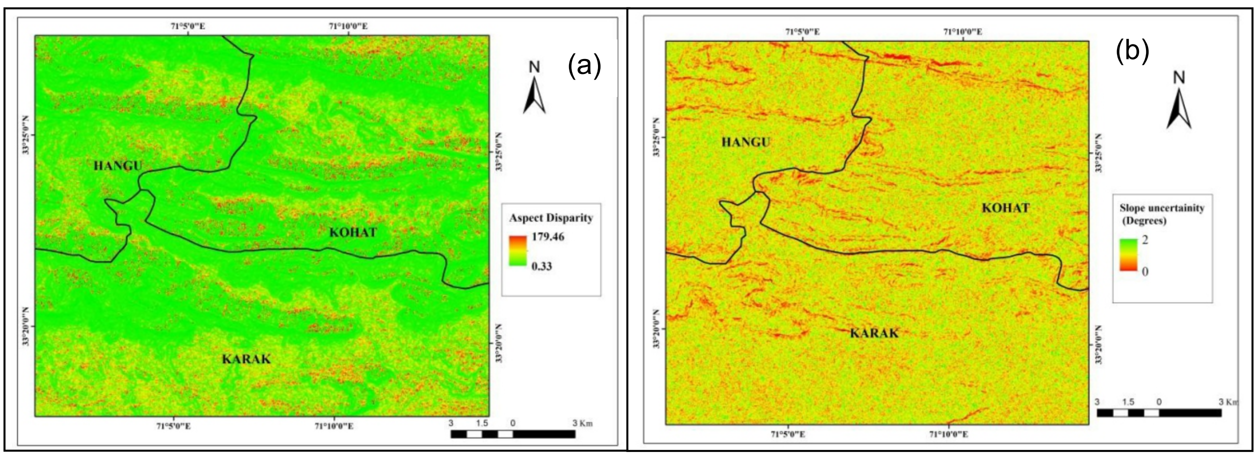

Fig. 4. Spatial distribution of uncertainties of aspect (a) and slope (b) computed from the ASTER DEM.

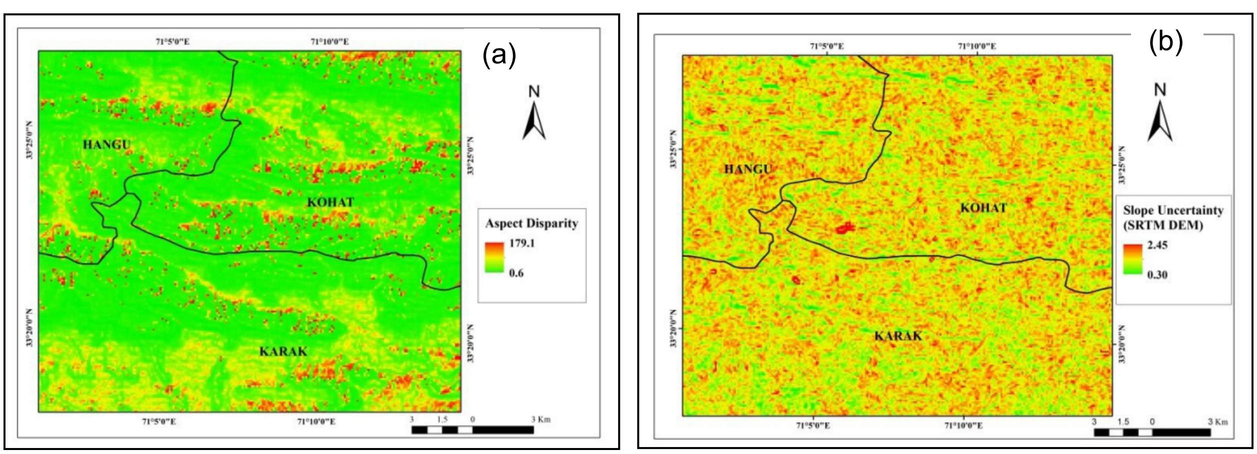

Fig. 5. Spatial distribution of uncertainties of aspect and slope computed from the SRTM DEM.

6. Drainage pattern analysis

After fill sinks, minimum elevation of the ASTER DEM is increased from 508 m to 509 m, for the SRTM DEM the minimum elevation is raised from 513 m to 514 m. Minimum elevation of both the SRTM and ASTER DEMs were raised because of smoothening and averaging effect. Flow direction computed from the ASTER and Toposheet DEMs shows that water drains from North towards South due to maximum accumulation of pixels. Whereas, SRTM shows that water enters from North and East and drains towards South. Number of pixels according to direction encoding and area regarding each direction is given in Table 2 and Figure 6.

In the flow accumulation maps, maximum number of pixels is recorded in interpolated topo DEM i.e. 772740 whereas, from the ASTER DEM and SRTM DEM shows 756896 and 86178 respectively as shown in Table 3. The toposheet is showing higher accumulation values than the ASTER and the SRTM DEM and hence showing greater number of streams. Subsequently, the ASTER DEM is showing dense stream network than SRTM DEM due to higher accumulation value. Flow accumulation map computed from the SRTM DEM is shown in Figure 7.

Table 2: Descriptive statistics for flow direction from the ASTER and SRTM DEM and Toposheet.

Direction Encoding	Number of pixels			% of Area		
	Toposheet	SRTM	ASTER	Toposheet	SRTM	ASTER
1 East	94563	14878	105589	12	17.3	14
2 South-East	101986	9420	80762	13	11.1	11
4 South	170472	19712	157379	22	23	21
8 South-West	76933	6497	72141	10	7.5	9
16 West	53089	8903	82314	7	10.3	11
32 North-West	54698	4436	53301	7.0	5.1	7
64 North	128685	14986	130736	17	17.3	17
128 North-East	92314	7346	74674	12	8.5	10

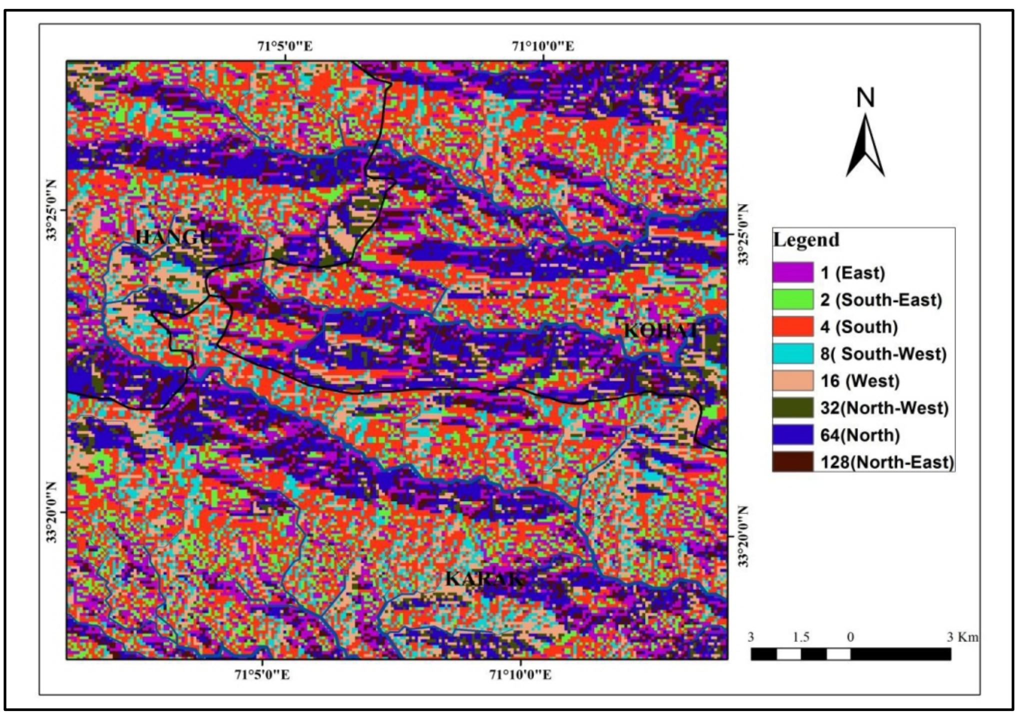

Fig. 6. Flow direction computed from the SRTM DEM.

The pixels with flow accumulation of >1 Km^2 were extracted as stream network (Fig. 9) and reclassified according to Strahler stream order (Table 4). The variation in the streams extracted from the ASTER, SRTM and Topographic DEM is shown in Figure 8 and Figure 9.

Table 3. Number of pixels with corresponding area from the ASTER, SRTM DEM, and Toposheet.

DEMs	Number of Pixels	Area in km^2
ASTER	756896	681
SRTM	86178	698
Toposheet	772740	695

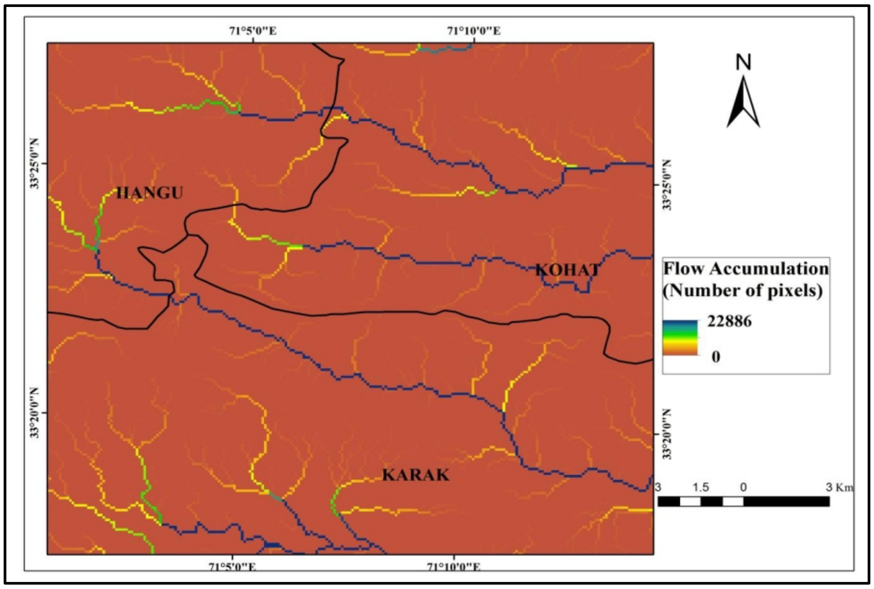

Fig. 7. Flow accumulation from the SRTM DEM.

Table 4. Stream length and number of streams according to Strahler stream order.

	Number of Streams			Length of Streams		
Strahler Stream Order	ASTER	SRTM	Toposheet	ASTER	SRTM	Toposheet
1St Order	297	271	433	276	247	241
2nd Order	124	132	247	100	109	100
3rd Order	131	125	151	94.3	95	94.3

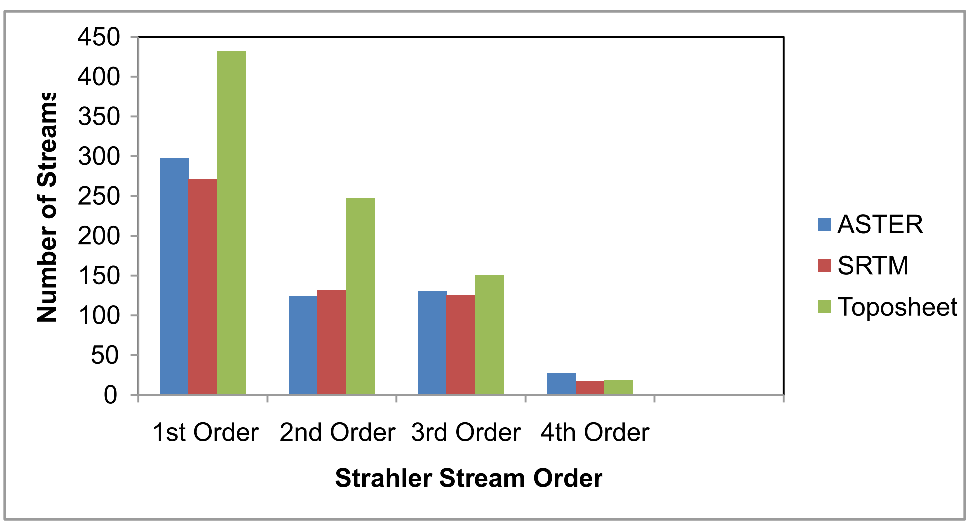

Fig. 8. Showing variation in number of streams according to Strahler stream order of ASTER, SRTM DEM, and Toposheet.

7. Impact of DEM resolution on terrain representation

The impact of DEM resolution on the terrain representation is assessed graphically through horizontal elevation profile of 7 km from the ASTER, SRT and Topo DEMs (Fig. 10). The impact of DEM resolution on smoothening, shape and height is significant on terrain features with a base width smaller than the respective DEM resolution. Topographic features larger than the DEM resolution, but still smaller than the neighborhood size, will be suppressed and smoothened during the topographic attribute computation.

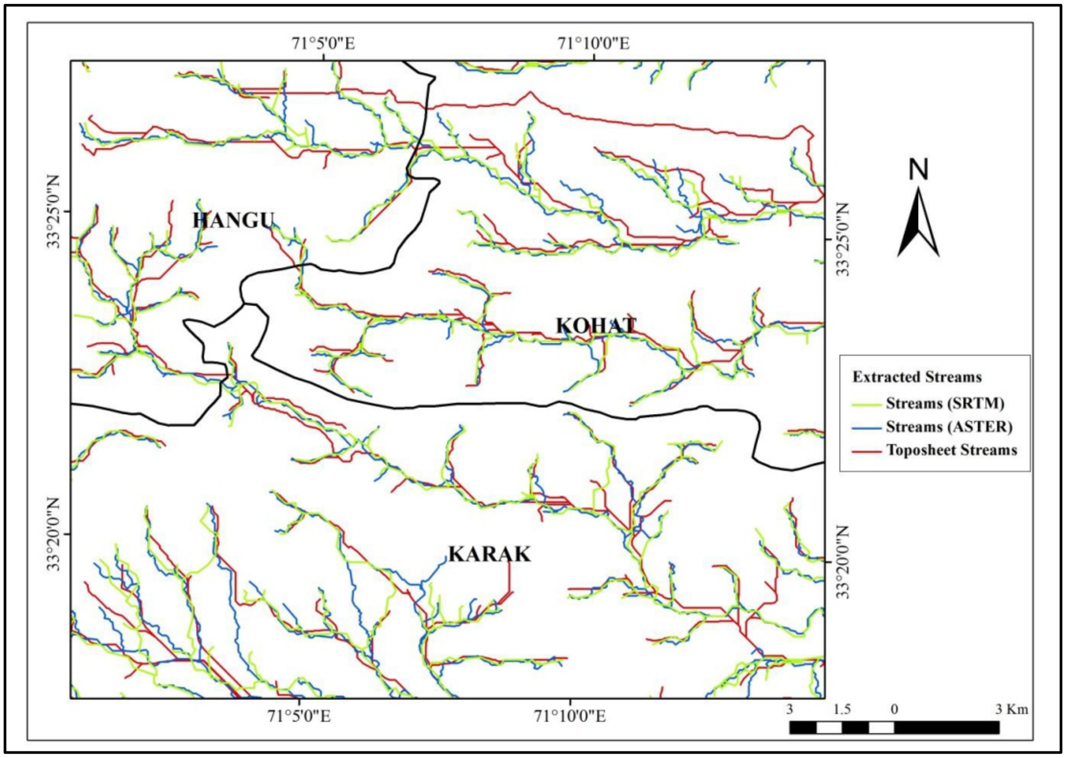

Fig. 9. Streams extracted from the ASTER, SRTM and Toposheet DEM according to Strahler stream order scheme.

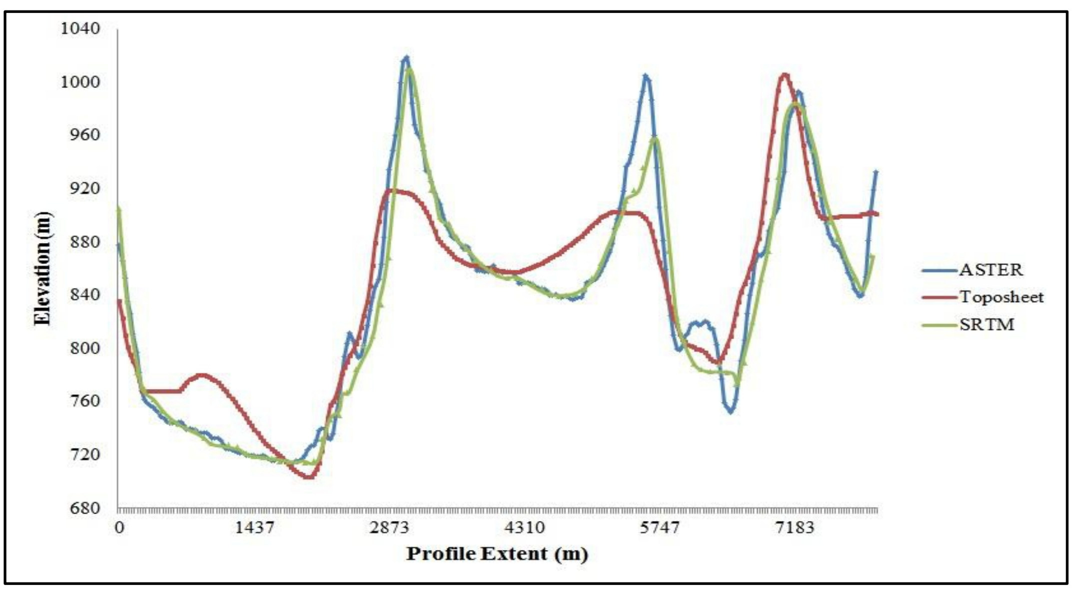

Fig. 10. Elevation profiles from ASTER, SRTM and Toposheet.

8. Conclusion

This study evaluate the impact of DEM resolution and vertical errors on computed topographic attributes and drainage pattern. Accuracy of remote sensing based ASTER and SRTM DEMs is assessed by comparing with the spot heights from Toposheet. In the study area the SRTM DEM has an RMSE of ±27.3 m and the ASTER DEM shows RMSE of ± 20 m. These errors in the DEMs are also due to the random errors that also propagate in the DEM-computed topographic attributes. The impact of random errors in ASTER and SRTM DEM is computed through MCS. Analysis revealed that aspect derived from the ASTER DEM is prone to an error of 31.2° and from the SRTM DEM is susceptible to an error of 29.8°. Slope derived from the ASTER DEM has an uncertainty of 1.2° and from the SRTM DEM has an uncertainty of 0.8°. So, the SRTM DEM was found to be more consistent in deriving topographic parameters than the ASTER DEM. Toposheet, ASTER and SRTM DEM were utilized to compute stream network. The automatic extraction of watershed delineation depends on the accuracy and resolution of DEM. The resolution of the DEM has sigificant impacts on the terrain reperesentation mainly due to smootherning and averging effect.

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