Proceedings of the Pakistan Academy of Sciences 49 (2): 131-138 (2012)

ISSN: 0377 - 2969

Pakistan Academy of Sciences

Original Article

Quality Assessment of Digital Elevation Models in Comparison with Global Positioning Data of a Stream Profile in Dera Ismail Khan

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Abstract: Digital Elevation Models (DEMs) represent the height of terrain and are widely used in many spatial information related applications. Accuracies of DEMs vary depending upon the requirements of different applications. This paper highlights the height accuracy of DEMs derived from SRTM 90M, ASTER 30m, HYDRO1k and Google Earth technologies against field data of a stream profile collected through Global Positioning survey. The methods involve collection of variable DEMs data, developing regression models to find relationship between DEMs and GPS based elevation data, and data quality assessment. The data generated for comparison of the elevation profiles derived from the DEMs against GPS is manipulated with the aid of Geographic Information System (GIS). Multiple linear regressions have been used to define the relationship between the DEM and the 30 plus GPS survey points. The results show a close relationship between the SRTM DEM and the GPS data with Mean Sum of Residual of 0.41m and Root Mean Square Error (RMSE) of 4m. The study provides insight of different DEM technologies available from open sources which can be utilized for detail planning and management of watershed areas of the country in future.

Keywords: Global positioning system, DEM, stream profile, root mean square, Dera Ismail Khan

1. INTRODUCTION

The resource managers and planners need detailed, timely, accurate and reliable data on extent, location and quality of land and water resources at small watershed level to a large basin level. In longitudinal profile survey of streams, points are surveyed along the stream longitudinally in order to calculate stream and water surface slope. Although, conventional survey techniques i.e. Total station and Global positioning System (GPS) offer opportunities for easier and reasonably accurate location of features on the earth's surface but in remote and hard areas like of Balochistan and Khyber Pakhtunkhwa, planning surveys are often confront accessibility problems. The application of satellite remote sensing is gaining importance for landuse surveys and mapping largely because of its ability to provide rapid and reliable information of remote and inaccessible areas within a relatively short time period. The Digital Elevation Model (DEM) data is being applied in a wide range of civil engineering and military planning tasks inside and outside the country. Nowadays, flood estimation [1, 2]; landslide detection; surface morphology mapping [3] and monitoring of underground mining subsidence [4, 5] can also be done with the aid of high resolution DEMs. [6] analyzed the influence of the DEM quality used in the preprocessing of the SAR data on the mapping accuracy of forest types. [7] detected the mountain peaks with varying shapes using a geomorphologically high quality DEM as a fundamental dataset. The term "digital elevation model" (DEM) is used generically to mean the digital cartographic representation of the elevation of the earth surface. It is sometimes referred as a "digital terrain model" (DTM). The (horizontal) spacing is specified in arc-seconds, with a smaller horizontal spacing usually implying a better resolution in height [8]. Although high resolution DEMs like airborne laser scanning (ALS) and radar interferometry i.e. so-called interferometric

Received, January 2012; Accepted, June 2012
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synthetic aperture radar (InSAR) are new technologies capable of creating high quality DEMs in a cost-effective manner, but provision of these is restricted due to technical and geopolitical reasons. Therefore, open source DEMs like The Shuttle Radar Topography Mission (SRTM) 90m, ASTER 30m and HYDRO1k can be utilized frequently for any topographic and hydrologic application in this area.

The most intuitive way to assess the quality of a DEM is to estimate the amount of error in the elevation values. In many cases, it will not be possible to make on-the-ground measurements of the "true" elevation due to time and accessibility constraints. Instead of determining the absolute accuracy of the DEM, it is more practical, and hence common, to measure the relative accuracy in comparison with sample point measurements known to be of a higher order of accuracy [9]. Assessment of DEM quality is commonly restricted to reporting a Root Mean Square Error (RMSE). In order to assess the DEM quality, the user needs to consider the influence of DEM quality on derived products and models, as stated by [10] in particular reference to hydrological models. Knowledge about DEM error is still at a primitive stage and incorporation of this knowledge into DEM-based modelling applications has only developed to a limited extent [11]. Currently majority of DEMs are generated using photogrammetric methods. Spatial modeling involving DEM data is undertaken in a wide range of application areas and for all types of environment. Although broader focus of its use is for the hydrological modeling in mountain environments, but there are other types of terrain or environments where its application exists. Therefore, four elevation models i.e. SRTM 90M, ASTER 30m, Google earth and HYDRO1k were compared with GPS data in order to assess accuracy of the data for longitudinal profile analysis of a stream at a watershed level. The data that has close agreement with the GPS data can serve as an alternative to the medium scale GPS surveying in the country.

2. MATERIALS AND METHODS

2.1. Study Area

The GPS survey was carried out to collect spatial data of irrigation structures, branch nodes and to plot profile of the Gud stream in Daraban Zam

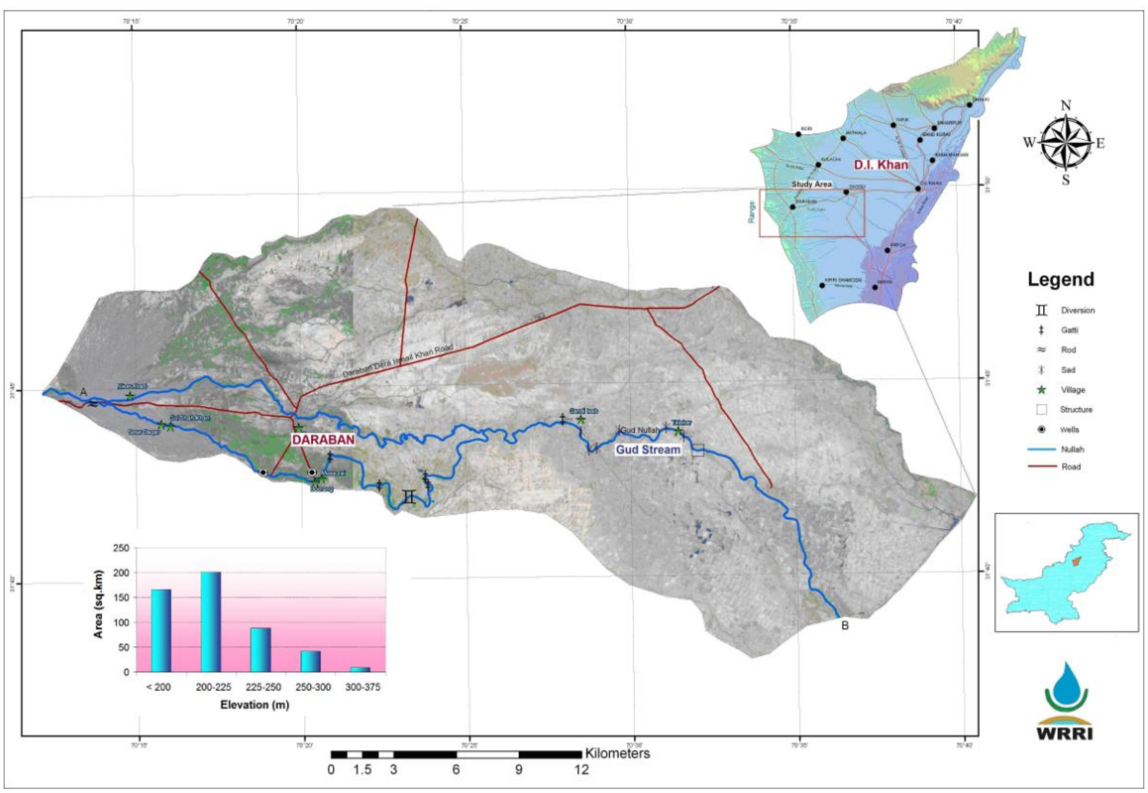

Fig. 1. Location of Gud stream in Daraban Command Area, D.I.Khan.

command area, D.I.Khan, Khyber Pakhtunkhwa province. The study area lies within longitudes 70° 12′ - 70° 40′ E and latitudes 31° 37′ - 31° 50′ N in the western part of the D.I.Khan district (Fig. 1). It has a mean length of about 45 km in SE direction. The elevation ranges between 180 and 417 meters above mean sea level (masl), which gradually decreases towards Indus floodplain in the east. Major area falls in the elevation range of 200 - 225 masl. The study area is well connected through D.I.Khan-Balochistan national highway with other parts of the country. Flood water of Daraban Zam (‘*Zam*’ locally used for a perennial stream in a limited context as it provides perennial flow along with flood water) is distributed in three branches i.e. *Gud* in the south, *Toya* (Shakh Shumali) in the north and *Lohra* in the middle. The Gud stream is about 43km in length starting from the point where Daraban Zam trifurcate into three rods (local term for irrigation offtakes from torrent channel or branches). The discharge of the stream is about 283 m^3/sec with command area of about 22,000 hectares [12]. There are 21 villages under irrigation through this rod. There are two irrigation systems in the zam area that is perennial water (*Kala pani*) and flood water (*Buga pani*). Both have traditional system of management, for perennial Tuman system is in practice and for flood Patti Dari system is in practice. In the up stream and middle stream where the water is received every year, Patti Dari system is working. The main landforms include sub-recent piedmont plains, eroded sub-recent piedmont plains and severely eroded land distributed in various parts of the area. In the western part of the piedmont plains along the mountains, the alluvial fill generally consists of coarse material i.e. coarse sand, gravels and boulders derived from the adjacent rocks. Eastward away from the mountains, the fill gradually becomes fine grained with extensive layers of clay alternating with fine sand layers.

A single unit Magellan *Sportrek* GPS mapping receiver was used for acquiring the profile data of Gud stream. The receiver consists of 12 parallel-channel technology which tracks up to 12 satellites to compute and update information with quadrifilar antenna. It possesses accuracy position of 7 meters and with WAAS (Wide Area Augmentation System) <3 meters [13]. All Magellan GPS receivers use GPS to obtain position, velocity and time information. In addition to these features, the *Sportrek* offers the ability to display one’s location on detailed maps providing one with a complete navigation tools. In 2D (two-dimensional) mode only three satellites are needed for a position fix and elevation is not computed. In 3D (three-dimensional) mode, a minimum of four satellites are needed to compute the position and at the same time, elevation is computed. Overall 66 points had been collected over length of about 30.4 km of Gud stream out of which 34 points along the channel were selected for this comparison study.

2.2. Characteristics of DEM Data Used

2.2.1 SRTM DEM

The Shuttle Radar Topography Mission (SRTM) is a joint project between the National Imagery and Mapping Agency (NIMA) and the National Aeronautics and Space Administration (NASA), USA. They obtained digital topographic data for 80% of the earth’s land surface with data points located at every 30x30 meters (1-arc-second) on a latitude / longitude grid to 90x90 meters (3-arc-seconds). The 3 arc-seconds (90m) data is available globally while 1 arc-second (30m) is available for United States only. The USGS distributes global SRTM elevation data in 1ºx1º tiles which can be downloaded from the USGS ftp server at ftp://e0srp01u.ecs.nasa.gov/srtm/version2/SRTM3/. Most common DEM format is the raster grid with elevations given at regularly spaced points or ‘posts’ [8]. Because DEMs are discrete representations of the earth’s continuous surface, sudden elevation changes i.e. cliffs or deep valleys may not be represented correctly by a regularly-spaced grid.

2.2.2. ASTER GDEM

The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM) was developed jointly by the Ministry of Economy, Trade, and Industry (METI) of Japan and NASA, USA. They contributed this DEM to the Global Earth Observation System of Systems (GEOSS), which is available at no charge to users via electronic download from the Earth Remote Sensing Data Analysis Center (ERSDAC) of Japan and NASA’s Land Processes Distributed Active Archive Center (LP DAAC). The ASTER instrument was launched by NASA in December 1999. It has an along-track stereoscopic capability using its near infrared spectral band, and its nadir-viewing and backward-viewing telescopes to acquire stereo image data with a base-to-height ratio of 0.6. The spatial resolution is 15m in the horizontal plane.

One nadir-looking ASTER visible and near-infrared (VNIR) scene covers about 60x60km ground area. The ASTER GDEM is in GeoTIFF format with geographic (lat/long) coordinates and a 1 arc second (30m approx.) grid. Pre-production estimated accuracies for this global product were 20m at 95% confidence for vertical data and 30m at 95% confidence for horizontal data. An upgraded ASTER GDEM Version 2 can be downloaded from the site http://www.gdem.aster.ersdac.or.jp/search.jsp.

2.2.3. HYDRO1k

The development of HYDRO1k database was made possible by the completion of 30 arc-seconds digital elevation model at EROS in 1996, entitled GTOPO30. HYDRO1k is a geographic database providing comprehensive and consistent global coverage of topographically derived data sets to organize, evaluate, or process hydrological information on a continental scale. This data set, with its nominal cell size of 1 km can be downloaded from site http://eros.usgs.gov/#/Find_Data/Products_and_Data_Available/gtopo30/hydro/asia. The basis of all of the data layers available in the HYDRO1k database is the hydrologically corrected DEM. The DEM is processed to remove all elevation anomalies that can interfere with hydrologically correct flow. The raster data layers of HYDRO1k are available in simple binary data of each continent.

2.2.4. Google Earth

Google Earth is a virtual globe map and geographic information program that was originally called Earth Viewer 3D and was created by Keyhole, Inc, a company acquired by Google in 2004. It maps the Earth through superimposition of images obtained from satellite imagery, aerial photography and GIS 3D globe. Most of the land area is covered in satellite imagery with a resolution of about 15m per pixel. This base imagery is 30m multi-spectral Landsat which is pan sharpened with the 15m panchromatic Landsat imagery. However, Google is actively replacing this base imagery with SPOT 2.5m imageries and several higher resolution datasets. The image data can be visualized in google earth after downloading software from the site http://www.google.com/earth/download/ge/ agree.html. Most of the Google image data are underlying with 3 arc second digital elevation data. Although 1 arc second elevation data is also available but for limited region only.

2.3. Data Comparison and Statistical Analysis

The DEM data of SRTM, ASTER and HYDRO1k were downloaded from open web sources and respective subsets of the data were developed in GIS. All the data were transformed into common coordinate system i.e. Universal Transverse Mercator (UTM) for comparison analysis. The overlay analysis of the data was performed in GIS which provides an ideal environment for datum conversion, geo-referencing, profile extraction, interpretation and visualization. The GPS points were draped over the respective sub images of DEMs data and underlying elevation values were recorded with the aid of spatial analyst tools i.e. extract values to points, of ARCGIS 9.3 software. The profiles of DEM and GPS data were drawn and scatter plots were developed to determine coefficient of correlation 'R^2' and regression equations. Profile lines are linear features that define the longitudinal view of the channel parallel to the direction of stream flow. The profile provides idea of channel slope which has a profound effect on the velocity of flow in a channel, and, consequently, on the flow characteristics of runoff from a drainage basin. Water surface elevation is measured at the bank of the stream. A variety of geomorphic parameters such as pool to pool spacing, pool length, average reach, riffle, run, glide and pool slopes an be measured from the profile graph http://www.rivermorph.com/detail/detail1003.asp.

To evaluate accuracy of the results, Mean Sum of Residuals (*MSR*), Root Mean Square (*RMS*) and standard deviation (σ) were computed. MSR is independent of sample size, but depends on the range in the measured values. The Root Mean Square error or RMSE value is based on the difference between DEM elevation and the elevation of test points measured by field survey or aero triangulation, or from a spot height or point on a contour line from an existing source map [14]. Standard deviation is a statistical measure of dispersion of a frequency distribution, equal to the positive square root of the mean squared deviation of a number of individual measurements of a variate from their population mean [15]. The *MSR*, *RMS* and standard deviation were computed using following equations:

$$MSR = \frac{1}{n}\sum_{i=1}^{n} Wi\left|m - o\right| \quad (1)$$

$$RMS = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left[Wi(m-o)\right]^2} \tag{2}$$

$$\sigma = \sqrt{\frac{\sum (x-\bar{x})^2}{n}} \tag{3}$$

Where, m = model point data of DEM; o = Observed data of GPS; W = Weight; σ = standard deviation; x = residual of model and observed data; $\bar{x}$ = the residual mean; n= number of values.

3. RESULTS

3.1. Analysis of Stream Profiles

The data was interpreted in GIS and extracted for developing profiles of different DEMs along the route of the GPS survey as shown in Fig. 2a-d. The GPS data of stream profile indicated drop of 136 meters over a length of 30.4 km in water surface of the stream. About 78% of this drop exists within 10 km length in the west side indicating gentle sloping terrain of Suleiman piedmont area. The slope in this part of the profile is about 0.01 while in the rest part, it declines up to 0.001 in the eastern part of the study area. The analysis of SRTM profile showed about 44% values on the lower side of the GPS values exhibiting an overall equal pattern of distribution (Fig. 2a). About 62% of the ASTER and 85% of the HYDO1k values were found on the lower side of the GPS values indicating an overall negative shift in profiles. The profile of Google earth showed 82% values on the higher side of the GPS data indicating a dominant upward shift.

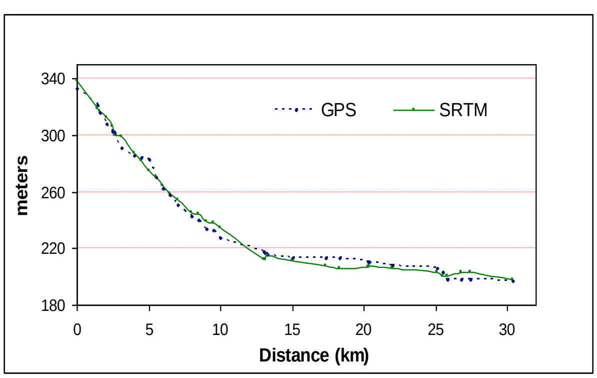

Fig. 2a. Stream profile under GPS and SRTM data.

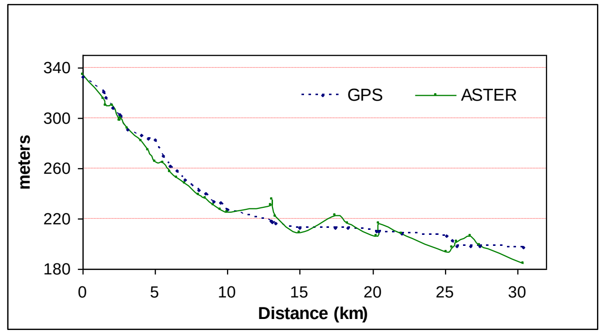

Fig. 2b. Stream profile under GPS and ASTER data.

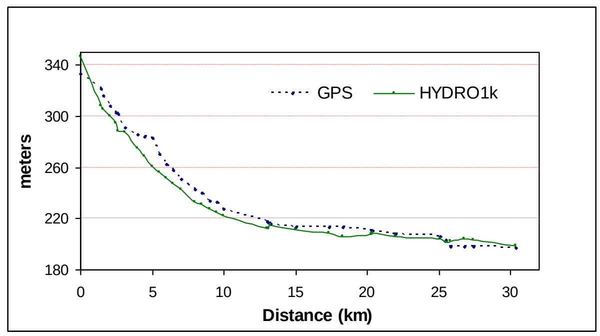

Fig. 2c. Stream profile under GPS and HYDRO1k data.

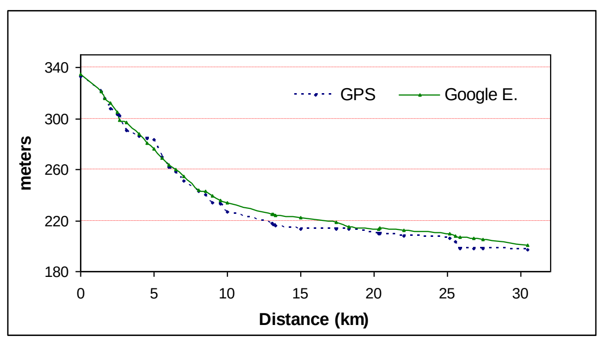

Fig. 2d. Stream profile under GPS and Google E. data.

3.2. Data Correlation Analysis

The scattergrams were developed of DEMs versus GPS data for correlation analysis (Fig. 3a-d). The regression equations obtained from correlation analysis of DEM and GPS elevation values are given as follows:

$y=0.9741x+5.9792$ *for* SRTM (4)

$y=1.024x-4.395$ *for* ASTER (5)

$y=1.0532x-7.1375$ *for* HYDRO1K (6)

$y=1.0522x-16.465$ *for* Google E. (7)

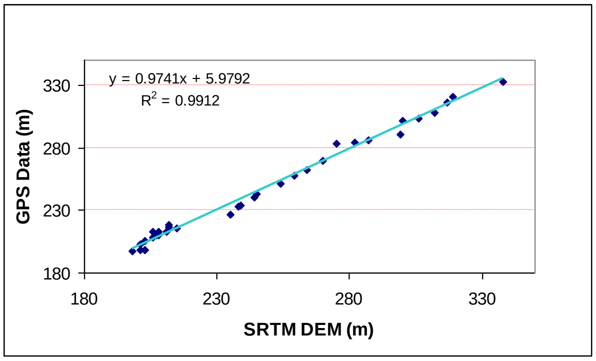

Fig. 3a. Relationship of SRTM vs. GPS data.

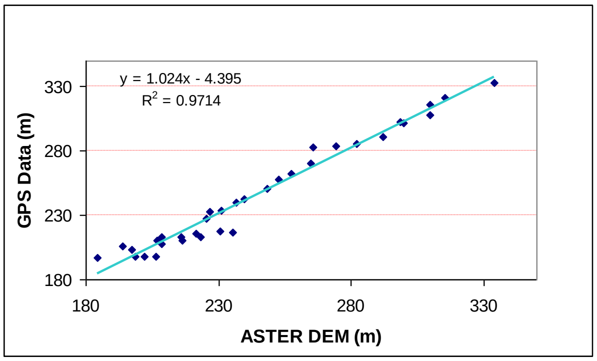

Fig. 3b. Relationship of ASTER vs. GPS data.

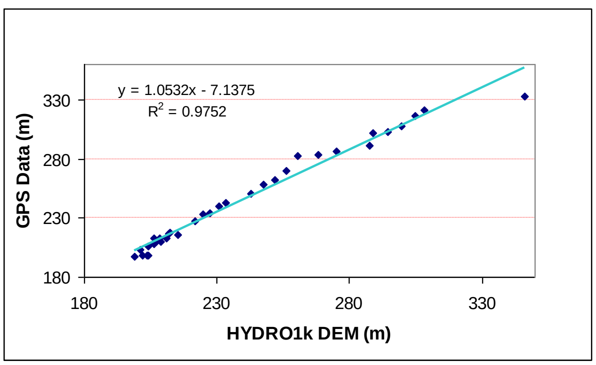

Fig. 3c. Relationship of HYDRO1k vs. GPS data.

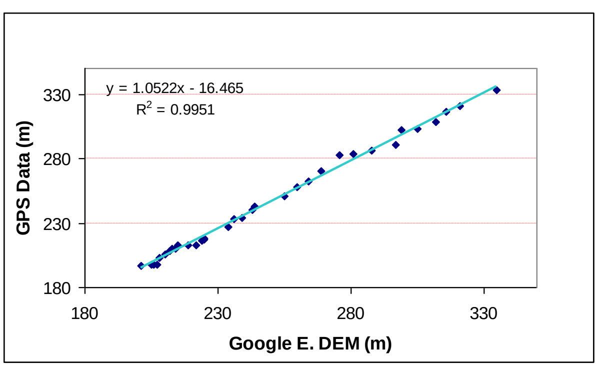

Fig. 3d. Relationship of Google E. vs. GPS data.

Where '*y*' represents the GPS elevation and '*x*' the corresponding DEM elevation value of the profile.

The comparison of DEMs and the GPS data indicated maximum correlation coefficient value of about 0.99 for SRTM DEM and Google Earth data (Table 1). The HYDRO1k and ASTER DEM data exhibited almost identical value of R^2=0.97 with later slightly lower than the former. The SRTM DEM had shown a least RMS value of about 4m indicating higher accuracy than that of HYDRO1k and ASTER DEMs which showed RMS values of 8.96m and 7.26m, respectively. The SRTM DEM had shown MSR value of 0.4 which is closest to zero. The MSR value was found maximum for Google Earth i.e. 3.44m while minimum for HYDRO1k DEM as (-) 5.65m. The ASTER DEM exhibited the maximum standard deviation value of 7.22m followed by HYDRO1k DEM which indicated value of 6.99m.

4. DISCUSSION

There was a topographical effect observed on various DEMs data when compared with GPS profile data. The ASTER and HYDRO1k profiles indicated an overall downward shift in values (Fig. 2a and 2b). ASTER data showed an underestimation above 226 masl while HYDRO1k exhibited underestimation above 202 masl. For plain to gentle slopes, these datasets seem provide better accuracy. On the contrary, there was an upward shift visible in the profile of Google earth as compared with GPS profile (Fig. 2d). The Google earth data was found overestimated below 264 masl while above this elevation it was in agreement with the GPS profile. The SRTM data exhibited more or less uniform distribution over the GPS profile. A DEM might be affected by an overall vertical shift, making its absolute accuracy poor, but still has good relative accuracy [8]. For a DEM the relative accuracy specifies the accuracy of the differences in elevation between 'posts' and usually describes the internal consistency of the dataset.

The standard deviation (σ) values determined of DEMs and GPS data residual also indicated lowest value of 4.14m for SRTM DEM. RMS is problem dependant and its value is affected by the range in the

Table 1. Correlation coefficient and error estimation between various types of DEM and GPS elevation data.

Data	R^2	MSR	RMS	σ
SRTM 90m	0.9912	0.412	4.095	4.135
ASTER 30m	0.9714	-1.465	7.258	7.216
HYDRO1k	0.9752	-5.655	8.964	6.991
Google E. 3Arc	0.9951	3.441	4.968	6.363

measured values. It is considered to be the best error measure equation if errors are normally distributed [16]. However, determination of ground points may give higher RMS values for densely vegetated bank areas than of non-vegetative areas [17]. Keeping in view the quality of SRTM DEM, the data had already been used to demonstrate profiles sections of Vehowa stream [18], generation of slope and drainage network of Pishin-Lora basin [19], delineation of watershed boundaries and drainage network of Rod-kohi (Hill-Torrent) region and Daraban catchment [20, 21]. According to [22], SRTM DEM data can be used to replace the DEM from 1:250,000 scale topographic maps in many situations e.g. for the study of mountain geomorphology, ecology and hydrology. Furthermore, compared with the actual DEM determined after ground surveys, the absolute elevation error is less than 5m in relatively flat basins and wide valleys on the plateau, while it is greater in mountainous areas. Thus SRTM DEM surface seems to provide a better approximation of the actual spatial variation so as to represent data collected through field surveying.

5. CONCLUSIONS

The results of the study show that SRTM 90m DEM has closer agreement with the GPS elevation data than other DEMs like ASTER, HYDRO1k etc. The SRTM DEM can provide an alternative of medium scale GPS survey for topographic or elevation profile analysis. Although quality of DEMs data like ASTER, HYDRO1k and Google earth was reasonable when compared with GPS data but to some extent only as it indicated variation with topography which needs to be investigated in detail. As error estimate did not relate to true elevation, but the elevation recorded through GPS source, there could be chances of errors existence in GPS parameters and surveying method etc. which can be explored through applying advance GPS and surveying techniques. The regression equations derived from GPS and DEMs data relationship during this study can help in transforming DEM data to equivalent GPS elevations useful for field surveying and spatial planning in the respective area. Although the results described in this paper are preliminary but it provides insight of data quality of various DEMs available from open sources which can be utilized for detail planning and management at watershed to a regional level in the country.

6. ACKNOWLEDGMENTS

The work is conducted under a research project on Water Management of Spate Irrigation Systems in Rod-kohi Areas of Pakistan for which support of Ministry of Food and Agriculture is highly acknowledged. The authors also wish to thank field staff of D.I.Khan component of the project for GPS data collection and GIS team members of Water Resources Research Institute for development and manipulation of the database in GIS.

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