Redefining the Border line of the Neka River's Watershed with Comparing ASTER, SRTM, Digital Topography DEM, and Topographic Map by GIS and Remote Sensing Techniques

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Abstract: The accurate and precise calculation of the area for land features has a key role in the estimating the change detection of land uses and the classification of geomorphologic units as well as in the evaluating of land use. In particular, the delineation of borders between watersheds is a base in hydrologic analysis. Recent advances in spatial tools of GIS environment and the availability of various remotely-sensed data make the reliable determining of topographical boundaries possible. So an integrated approach of data analysis and modeling can accomplish the task of delineation. The main aim in this research is to evaluate the delineation method of watershed boundary by using four different digital elevation models (DEM) including ASTER, SRTM, Digital Topography, and Topographic maps. In order to determine a true reference of boundary of watershed, sample data were also obtained by field survey and using GPS. The comparison reference points and the results of these data showed the average distance difference between reference boundary and the result of ASTER data was 43 meters. However the average distance between GPS reference and the other data was high; the difference between the reference data and SRTM was 307m, and for Digital Topographic map, it was 269m. The average distance between Topographic map and the GPS points differed 304 meters as well. For the statistical analysis of comparison, the coordinates of 230 points were determined; the paired comparisons were also performed to measure the coefficient of determination, R^2, as well as the analysis of variance (ANOVA) in SPSS. As a result, the R^2 values for the ASTER data with the Digital Topography and Topographic map were 0.0157 and 0.171, respectively. The results showed that there were statistically significant differences in distances among the four means of the selected models. Therefore, considering other three methods, the ASTER DEM is the most suitable applicable data to delineate the borders of watersheds, especially in rugged terrains. In addition, the calculated flow directions of stream based on ASTER are close to natural tributaries as well as real positions of streams.

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1. Introduction

The sustainable land-use system in the mountainous regions has vital importance in government and community levels. So that, in the developing countries, the hydrologic study of mountain watersheds is considered seriously. In fact, the accurate and authentic knowledge about the natural phenomena of watersheds is necessary to construct a real model of the process, especially in simulation models and evaluation systems (Corresponding & De Jong, 2005).

In hydrology studies, the demarcation and delineation of boundaries between watersheds is a challenge to estimate the planimetric area of watershed. However, only few researches about the delineation of watershed have been done, particularly at small scales, such as the report of the American Society of Agriculture and Biological Research (Pryde, 2007) in Illamanga subwatershed in North America.

2. Previous Research

2.1 Digital Elevation Data

Digital elevation data are available from various sources including the spaceborne earth observation sensors, eventually through Google Earth images, which have reduced the complexity of the authenticity of the elevation data. Additionally, high-resolution digital elevation data are provided by the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), which have the capability of taking along-track stereo images. Despite this fact, in some places such as less developed regions or in rugged terrains with steep slopes, the accurate data of digital elevation are not accessible (Kaab, 2002, 2005; Wang & Qiu, 2006). Digital elevation model (DEM), or digital terrain model (DTM) in remote sensing, is a continuous elevation surface as a grid (Podobnikar, 2009). Since the generation of DTM in the 20th century, many different techniques have been developed (Gesch, et al., 2002; Hirano, Welch, & Lang, 2003; MAUNE, 2007; Miller & Laflamme, 1958; Muskett, et al., 2009). The recent developments in remote sensing have also made better topographic observations; accordingly, topographic measurements have been reliable (Homer, et al., 2007) . At small scales, spaceborne systems (with coarse Ground Sampling Distance - GSD) such as shuttle radar topographic mission (SRTM) collected 80% of altitude of the earth's landmass with the spatial resolution of 30m or 90m (Rabus, Eineder, Roth, & Bamler, 2003). At medium scales, radar interferometric techniques (medium to high resolution) had been applied to generate global DTMs (Heipke, et al., 2007; Madsen, Zebker, & Martin, 1993). For large scales and more local usage, airborne laser scanning like Light Detection and Ranging (Linder) and aerial photogrammetric techniques have been applied to create DTMs with high spatial resolutions(Hudak, Lefsky, Cohen, & Berterretche, 2002; Li, Andersen, & McGaughey, 2008; Næsset, 2002)

DTM has versatile usages from forestry to water resources including watershed management, flood hazard mapping, and even to timber harvest or fire management in forest. The elevation of terrain is a basic input for environmental, forestry, topographic and hydrologic models; therefore, the accuracy of elevation models is critical to modeling environment (Andersen, Mcgaughey, & Reutebuch, 2008; Kellndorfer, et al., 2004). Hence, there are many standards for topographic mapping such as the National Standard for Spatial Data Accuracy (Zandbergen, 2008) and the National Digital Elevation Program (Gesch, et al., 2002).

2.2 The Accuracy Assessment of SRTM DTM

The measured signals of the Shuttle Radar Topography Mission (SRTM) are the reflected radar of elevation, and mainly their attributes are related to the structure of terrain as well as the electromagnetic behaviors of scattering environment t(Bhang, Schwartz, & Braun, 2007). The land cover of the terrain has a major influence over the signals. In particular, the existence of vegetation increases the complexity in scattering medium, as the wavelengths of C-band could not reach the earth under vegetation cover (Braun & Fotopoulos, 2007; Carabajal & Harding, 2005). Considering performance evaluations, the SRTM project team have endeavored to decrease the absolute vertical error, approximately 5m (Brown Jr, Sarabandi, & Pierce, 2005; Rosen, et al., 2001). An analysis by using GPS and NED data to evaluate the accuracy of the SRTM data in southeastern Michigan showed that the absolute and relative height errors are less than GPS ground control point targets (Braun & Fotopoulos, 2007). Further study indicates the accuracy of SRTM DGPS data is acceptable even for barren land surface. And the DTM data derived from IFSAR are dependent on terrain. According to SRTM project team, the absolute horizontal circular accuracy of SRTM is less than 20m, while the absolute vertical accuracy and the relative vertical accuracy are less than 16m and 10m, respectively (Kellndorfer, et al., 2004).

2.3 The Accuracy Assessment of ASTER DTM

Before the launch of ASTER, the team project applied four study fields to evaluate the accuracy of elevation (Hirano, et al., 2003). Even, using the stereo pair of ASTER images on personal computers, DEMs are calculated with 30 to 150-meter spatial resolutions; and the quality of these data are also satisfactory with a RMSE (a root-mean-square error) of ±7 and ±15m. These results are also confirmed by the United States Geological Survey (USGS) at EROS Data Center (EDC) with a RMSE of ± 8.6m. The US and Japan ASTER Project group studied the extraction of elevation validity by means of correlation techniques and estimated the accuracy of new ASTER Global DEM. This result was little greater than the 20-meter accuracy at a 95% confidence level prior to GDEM production. In comparison to the angle of horizontal measurement the vertical accuracy from NED data was 2-to-3 meters as the RMSE. As per the study, when more than 13,000 GPS points were chosen the RMSE dropped to 9.35 meters. The vertical error was below the estimated ASTER GDEM vertical error of 20 meters at a 95% confidence level. However the major shortcoming of the ASTER GDEM version 1 is, it cannot be applied for inland water bodies, because the elevation of inland lakes are not accurate and most the lakes existence are not indicated in ASTER GDEM. The vertical accuracy of this ASTER DEM was checked against 40 DGPS survey points and 12 points digitized from the USGS 1:24,000-scale topographic quadrangles, yielding an RMSE of ±8.6 m. This generally corresponds with other validation results reported by EDC (DAAC, 2001; Hirano, et al.,

2003) The recent exploitable advantages of the automatic generation of digital elevation models are useful in the modeling of watershed, especially in the delineation of basins as well as the deriving of their boundaries. The Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER), onboard Terra spacecraft of NASA's Earth Observing System (EOS), has 14 bands in the spectrums of the visible and near-infrared (VNIR), short wave infrared (SWIR), and thermal infrared (TIR). They provide images in high-quality spatial resolutions including 15-meter resolution in VNIR bands, 30-meter resolution in SWIR bands, and 90-meter resolution in SWIR bands. The ASTER Digital Elevation Model (DEM) is obtained through bands such as 3N (Nadir Viewing) and 3B (backward viewing) captured from Visible near Infrared (VNIR) Sensor. In VNIR two telescopes have been assemble to generate stereoscopic data. The Band – 3 stereo pair have a spectral range of 0.78 and 0.86 microns with a base – to – height ratio of 0.6 and an angle of intersection at 27.7^0. There is a time lag of approximately one minute between the acquisition of the nadir and backward images(Grohmann, Smith, & Riccomini, 2010; Mo, Liu, Lin, & Guo, 2009).

2.4 Accuracy Assessment of Google Image

Google Earth data are significantly productive in the study of land-cover and land-use change, and its potential is not well harnessed (Sheppard & Cizek, 2009). Google Earth provides high spatial resolution of 2.5 meters for 20 % of the earth's surface. They are exploitable to extract land features as well as to study the effects of human activities in environment.

To characterize the horizontal positional accuracy of the high-resolution Google Earth archive, the locations of 436 control points in the GE imagery to their equivalent positions in the Landsat dataset was used, so that, it has the positional accuracy of 50 meters as the root mean squared error (RMSE). In an ideal assessment of spatial accuracy, it would determine the position of these Sensors 2008, 976 control points through a global ground-based campaign using global positioning satellites (GPS).done for below cities such as Sao Paolo, Brazil, San Salvador, El Salvador, Chonan, South Korea, and Anqing, China(Potere, 2008)

3. The characteristics of Study Area

Neka watershed is located in the northern part of Iran. The Neka River basin is one of the largest watersheds in the Iranian province of Mazandaran. The Neka River is flowing down the northern flank of the Alborz Mountains towards the Caspian Sea, and it goes through Neka City and divides this city into two parts - eastern and western parts. The Neka watershed is covered with Quaternary formations. Climate is temperate with mild winter and hot summer. The study area is used as rain-fed agriculture and rangeland of cattle-grazing. The geographical location of the Southern Neka basin is shown in Figure 1.

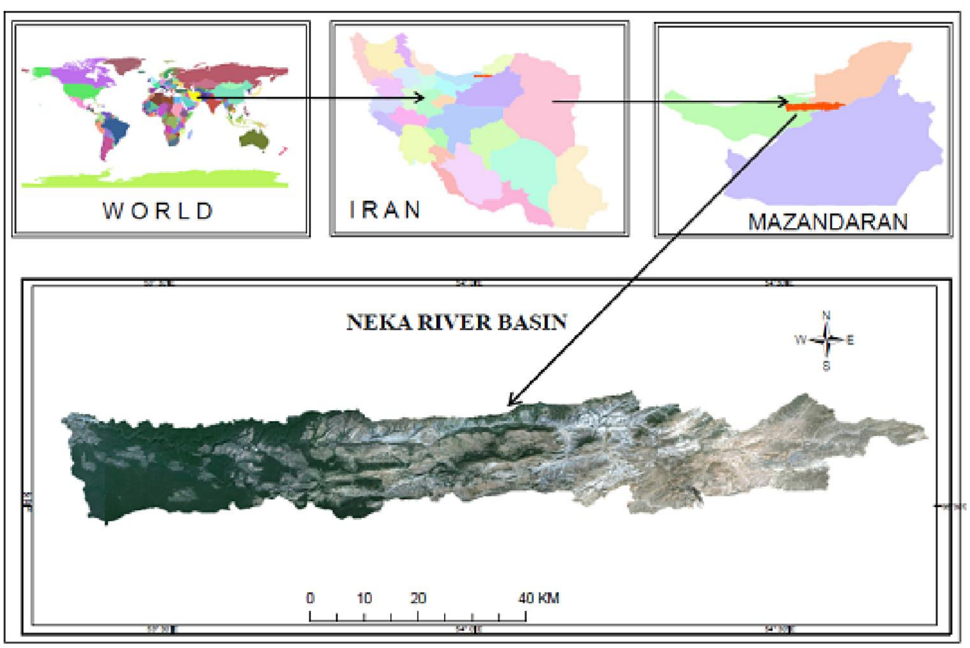

Figure 1: The location of the Neka River basin

4. Materials and methods

4.1. Database

The accurate delineation of watershed's boundary and the comparisons of delineation methods need various data sources, available through scientific database such as ASTER and STRM projects. Table 1 shows all the data applied in this project.

Table 1: The list of database

Data	Date	Spatial Resolution/Scale	Source
SRTM (DEM)	2002	90 m	USGS
ASTER (DEM)	2009	29 m	ASTER G DEM
Digital Topographical Map	2004	1:25,000 scale	Iran Geographical Organization
Topographical Map	1965	1:50,000 scale	Iranian Geographical Organization
PAN IRS	2004	5.5 m	Indian Remote Sensing
Google Image	2010	1.5 m	Google Earth (SPOT)

The topographical map at a 1:50,000 scales, which were published by the Iran Geographical Organization in 1965, were scanned and geo-referenced in GIS environment. For this study area, 11 topographical maps were used to draw the manual border line of the watershed of Neka.

The ASTER DEM data for the year 2009 were downloaded from GDEM-ASTER website and re-sampled to the spatial resolution of 29m. In addition, SRTM data (DEM) of USGS with 90-meter resolution (2002) were also downloaded. The digital topographical map, published by Iranian geographical organization in 2004 at scale 1:25,000 (Ahmadi & Nusrath, 2010), was applied to obtain the boundary of the considered watershed in the €study area.

The product of Google images were downloaded through Google Web Service (2009).

The IRS panchromatic data on the first of June, 2004 were geo-referenced with 50 GPS points, and the RMSE (the Root Mean Square Error) was less than 0.5 pixels, image Geo referenced to the UTM projection based on the WGS84 datum. The re-sampling was done at 5.5m.

4.2. Methodology

In order to delineate the boundary of watershed, four kinds of data were utilized such as ASTER, digital topography DEM, SRTM DEM, and Topographic map (manual). The topographic map from the Iranian Geographical Organization was used to digitize the boundary of the Neka river watershed (Figure 2). The total area of this watershed was about 1,887.62 square kilometers.

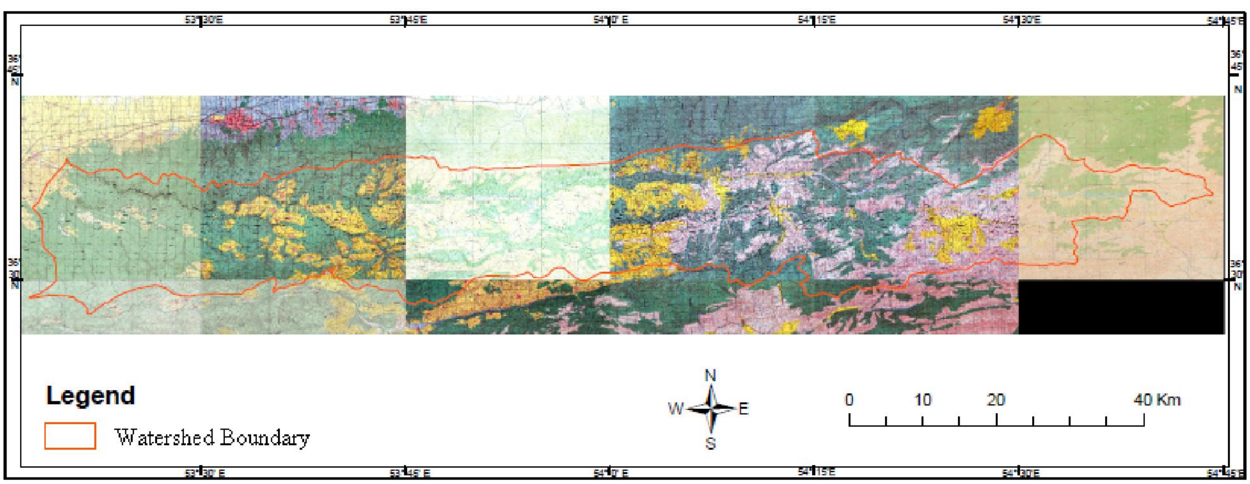

Figure 2: The catalog of watershed border line (red-colored line) based on the topographic map

Digital topography DEM, Aster DEM and SRTM DEM were analyzed using spatial hydrology tools of ArcGIS. The available techniques in GIS environment include filling sinks; determining flow direction, finding flow accumulation, and identifying the watershed outlet are applied. The final output of this process is generally in a raster format, so it is converted to a polygon map.

5. Results

The four obtained boundaries of the considered watershed were compared statistically. Regression analyses were applied to compare each of the DEM-based watershed boundaries with the 230 GPS points, which had 120-meter intervals. For the regression analyses, a Cartesian coordinate system was used to determine the similarity of the pair values of the boundaries. Additionally, the one way analysis of variance (ANOVA) was conducted to determine the discrepancy between the GPS point and the watershed boundary line.

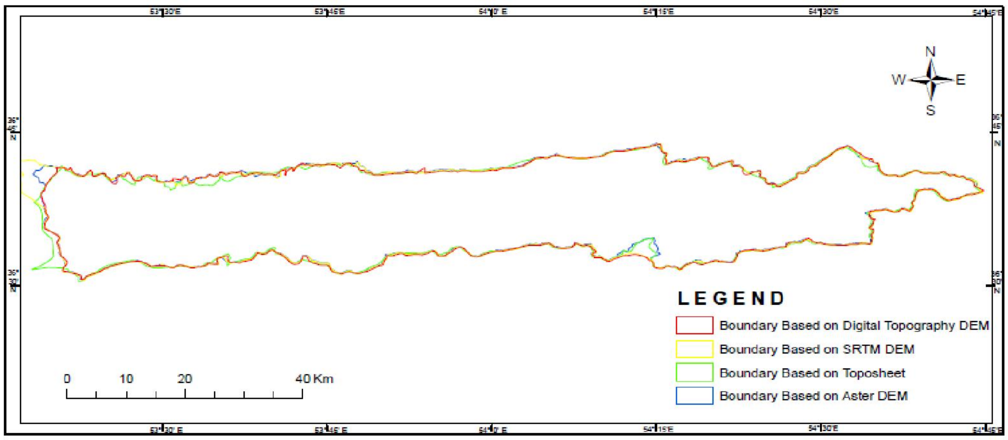

Figure 3: The comparison of the Neka River watershed resulted from ASTER, SRTM, Digital Topographical DEM and Topographic map

Figure 3 shows the dissimilarity between the ground GPS points and the delineated ASTER, SRTM, Topographic map (manual) and Digital topographical map boundaries. The area of the watershed delineated from a topographic map (manual) is 1,887.62 sq. km, while the amounts of area from ASTER, the digital topography DEM, SRTM, and are 1,901, 1,906.72, and 1,934.31 sq. km, respectively. As a result, there are differences among the designed boundaries. For land evaluation research, instead of checking the error in the total area of the watershed, the exact water- dividing points are required. Eminently, finding error in the area was discarded and instead the distance error between the GPS point and other boundary line has been calculated.

Table.2: Descriptive statistics of the difference in distance between limits

	SRTM	Aster	Digital	Topograp
Mean	304.2	43.41	269.87	307.33
Standard Error	42.08	13.22	32.47	32.12
Median	111.6	23.44	129.33	171.75
Mode	68.93	8.60	129.36	73.23
Standard	639.5	200.8	493.52	488.13
Sample	409,0	40,35	243,562.81	238,267.1
Kurtosis	10.37	217.2	14.98	15.73
Skewness	3.33	14.54	3.82	3.78
Range	3155.	3037.	3190.11	3403.47
Minimum	1.54	0.01	1.77	1.35
Maximum	3,156.	3,037	3,191.88	3,404.82
Sum	70,29	10,02	62,339.95	70,992.57
Count	231.0	231.0	231.00	231.00
Confidence	82.91	26.04	63.98	63.28

The ArcGIS tool, that measures the straight-line distance from each GPS point cell to the closest boundary line source, were used to get the statistical descriptions of the differences in the distance and to compare between four DEM-based boundaries to find out which boundary is closer to the exact ground data, as shown in Table 2. The calculation of error was made between ground GPS points and the boundary line derived from ASTER DEM, Top sheet hand boundary, Digital Topography DEM and SRTM DEM using analysis tools in ArcGIS. As per the analysis the ASTER DEM boundary line has a mean variation of 43 meters distance from the GPS point which is less than the other three boundary lines while this for SRTM is 304m, for Topographic map is 307m and for Digital topography DEM is 269m.

5.1. Visual cross examination of four boundary line with Google Image and PAN IRS

Visually the four boundary lines, overlaid on Google image, are overlapping on each other on steep slopes, but on gentle slopes the boundary lines are deviating. Among the four boundary lines, the Aster DEM boundary line is exactly cutting across the water divided line, as shown in Figure 4. Similarly, when the boundary lines were overlaid on PAN IRS, it is confirmed that the boundary lines merge on steep slopes, but on gentle slopes, they deviate each other, as shown in Figures 5. In this case, Aster DEM boundary line is cutting exactly on the water divided point, either on steep slope or gentle slope.

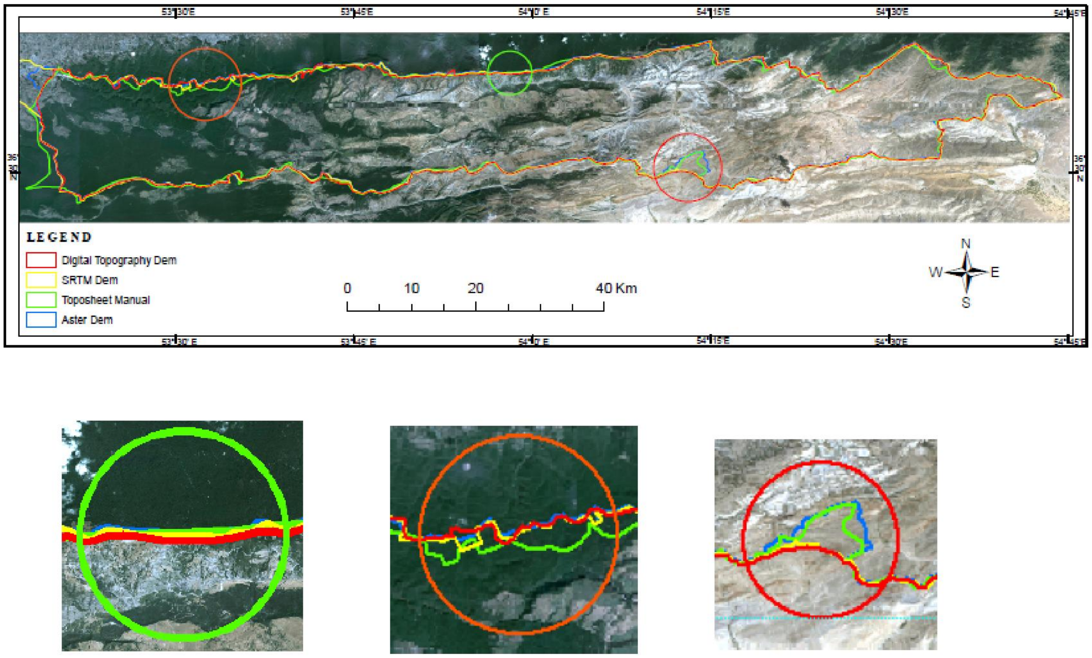

Figure 4: Visual Cross-section of four boundary line with Google Image

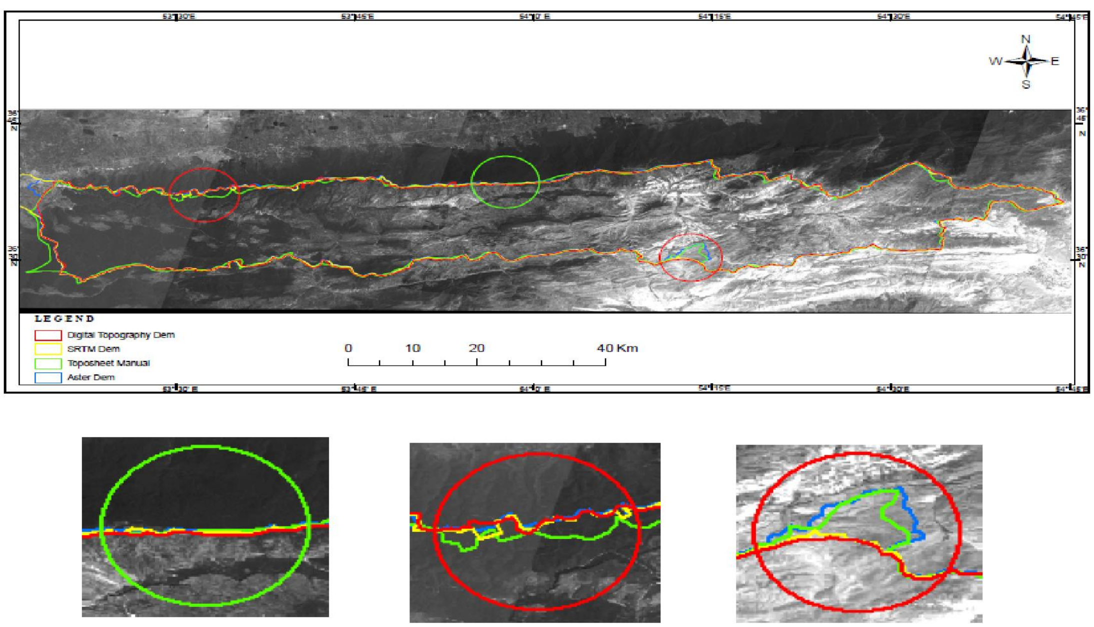

Figure 5: Visual Cross-section of four boundary lines with PAN IRS

6. Conclusions

The methodology of this project describes the evaluation of delineation techniques of a watershed based on digital elevation models. As a result, the obtained accuracy for the delineation of watershed is dependent upon the quality of digital elevation models. The ASTER DEM is a suitable demarcation model to delineate the boundary of watershed in the places with rugged and steep slopes.

According to the observation on Google map, the demarcated boundary of watershed based on ASTER data has showed less errors comparing with the other three boundary lines. Additionally, the comparison with IRS PAN Data has also proved the same result.

ASTER products are reasonable having low price and good resolution. Comparing to this, as the SRTM data have higher spatial resolution, the vertical accuracy of SRTM data is higher than others. Their disadvantages also are the vegetation influence; in other words, radar could not reach the true terrain's surfaces. As a result, the delineated boundary of watershed based on ASTER digital elevation models has a complementary role over the other demarcation models.

The overall methodology adapted in this research has evaluated the delineation of the watershed boundary comparing with each other and proved that, ASTER is the best source of data for the delineation.

Based on the above testing and comparisons, it also imply the fact that the future researcher can straight away use the ASTER data for any hydrology and land use system and land evaluation studies.

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