International Journal of Agricultural Engineering, Vol. 3 No. 2 (October, 2010) : 232 -235

Research Paper :

Analysis of watershed boundaries derived from ASTER, SRTM digital elevation data and from manually digitized topographic map

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Accepted : ***June, 2010***

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ABSTRACT

The watershed is natural entity having ridge line which contributes runoff to single outlet. This plays important role in the planning of natural resources. A properly delineated watershed forms a convenient hydrological unit for computation of water balance parameters and thus implementation of water management schemes. The objective of this work was to evaluate the accuracy of watershed boundaries derived from different sources of digital elevation data and manually digitized topographic map. The present case study was done for the Nanduri (Saptshrungi gad) watershed, which is located in Kalwan Tahsil Dist. Nashik, Maharashtra (India) having average elevation range from 590 to 1300m.From the present study it was found that the boundaries derived from the ASTER DEM were more closer to the manually digitized watershed boundaries. As ASTER DEMs appeared to be highly complementary to other types of satellite-derived data, such as Shuttle Radar Topography Mission (SRTM). It had been shown that a fusion of DEM from different sources (optics and radar) lead to improved results in comparison to the reference DEM.

Key words : Watershed, SRTM, ASTER, DEM, Delineation

The watersheds are natural hydrological entities that cover a specific aerial expanse of land surface from which the rainfall runoff flows to a defined drain, channel, stream or river at any particular point. The terms region, basin, catchment, watershed etc are widely used to denote hydrological units.

In the last two decades, watershed management has gained the top most priority in water resources sector. Implementation of any water management measure requires a suitable hydrological unit. A properly delineated watershed forms a convenient hydrological unit for computation of water balance parameters and thus implementation of water management schemes. The objective of this work was to evaluate the accuracy of watershed boundaries derived from different sources of elevation data.

METHODOLOGY

Digital elevation eata (DEM):

Digital elevation models are data files that contain the elevation of the terrain over a specified area, usually at a fixed grid interval over the surface of the earth. Digital elevation models may be prepared in a number of ways, but they are frequently obtained by remote sensing rather than direct survey. Digital elevation models (DEM) provide good terrain representation from which the watersheds can be derived automatically using GIS technology.

The United States Geological Survey (USGS) is the primary distributor of DEMs in the U.S.(USGS, 2000). The Shuttle Radar Topography Mission (SRTM), developed jointly by the National Aeronautics and Space Administration (NASA) and the National Geospatial Intelligence Agency (NGA), provides elevation datasets for the globe at 3 arc second resolution (approximately 90 m at the equator) (USGS, 2006).

The original SRTM dataset was developed from raw radar echoes into DEMs, which are readily available at several resolutions, 1 arc second resolution for the US, and at 3 arc seconds for the world (USGS, 2006). The SRTM is projected into a geographic coordinate system (GCS) with the WGS84 horizontal datum and the EGM96 vertical datum (USGS, 2006).

The SRTM data are available in NASA-distributed "Research" grade and National Geography Agency (NGA)-distributed "Finished" grade formats. Voids are present in certain regions of SRTM datasets (USGS, 2006). Grohman *et al.* (2006) explain that voids, or no data holes, in SRTM data can be attributed to the complexity of interferometric synthetic aperture radar (ISFAR) technology and topographic shadowing from cloud cover and dense vegetation. The "Research" grade SRTM data have not been processed to fill data voids (USGS, 2006). The USGS and the Consultative Group on International Agricultural Research - Consortium for Spatial Information (CGIAR-CSI) distribute processed versions of SRTM data. CGIAR-CSI utilizes the NGA-distributed "Finished" grade SRTM and applies a post-processing hole-filling algorithm to address the data void regions remaining in the "Finished" grade SRTM (CGIAR, 2006). CGIAR-CSI distributes the data in 5 degree by 5 degree tiles.

The Advanced Space borne Thermal Emission and Reflectifhlon Radiometer (ASTER) is an advanced multispectral imager that was launched on board NASA's Terra spacecraft in December, 1999. ASTER covers a wide spectral region with 14 bands from the visible to the thermal infrared with high spatial, spectral, and radiometric resolution. The spatial resolution varies with wavelength: 15 m in the visible and near-infrared (VNIR), 30 m in the short wave infrared (SWIR), and 90 m in the thermal infrared (TIR).

The ASTER Digital Elevation Model (DEM) product is generated using bands 3N (nadir-viewing) and 3B backward-viewing) of an ASTER Level-1A image acquired by the visible near Infrared (VNIR) sensor. The VNIR subsystem includes two independent telescope assemblies that facilitate the generation of stereoscopic data. The Band-3 stereo pair is acquired in the spectral range of 0.78 and 0.86 microns with a base-to-height ratio of 0.6 and an intersection angle of about 27.7^0. There is a time lag of approximately one minute between the acquisition of the nadir and backward images. View a diagram depicting the along-track imaging geometry of the ASTER VNIR nadir and backward-viewing sensors.

Study area:

The present case study was done for the Nanduri (Saptshrungi gad) watershed, which is located in Kalwan Tahsil Dist. Nashik, Maharashtra (India) having average annual Rainfall of 625 mm. The watershed is having main two streams which further join to the river Girna. The study area is having major area under agriculture and forest, having elevation range from 590 m to 1300 m. Major crop grown in *Kharif* season are Paddy, Bajara, groundnut, maize and in *Rabi* season Wheat and gram.

Watershed delineation from DEMs:

Watershed boundaries were derived from the DEMs using automated procedures with the Watershed Delineator (written by ESRI and the Texas Natural Resource Conservation Commission), an ArcGIS Extension that requires the Spatial Analyst extension to be installed as well. The GIS technique for watershed delineation consists of the following steps. First, the "Fill" tool was used to fill sinks in the elevation grid; this removed small imperfections in the data and enabled the "Flow Direction" tool (the second step) to run properly and create a grid of flow direction from each cell in the elevation grid to its steepest down slope neighbor. Then, the "Flow Accumulation" tool was used to create a grid of accumulated flow to each cell from all other cells in the flow direction grid. The next step was to identify the watershed outlet grid, ensuring that was located directly over a grid cell from the drainage network. Finally, the "Watershed" tool was used to delineate the watershed for the specified outlet. Boundaries (in grid format) were defined. Using Spatial Analyst, the watershed boundary and the stream grids were then vectorized to produce polygon and polyline themes, respectively, for further analysis and comparison.

The three watershed boundaries were compared visually. Then Regression analyses were performed to compare each of the DEM-based watershed boundaries to the manually-delineated boundary. For the regression analyses, a Cartesian coordinate system was used to compare the values of x at the same y location on the two boundaries to determine how similar they were. A total of 400 points, at constant intervals of 1000 m, were utilized in each regression analysis for the complete watershed boundary. Then, a t-test was conducted to determine if the differences in the x-values between one DEM-based boundary and the manual boundary were significantly different than the differences in x-values between the other DEM-based boundary and the manual boundary.

RESULTS AND DISCUSSION

Visually, there were small differences between the manually-delineated and the SRTM-based boundaries (Fig. 1), while the ASTER-based boundary varied from the manually-delineated one, especially in two places. Along the northeast side of the watershed boundary, the biggest difference in x coordinates between the ASTER-based and manual boundaries was 228.3 m while the difference between the SRTM-based and manual boundaries at the same point was 43.6 m. The area of the watershed delineated manually was 14,583.38 ha, while the SRTM-based watershed area was 14,632.72 ha (0.34% larger), and the ASTER-based watershed area was 14,990.26 ha (2.79%) larger than the manual boundary.

The Euclidean Distance ArcGIS - tool that measures the straight-line distance from each cell to the closest source were used to obtain the statistical descriptions of the differences in distance between one DEM-based boundary and the manual boundary which are summarized

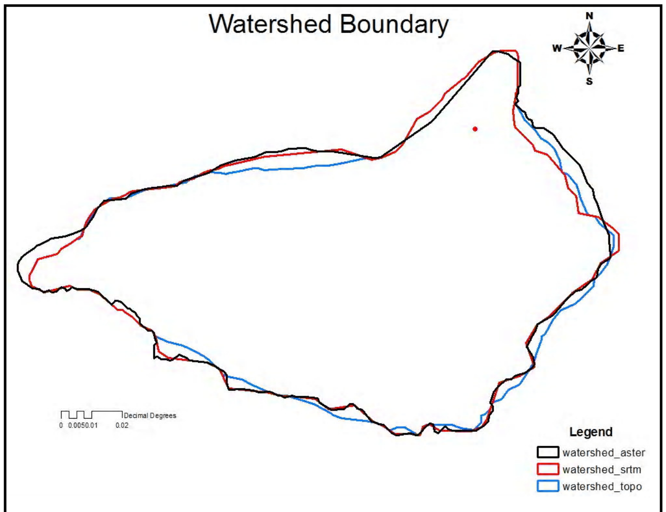


Fig. 1 : Watershed boundary comparison

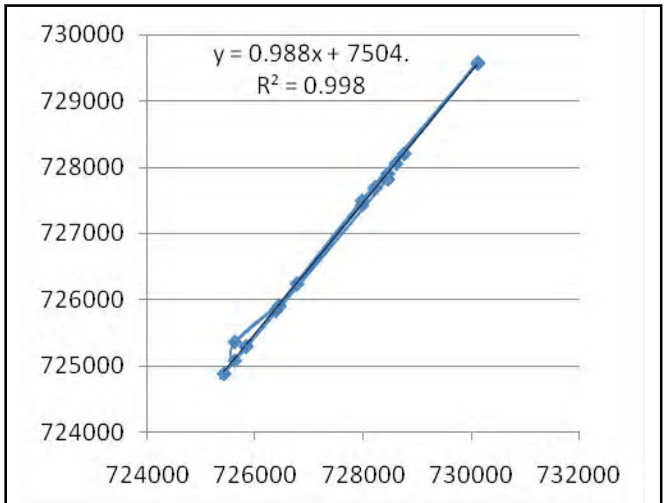
in Table 1.

The regression analyses comparing 400 x-y points along the complete boundaries yielded an R^2 of 0.999 between the SRTM and manual boundaries; the R^2 for the comparison between the ASTER and the manual boundaries was 0.988. Then, the perimeter was divided into ten segments, and the regression analyses were performed for each segment. The comparison for only one segment yielded an R^2 less than 0.90, specifically, the northeast segment, where the main difference between the ASTER-based boundaries and the others occurred (Fig. 1).

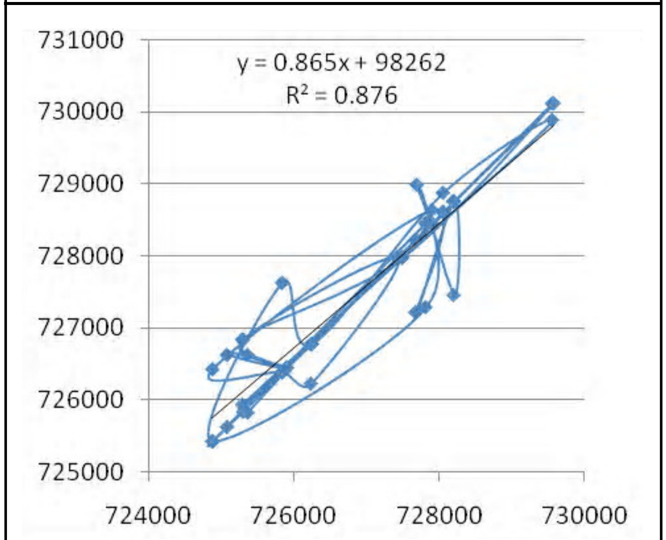
Table 1 : Descriptive statistics of the difference in distance between limits

	ASTER	SRTM
Mean	137.36	93.34
Standard error	8.78	2.27
Median	63.45	53.19
Mode	12.28	13.39
Standard deviation	169.23	79.37
Sample variance	104428.71	13698.47
Range	1213.29	491.35
Minimum	0.08	0.19
Maximum	1213.37	491.54
Confidence level	29.20	7.64

The t-test comparing the distance differences [(ASTER vs. manual) and (SRTM vs. manual)] indicated the mean values, 137.36 (±169.23) and 93.94 (±79.37) for the ASTER and SRTM, respectively, were significantly different in the distance differences ($p = 0.001$). Also t-test were computed for the different segment alone and showed that there was a significant difference ($p< 0.001$) in the distance differences for the North - East and North - West segments, the other ones had no statistic differences.



2 (a)



2 (b)

Fig. 2 : Northeast side segment regression analysis: a) SRTM – manually digitized watershed segment and b) ASTER - manually digitized watershed segment

The reason for the difference in the watershed boundaries was found by looking at the flow networks associated with each type of elevation data. The flow network generated from the ASTER-based DEM had several errors. To determine the cause of the errors in the ASTER stream network, map algebra was used to determine where the "Fill" tool had filled the sinks. It was found that the errors in the stream network occurred where some especially large (60 to 100 m) filling had occurred. Such a large fill indicates that there was probably an error in the original ASTER DEM.

The ASTER-DEM was corrected with the following rule: If the ASTER raster has a missing value or it is equal to zero and if the difference between the ASTER and the SRTM is greater than 100 m, it is replaced with the SRTM value, if not, an average of the ASTER and SRTM values is used. The corrected DEM was processed to obtain a new watershed boundary (Fig. 3).

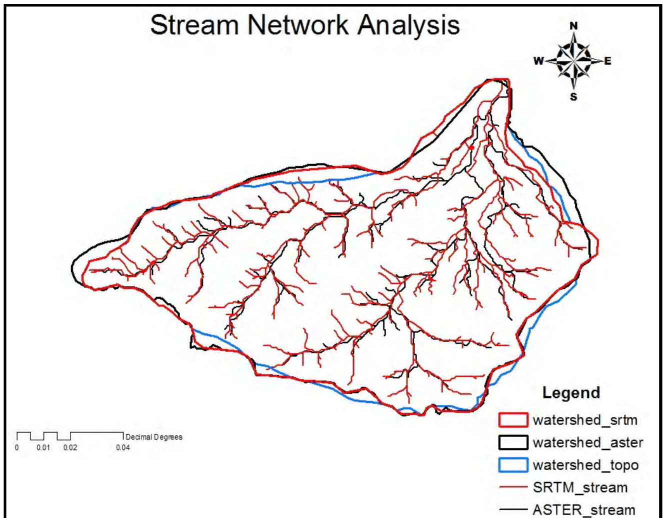


Fig. 3 : Stream network analysis

Once the ASTER DEM is corrected the Arc GIS Watershed Delineator draws the boundary through the right place, with almost no difference with the SRTM and also with the Hand-drawn Boundaries (Fig. 4).

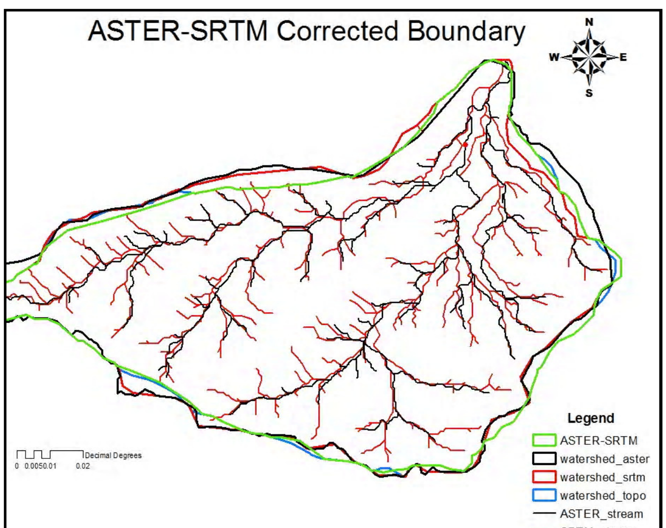


Fig. 4 : ASTER-SRTM corrected boundary

Conclusion:

The methodology described in this paper allows evaluate watershed delineation on DEMs of different source. The accuracy of the watershed delineation it is highly dependent on the accuracy and good quality of the Digital Elevation Model available (DEM). ASTER data have several advantages, including high spatial resolution, good correlation over vegetated areas. Its disadvantages include mainly the potential masking by clouds. On the other hand, elevation models produced from SRTM data will be the highest resolution topographic dataset ever produced for the Earth's land surface. Therefore, an obvious advantage of SRTM is the significant increase in spatial resolution and vertical accuracy over existing global elevation data. Although, the accuracy is clearly dependent upon the terrain vegetation as radar cannot penetrate it. Finally, ASTER DEMs appear to be highly complementary to other types of satellite-derived data, such as Shuttle Radar Topography Mission (SRTM). It had been shown that a fusion of DEM from different sources (optics and radar) leads to improved results in comparison to the reference DEM.

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