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Comparison of watershed boundaries derived from SRTM and ASTER digital elevation datasets and from a digitized topographic map.

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Abstract. *Watersheds are natural integrators of hydrological, biological, and geological processes and as such require an integrated approach to data analysis and modeling, which usually starts delineating accurately a polygon vector layer of watershed boundaries as input. In that way, the Río Illangama watershed in Alto Guanujo, Ecuador, had been isolated with the objective of evaluate the accuracy of watershed boundaries derived from three different sources: One was delineated by hand and other two were derived from a 30-m ASTER DEM and a 90-m SRTM DEM, using the Spatial Analyst extension of ArcGIS. Visually, there are small differences between the manually-delineated and the SRTM-based boundaries, while the ASTER-based varies from the manually-delineated one. The area of the watershed delineated manually is 13,061.3 ha, while the SRTM-based and the ASTER-based watershed are 0.66% and 2.6% larger. The regression analyses comparing the complete boundaries yielded an R^2 of 0.999 between the SRTM and manual boundaries and the 0.988 for the ASTER and the manual boundaries. The t-test comparing DEMs indicated a significant difference ($p< 0.001$) in the distance differences. To determine the cause of the errors in the ASTER DEM, map algebra was used to define where the "Fill" tool had filled the sinks finding that the errors in the stream network occurred where some especially large (60 to 100 m) fills had occurred. Then the ASTER-DEM was corrected and processed to obtain a new watershed boundary with almost no difference with the Hand-drawn boundaries. Therefore, the accuracy of the watershed delineation depends on the first place on the accuracy of the Digital Elevation Model available (DEM)*

Keywords. GIS, DEM, Watershed.

Introduction

Watershed-based natural resource management in mountain regions is gaining interest and acceptance with government and community organizations (FAO, 2006; Estrada and Posner, 2001; CONDESAN, 2004). Hydrological research in mountain watersheds of developing countries is a relatively new field, therefore, hydrologic and erosion data are necessary for the development of mathematical watershed models that can simulate and evaluate existing and proposed management scenarios (de Jong et al., 2005).

Researchers at Virginia Tech are involved in a long-term research project funded by the Sustainable Agriculture and Natural Resource Management Collaborative Research Support Program (SANREM-CRSP) funded by USAID. The focus of the project is developing and evaluating watershed-based natural resource management strategies for small-scale agriculture in the sloped areas in the Andean Region of South America.

Watershed modeling is one important component of the project. A crucial step in data preparation for modeling is delineating accurate watershed boundaries for the study watersheds. The objective of the work described on this paper was to evaluate the accuracy of watershed boundaries derived from different sources of elevation data.

Digital Elevation Data

Since the development of Geographic Information Systems (GISs), digital elevation models (DEMs) have been generated throughout the world. DEMs provide good terrain representations and are applied routinely in watershed modeling. DEMs can be used to derive flow networks and then automatically generate watershed boundaries for given outlet points using GIS technology. Therefore, an essential component to watershed delineation is a hydrologically sound DEM of the land area of interest.

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 Spaceborne Thermal Emission and Reflection 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°. 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.

Methods

Study area

The following description of the Río Chimbo watershed is summarized from Alwang et al. (2005), unless otherwise noted. The Río Chimbo drainage basin comprises four cantons (Guaranda, Chimbo, San Miguel and Chillanes), three ecological regions (Andean plain, subtropical and paramo), and four Holdridge zones (boreal, low temperature mountain, temperate mountain and subtropical humid forest). The Río Chimbo drainage basin contributes between 30 and 40 percent of the total water input to the Guayas River. Two sub-watersheds within the Río Chimbo drainage basin have been isolated for detailed analysis (the Río Illangama watershed in Alto Guanujo and the Río del Alumbre watershed in Chillanes). The study area has an annual rainfall range of 500 to 4000 mm and elevations from approximately 900 to 5000 m (Jarvis et al., 2006).

The Bolívar province is a significantly impoverished region (more than 76 percent of the population is poor). Land owners typically own 3 to 5 ha on average in the upper section of the Río Chimbo basin and 1 to 4 ha on average in the lower section. Agriculture is the major economic activity in the study area (greater than 60 percent); irrigation occurs on less than 3 percent of the land; less than 1 percent of households own tractors; approximately 50 percent do not have access to electricity; and approximately 70 percent do not have adequate human waste disposal. The Río Chimbo drainage basin is characterized by several environmental problems. Water is being polluted by human wastes. The upper section of the Río Chimbo contains significant levels of sedimentation. Agro-chemicals are contaminating the waterways. Soil moisture content is declining as a result of deforestation. Native animal and plant species populations are declining as well (Alwang et al., 2005).

Data preparation

Three different sources of data were used to delineate watershed boundaries for the analysis. One watershed boundary (HDD-WSB) was delineated by hand and then digitized by ECOCIENCIA personnel, a SANREM partner in Ecuador, using the most detailed topographic data available for the area (1:50 000 topographic map). Watershed boundaries were also derived from two DEMs,including a 30-m ASTER (ASTER-WSB) DEM and a 90-m SRTM (SRTM-WSB) DEM.

The 3 arc second "Finished" SRTM digital raster elevation dataset of Bolívar, Ecuador was obtained from the USGS EROS Data Center; a post-processed version of the dataset was also obtained from the CGIAR-CSI. ArcGIS software was utilized to analyze the SRTM DEMs. The original 3 arc second SRTM was distributed by NASA with a pixel shift in the data. The spatial orientation has been recently corrected and the SRTM of the study area was adjusted.

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.

Analysis

The three watershed boundaries were compared visually. Regression analyses were then conducted 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 468 points, at constant intervals of 100 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 are small differences between the manually-delineated and the SRTM-based boundaries (fig. 1), while the ASTER-based boundary varies from the manually-delineated one, especially in two places. Along the northwest side of the watershed boundary, the biggest difference in x coordinates between the ASTER-based and manual boundaries is 1,775.3 m while the difference between the SRTM-based and manual boundaries at the same point is 23.6 m. The area of the watershed delineated manually is 13,061.3 ha, while the SRTM-based watershed area is 13,147.7 ha (0.66% larger), and the ASTER-based watershed area is 13,398.2 ha (2.6%) larger than the manual boundary.

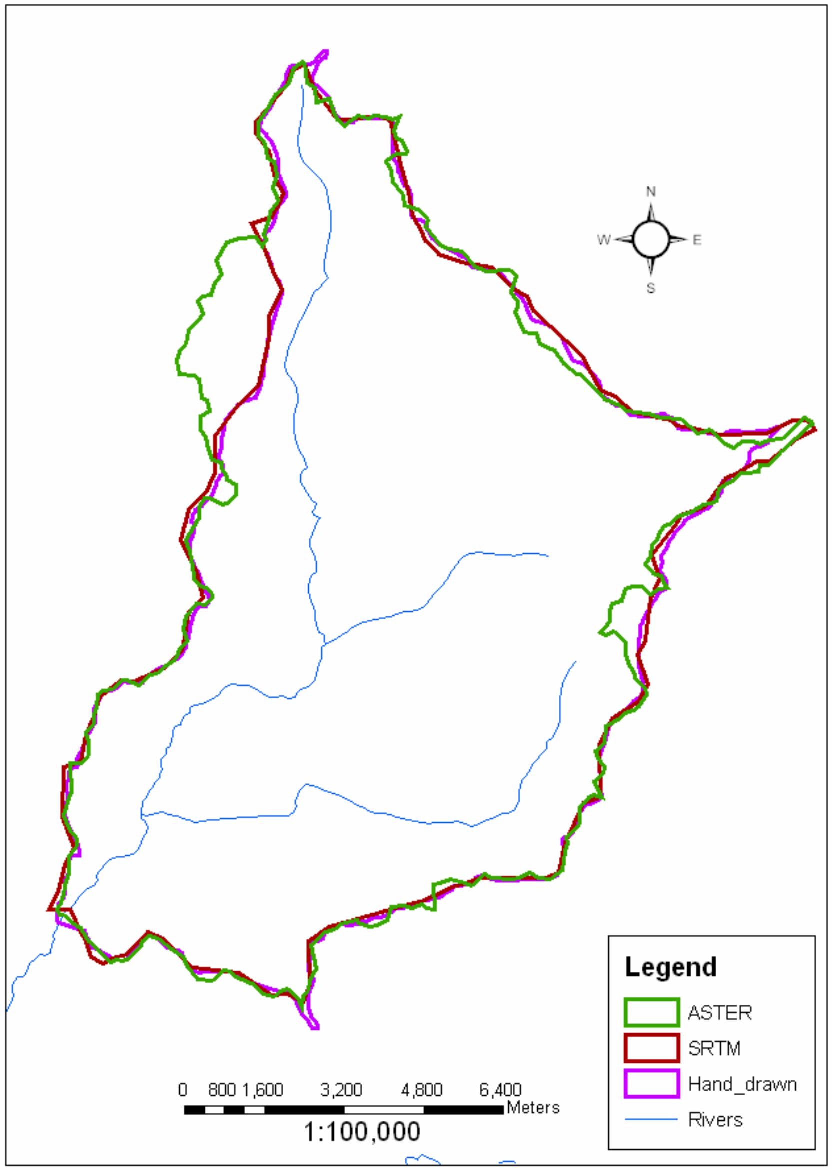

Figure 1. Illamanga Sub watershed boundaries comparison.

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 in table 1.

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

	Aster	*Srtm*
Mean	198.20	88.03
Standard Error	16.34	4.34
Median	71.42	60.74
Mode	14.78	16.47
Standard Deviation	353.44	93.85
Sample Variance	124918.07	8808.09
Range	1775.87	635.68
Minimum	0.06	0.21
Maximum	1775.93	635.89
Confidence Level(95.0%)	32.10	8.52

The regression analyses comparing 468 x-y points along the complete boundaries yielded an R2 of 0.999 between the SRTM and manual boundaries; the R2 for the comparison between the ASTER and the manual boundaries was 0.988. Then, the perimeter was divided into nine segments, and the regression analyses were performed for each segment. The comparison for only one segment yielded an R2 less than 0.90, specifically, the northwest segment (fig. 1), where the main difference between the ASTER-based boundaries and the others occurred (fig. 2).

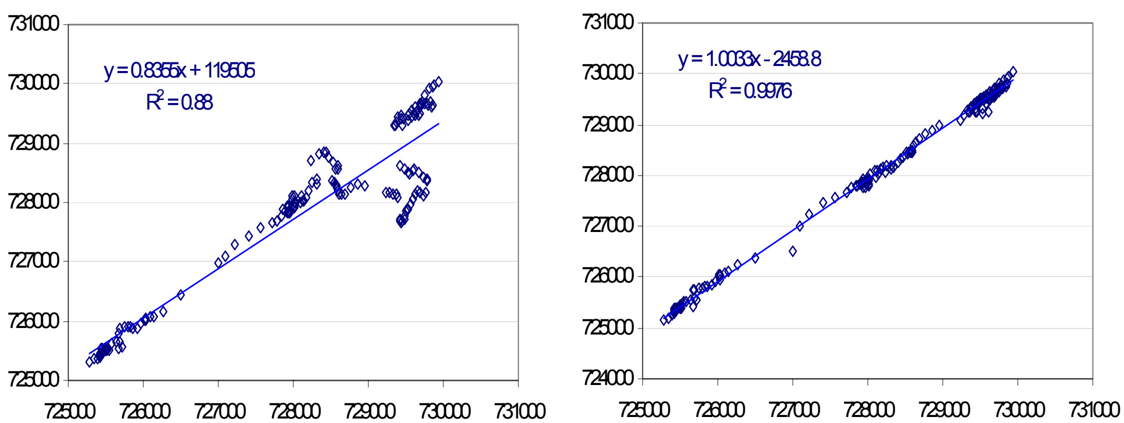

Figure 2. West-side segment regression analysis: a) ASTER – Hand-drawn and b) SRTM – Hand-drawn.

The t-test comparing the distance differences [(ASTER vs. manual) and (SRTM vs. manual)] indicated the mean values, 192.2 (±353.4) and 88.0 (±93.9) for the ASTER and SRTM, respectively, are significant different in the distance differences (p = 0.001). Also t-test were computed for the different segment alone and showed that there is 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.

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. In one location (fig. 3, location A), a stream was indicated, which according to an ALOS satellite image, would have to flow over a mountain. In a second location (fig. 3, location B), there are a parallel and criss-crossing streams. 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 (fig. 4). Such a large fill indicates that there was probably an error in the original ASTER DEM.

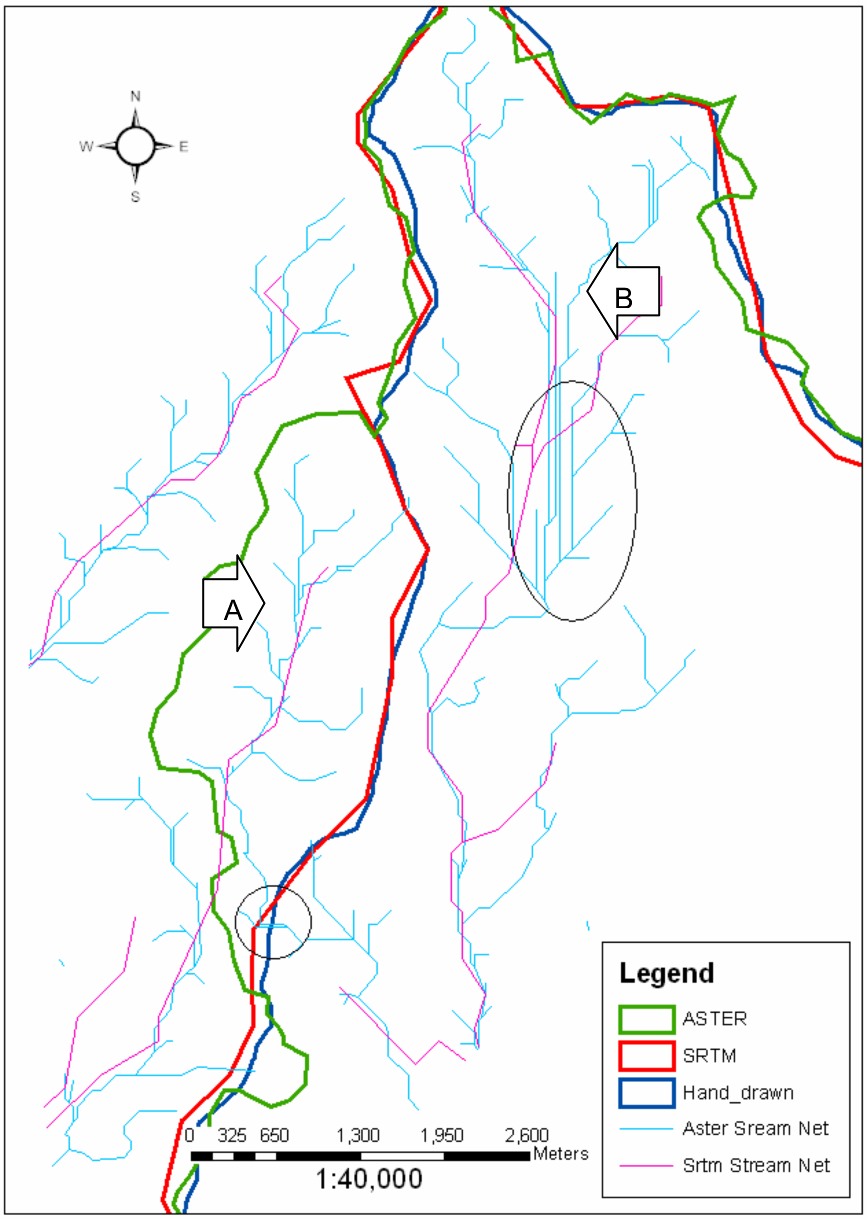

Figure 3. Stream network analysis.

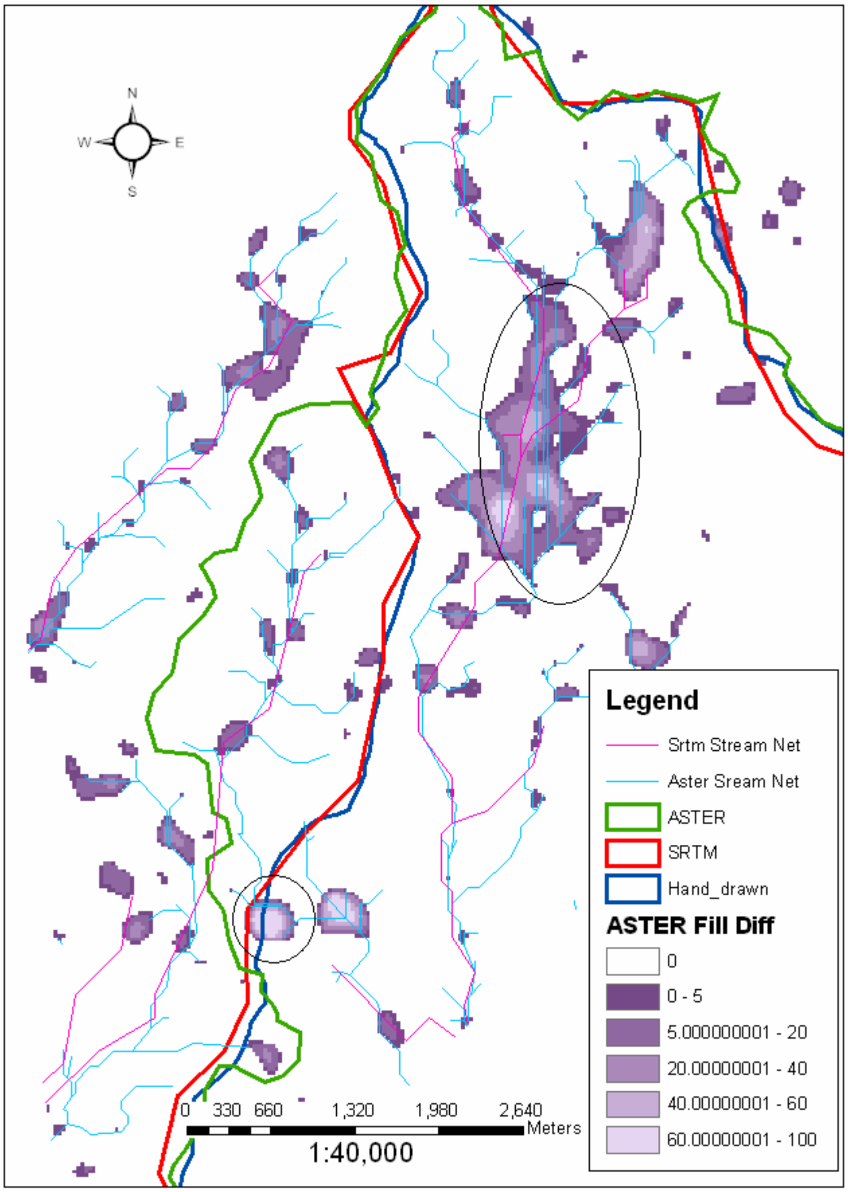

Figure 4. Stream network analysis after fill procedure.

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. 5).

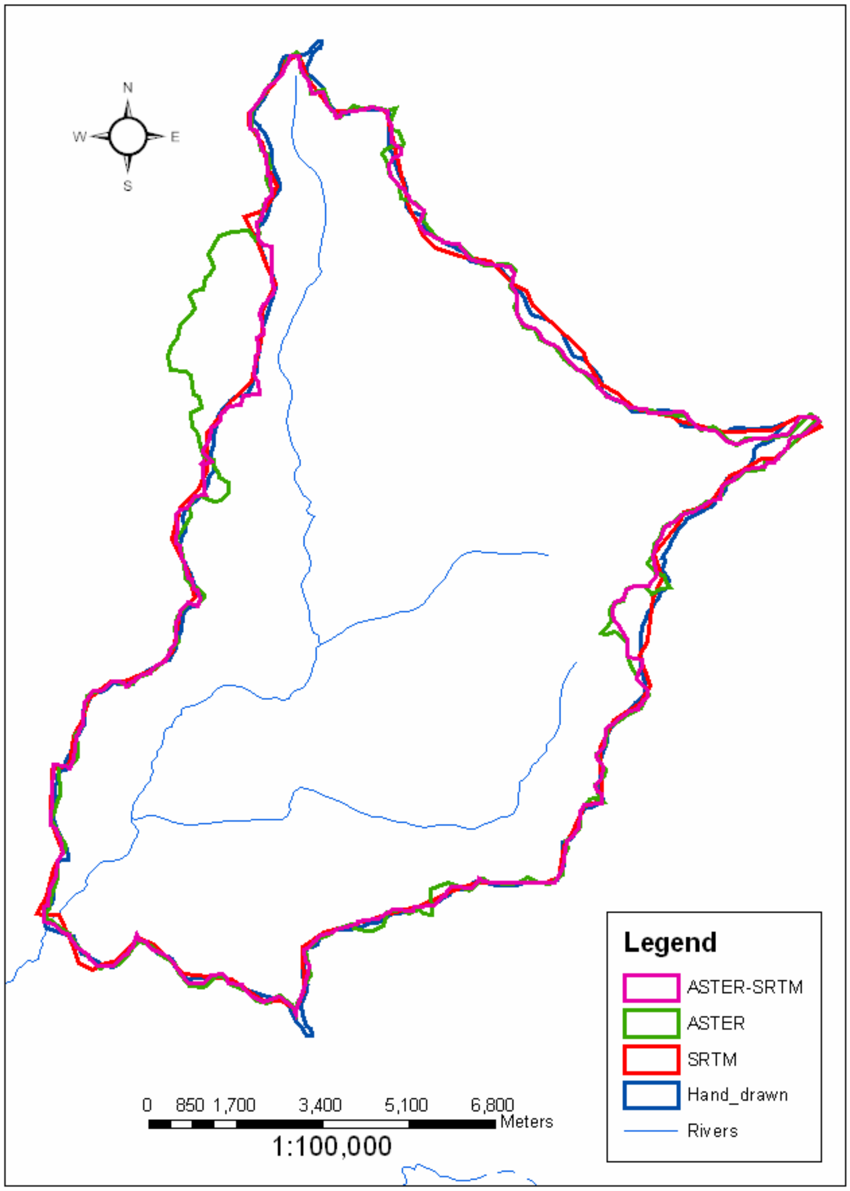

Figure 5. Illamanga Sub watershed boundaries comparison including the fourth boundary.

Once the ASTER DEM is corrected the Arc GIS Watershed Delineator draw the boundary through the right place, with almost no difference with the SRTM and also with the Hand-drawn Boundaries. On the other hand, it is really interesting that the corrected DEM still have a difference on the right side segment, this place is even harder to define in a topo map, an ALOS satellite image it has been proceeded to define this segment.

Conclusions

The methodology described in this paper allows evaluate watershed delineation on DEMs of different source. The accuracy of the watershed delineation it is highly dependant on the accuracy and good quality of the Digital Elevation Model available (DEM).

ASTER data have several advantages, including low cost, 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 a 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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