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Comparability Studies of High and Low Resolution Digital Elevation Models for Watershed Delineation in the Tropics: Case of Densu River Basin of Ghana

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The Densu River Basin is one of the most important basins in Ghana acting as a source of potable water and habitat for vital aquatic species. In order to understand the basin's characteristics and eventually plan and monitor water resources, reliable watershed's properties are important. GIS methods have proven to provide more reliable methods for watershed delineation compared to traditional techniques. In answer to this, this study employed the use of both high and low resolution Digital Elevation Models (DEMs) from ASTER and Shuttle Radar Topography Mission (SRTM) respectively to delineate the watershed of the Densu River Basin. This is because *Advanced Spaceborne Thermal Emission and Reflection* (ASTER) 30m DEM and SRTM 90m DEM are freely available globally. The results indicated that both DEMs have a good representation of the watershed of the Densu River Basin. The coarser resolution, SRTM, produce a better closeness in terms of watershed area and representation compared to the ASTER. For sensitivity modelling such as flood forecasting, on the contrary, ASTER is apparently better as a result of high accuracy in the estimation of the longest flow length of the river. This study hopes to contribute towards the application of the methods used in this research for other basins in Ghana and other parts in the West Africa sub-region which do not have accurate watersheds for water resources planning and management.

Keywords: reliability, watershed delineation, ASTER, SRTM, DEM, tropics, Densu River Basin

Introduction

Topography is an important land-surface characteristic that affects most aspects of the water balance in a catchment, including the generation of surface and sub-surface flow, the flow paths followed by water as it moves downhill slopes. The advents of remote sensing and Geographic Information Systems (GIS) have resulted in the availability of Digital Elevation Models (DEMs). DEMs are the digital representation of the natural topography as well as man-made features on the surface of the earth. This has improved the face of hydrological modelling and water resources management over the last few decades (Moore et al., 1991). Hydrological modelling is fast growing as a result of the growing technological advancement and excellent computer computation speed and reliability. Modelling in hydrology typically involves the investigation of landscape and hydrological features such as terrain slope, drainage networks, and watershed boundaries. Traditionally, these features were determined from topographic maps, field surveys and sometimes photographic processing and interpretation. These traditional techniques are tedious, time consuming and prone to errors.

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Nowadays, GIS technology is being used exhaustively to overcome the challenges in spatially and temporally varying data to successfully model different hydrologic phenomena for different watersheds. Though, there are widely available hydrologic models for different applications, the accuracy of the results of these models is still a difficult subject under continuous research (Tsihrintzis & Hamid, 1997).

The fundamental modelling unit in hydrology is watershed level and recent modelling approaches have further emphasized this need (Zhang and Savenije, 2005). It is common practice therefore to perform automatic delineation of watersheds using GIS software and available satellite data such as DEM. This is because the DEM has been found to efficiently represent ground surface and allow automated extraction of hydrological features, thus bringing advantages in terms of processing efficiency, cost effectiveness, and accuracy assessment, compared with traditional methods based on topographic maps, field surveys, or photographic interpretations (Bolch et al., 2005). A DEM provides the most convenient way of extracting topographic information such as watershed properties (DeVantier et al., 1993). Modelling at watershed basis has been the solid foundation for most outstanding modelling tools in the past two decades (Arnold & Fohrer, 2005, Singh, 1995). The two most widely free and

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globally available DEM are the Shuttle Radar Topography Mission (SRTM) and the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER). The SRTM mission in February 2000 approximately covered 80% of the earth surface using methods of radar-interferometry. The Shuttle Radar Topography Mission DEM with a resolution of 3" (approximately 90m) are available globally. On the other hand, ASTER is a high spatial resolution and currently provides 30m resolution DEM free of charge globally (Bolch et al., 2005). After the 1980s, there has been considerable efforts by hydrologists to increase the accuracy and reliability of DEMs (Sui and Maggio, 1999). Regardless of these efforts, it is apparently not clear as to which terrain model or DEMs are most suitable for watershed of particular size, study area or climate zone (Leitão, 2010). Several literatures have attempted to derive spatial indices and compared stream network and watershed areas of different resolution DEMs. It is generally asserted that high resolution DEMs provide detailed terrain and hydrological features compared to coarse resolution. This research hopes to further investigate and assert by comparing the readily available DEM sources – ASTER and SRTM.

It is generally argued that high resolution DEMs are better for delineation of watersheds since they provide denser stream networks (Bolch et al., 2005). However, the validity of this statement is subject to further verification under different reliefs. In most instances, the quality of DEM is judged by the root mean square (RMS) as in some researches (Wise, 2000). However, the complex nature of hydrology introduces several broad factors and hence it is probably inaccurate to ascertain the quality of the DEM especially in watershed delineation. The introduction of atmospheric conditions during the acquisition of satellite data could pose some errors in the correct estimation of elevations (Rahman and Dedieu, 1994).

The availability of high quality resolution DEMs is increasing, just as private, free and open source GIS software are also available. For instance, NASA provides globally free 30m ASTER DEM to the public. Software packages for hydrological and water resource simulation models provide tools for managing and manipulating the associated satellite data and interpretation are also common (Hughes & Forsyth, 2006). The use and the development of free and open source GIS software have evolved over the last several years and promises a brighter future for hydro-informatics and hydrological modelling (Chen et al., 2010). This is partly because free and open source GIS software have almost level up to the computation time and accuracy as in functionality, data acceptability and user friendliness. Another reason is that it allows the increased participation from local communities to use, modify and in event supports the creation and sharing of local knowledge (Wilson et al., 2000). ILWIS Open which is a GIS and Earth Observation based software capable of watershed delineation is used for this case study.

In order to contribute to the growing interest of which DEM to use in hydrological modelling, this research compares the reliability of ASTER and SRTM DEM for the Densu River Basin of Ghana. The main objective of this research was to determine which resolution size would be most appropriate for watershed delineation in the tropics. It was also to evaluate the use of the D-8 algorithm in watershed delineation. In order to achieve this, the paper compares watershed delineation created by ASTER and SRTM DEMs for the same study area and the same outlet location.

The Study Area

The Densu River Basin stretches from latitude 50 30′ N to 60 20′ N and longitude 00 10′ W to 00 35′ W. It shares boundaries with the Odaw and Volta basins to the east and north respectively, the Birim basin in the northwest and the Ayensu and Okrudu in the west. The Densu River is one of the coastal river systems that take their source from the Atewa-Atwiredu range of hills in the East Akim District of the Eastern Region. It is having a drainage area of about 2,801 km^2 and its main tributaries include the Mame, Kuia, Adaiso, Dobro and Nsaki rivers. From the source at an elevation of about 760 m above sea level, the river flows southeast till it reaches Mangoase where it changes course, and flows southwards into the Weija Lake. The river cuts through the southern reach of the Akwapim-Togo Ranges at Weija, thereby forming a narrow gorge that has facilitated the construction of the Weija dam.

The catchment area includes parts of six (6) districts in the Eastern Region (Akwapim North and South Districts, East and West Akim Districts, Suhum-Kraboa-Coaltar District and the New Juaben District), the Ga District in the Greater Accra Region and Awutu-Efutu-Senya District in the Central Region. The climate of the basin is characterised by a maximum and minimum temperatures of 320C in March/April and 230C in August respectively. The mean annual temperature is about 270C. It also has variations in the duration, intensity and seasonal distribution of rainfall. The basin falls under two distinct climatic zones which are the dry equatorial climate of the south-eastern coastal plains, and the wet semi-equatorial climate further north from the coast. Both climatic zones are characterised by two rainfall regimes with different intensities. The major rainy season extends from April/May to July and attains a peak in June when the maritime instability causes a surge of the moist south-westerly air stream resulting in the intensification of the monsoon rain. The second rainfall period is a minor one that occurs between September and November when several disturbance lines give rise to local thunder activities, especially in the upper and middle belts which are covered with moist semi-deciduous forest. The annual rainfall ranges from 1700 mm in the wet interior to 800 mm in the dry equatorial zone near the coast.

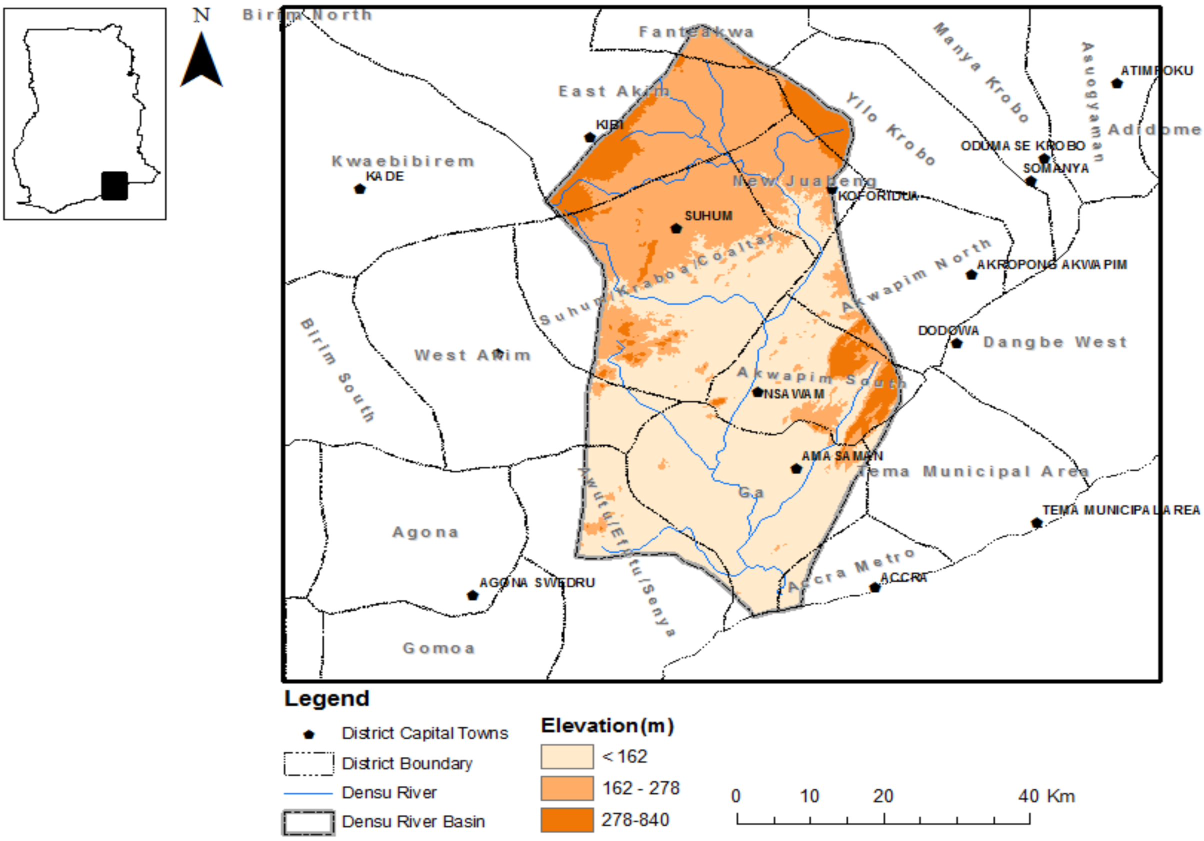

Figure 1: Map showing Densu River Basin

Methodology

Data sources

The main data sources used are the SRTM 90m DEM and the ASTER 30m DEM. Further brief description of the source data is provided below.

SRTM

The SRTM is an international research effort that obtained digital elevation models on a near-global scale from 56° S to 60° N, to generate the most complete high-resolution digital topographic database of Earth prior to the release of the ASTER GDEM in 2009. SRTM consisted of a specially modified radar system that flew on board the Space Shuttle Endeavour during the 11-day STS-99 mission in February 2000, based on the older Space borne Imaging Radar-C/X- band Synthetic Aperture Radar (SIR-C/X-SAR), previously used on the Shuttle in 1994. The spatial resolution is 3 arc-second or about 90mX90m for non-US territory. The elevation value is in the format of the signed 16-bit integer. The data are in raster format and are organized in individual tiles in latitude and longitude. SRTM DEMs are freely available globally(CGIAR-CSI, 2012).

ASTER

ASTER is an imaging instrument flying on Terra, a satellite launched in December 1999 as part of NASA's Earth Observing System (EOS). ASTER is a cooperative effort between NASA, Japan's Ministry of Economy, Trade and Industry (METI) and Japan's Earth Remote Sensing Data Analysis. ASTER has been used to obtain detailed maps of land surface temperature, emissivity, reflectance and elevation. The three EOS platforms are part of

NASA's Science Mission Directorate and the Earth-Sun System, whose goal is to observe, understand, and model the Earth system to discover how it is changing, to better predict change, and to understand the consequences for life on Earth. It provides high-resolution images of the planet Earth in 15 different bands of the electromagnetic spectrum, ranging from visible to thermal infrared light. The resolution of images ranges between 15 to 90 meters. The ASTER GDEM is providing freely available global DEMs at 30m resolution, which is currently the highest freely available resolution DEM (USGS, 2012).

Approach

The general approach adopted according to the processing steps in ILWIS is shown in Figure 2.

- In order to start the delineation process, it is important to clean up the DEM so that local depressions (sinks) are removed from the DEM. The Fill Sink is applied such that any pixel with a smaller height value than all of its 8 neighbouring pixels or vice versa; and any group of adjacent pixels have smaller height values than all pixels that surround such a depression or versa is removed

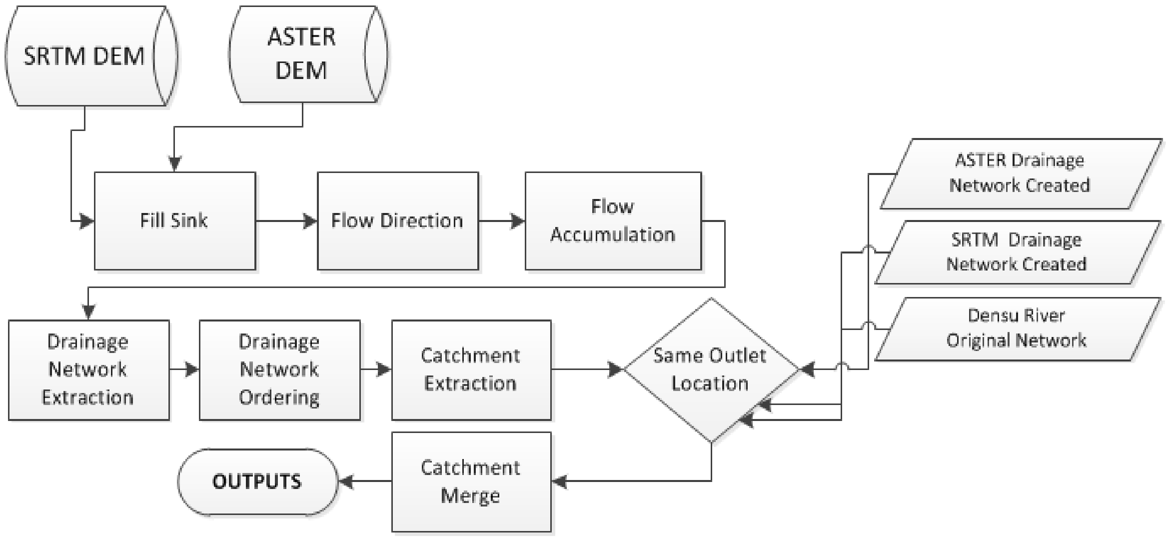

Figure 2. General processing steps in ILWIS for watershed delineation

- ILWIS Open employs the D-8 mechanism for its delineation process. After the fill sink operation, the Flow Direction was then applied. The Flow direction was calculated for every central pixel of input blocks of 3 by 3 pixels, each time comparing the value of the central pixel with the value of its 8 neighbours. The output map contained flow directions as N (to the North), NE (to the North East), etc.
- The Flow accumulation operation performed a cumulative count of the number of pixels that naturally drain into outlets. This operation could be used to find the drainage pattern of a terrain.
- The flow direction and flow accumulation maps became an important input maps for the final watershed extraction processes. Other intermediary steps such as Catchment network extraction, catchment network ordering and catchment extraction were further performed. These processes were iterative (*one complete step was an input for next step*).
- The last most important step for this research was the Catchment Merge operation. The purpose of this operation was to extract the watershed for the area of interest or study. The derived watershed for each of the SRTM and ASTER was determined as in:
- Physical Characteristics: This was the comparison of areas, longest flow path and overland flow path length of the SRTM and ASTER derived watersheds to original Densu river basin's characteristics. The % error was then calculated for each of the cases as:

$\%Error = \left(\frac{P_i - P}{P_o}\right) X100$ Where,

P_i denotes the *watershed area* and *longest flow path* under consideration and P_o denotes the original derived watershed properties of the Densu River Basin. The parameter area, longest flow path and overland flow length were considered the most important concern because of their practical relevance towards hydrological modelling. For instance, the estimation of time of concentration is based on the longest flow length and watershed area. In view of this, it was assumed that the DEM ability to determine these parameters accurately typically meant that the DEM was appropriate and suitable for watershed delineation under the area in question.

Results and Discussion

The networks derived from ASTER, SRTM and the original watershed were compared to give an overview of the performance of the different methods (Figure 3 & Table 1). It was observed that derived stream network from ASTER gave a denser network compared to the SRTM and this was consistent with the fact that the resolution of ASTER used is finer than that of the SRTM. Table 1 provides information on the stream orders extracted using ASTER and the SRTM DEMs. It can be observed that the drainage vector file provided by ASTER has 5th Strahler order and 398th order for Shreve ordered streams while SRTM has a 4th Strahler order and 80th order for Shreve streams. ASTER therefore gives a denser network as compared to the SRTM. This has also confirmed the fact that the resolution of ASTER used is finer than that of the SRTM. The spatial description of the watersheds extracted by both data sources closely represented that of the original see Figure 3.

The original watershed of the Densu River Basin show indication of watershed, which was derived for purposes of some particular engineering project. It is practically impossible to have straight ends in a watershed particularly for the region under consideration which is characterized by sharply changing elevation. The SRTM data gave a better approximation of the watershed area of the basin with an error of (6.26%).

For special hydrological modelling where forecasting based on the longest river path are important, the ASTER data gives a better approximation. However, both give an error less 1% indicating good performance from both datasets.

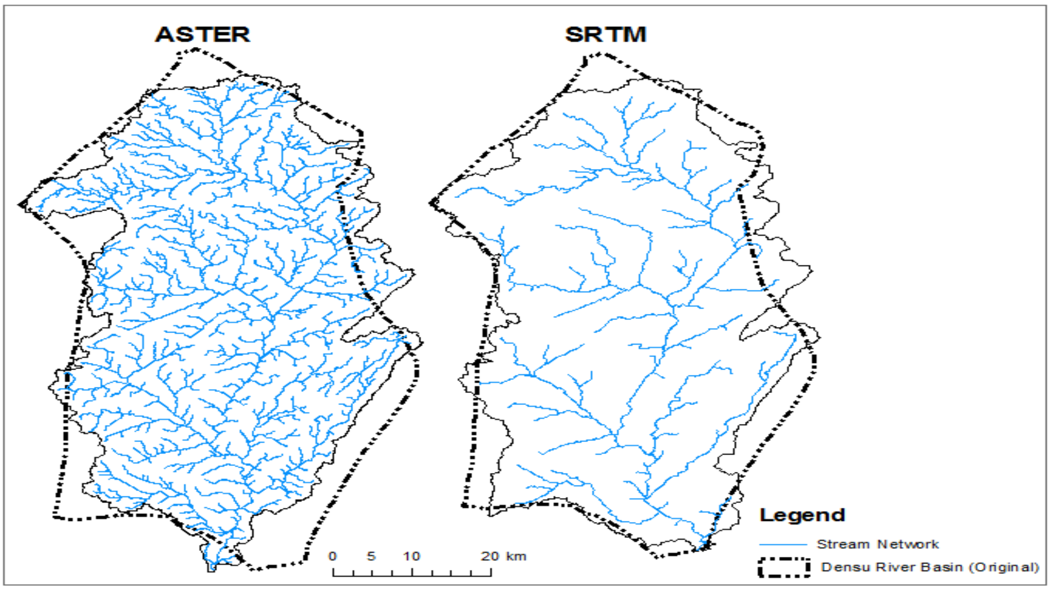

Figure 3. Comparison of watersheds of ASTER & SRTM for the Densu River Basin

Table 1. Physical parameters

Data Source	Longest drainage length (km)	Stream Order Count (Strahler & Shreve ordering)	Parameter				
			Watershed Area (m^2)	Longest Flow Path (m)	Drainage density/km^2	Error (%)	
						Watershed Area (m^2)	Longest Flow Path (m)
ASTER	1802.69	5^{th} , 398^{th}	2,472,422,524.36	139,493.98	729.12	11.75	0.08
SRTM	737.30	4^{th} , 80^{th}	2,626,023,623.77	140,876.52	280.77	6.26	0.91
Original	-	-	2,801,518,758.75	139,605.07	-	-	-

These results compliment previous research that SRTM data though of a coarser resolution than ASTER, performs equally well with watershed delineation for the Densu River Basin (Bolch et al., 2005). In this study, there were not really vast differences between the data sources as to watershed delineation. Therefore, depending on the kind of project under consideration, either SRTM or ASTER is preferable.

Conclusion

The availability of free global DEMs with good resolution proves a way out for obtaining retrieval watershed properties for important basins in Ghana. The study explored the feasibility of using ASTER and SRTM to delineate the watershed properties of the Densu River Basin. This basin is an important water resource for the southern part of Ghana. The delineated ASTER and SRTM were compared with existing old watershed created from topographic maps. The results indicated that both ASTER and SRTM DEMs are suitable for watershed delineation for the Densu River Basin.

The SRTM DEM provided a more precise estimation of the watershed area compared to the ASTER DEM. In estimation of the longest flow path length (important for flood forecasting), the ASTER DEM gave a very high precision. Regardless, both DEMs provided an error of less than 1%. It was found that both data sources are appropriate for undertaken similar studies in the Densu River Basin and similar other basins in Ghana and sub-region. The watersheds created showed a more realistic natural representation compared to the original watershed. In future studies, it is recommended to use the SRTM's watershed created in the study as underlying standard.

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