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Research Paper

Evaluation of automatic drainage extraction thresholds using ASTER GDEM and Cartosat-1 DEM: A case study from basaltic terrain of Central India

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ABSTRACT

In the study, the digital elevation models from ASTER GDEM and Cartosat-1 of 30 m resolution were used to evaluate the thresholds in automatic extraction of stream network at six thresholds of 0.05 km^2, 0.125 km^2, 0.25 km^2, 0.50 km^2, 1.0 km^2 and 2.0 km^2 in Neri watershed in basaltic terrain of Central India. At stream thresholds of 0.05 km^2, Cartosat-1 DEM shows higher channel initiation points (150) than ASTER (127). As we increase the stream thresholds from 0.05 km^2 to 2.0 km^2, the channel initiation points are consistently decreased in two input DEMs. The correlation coefficient R^2 between the drainage area thresholds and stream length for ASTER and Cartosat-1 DEM shows 0.94 and 0.92, respectively. The comparative evaluation of morphometric indices shows that threshold of 0.05 km^2 is found to be optimum to obtain the finer drainage networks particularly from Cartosat-1 DEM, when compare to the ASTER GDEM of same resolution.

1. Introduction

Accurate delineation of drainage networks is a prerequisite for many natural resource management issues (Paik, 2008; Liu and Zhang, 2011). Digital Elevation Model (DEM) refers to a quantitative model of a part of the earth's surface in digital form (Burrough and McDonnell, 1998). Several radar satellite based DEMs like Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) 30 m and Cartosat-1 DEM 30 m are available for the public. The availability of satellite based new topographic datasets have opened a new venues for hydrologic and geomorphologic studies including analysis of surface morphology (Staley et al., 2006; Frankel and Dolan, 2007; Patel et al., 2016) and channel network structure (Lashermes et al., 2007). The important application that has been widely used in surface hydrology modeling is the automatic extraction of the channel drainage network. Due to the increasing availability of grid DEMs, numerous research studies have been carried out to automate the extraction of drainage networks (Montgomerym and Dietrichm, 1989, 1992; Laurel and Souza, 2002; Maathuis and Wang, 2006; Maathuis, 2006; Moore et al., 1991; Tribe, 1992; Bertolo, 2000; Sameena et al., 2009; Pareta and Pareta, 2011; Singh et al., 2014; Reddy et al., 2004a, b; Sahu et al., 2016). A variety of methods have been developed to process raster DEMs automatically to extract drainage networks and measure their properties (O'Callaghan and Mark, 1984; Tarboton et al., 1991; Martz and Garbrecht, 1999; Al-Fugara et al., 2016). In any method of extracting drainage networks from DEMs is to specify a critical support area that defines the minimum drainage area required to initiate a channel. (Band, 1989; Tarboton et al., 1988; Gardener et al., 1991). The most commonly used procedures for extracting drainage networks from raster DEMs are based on O'Callaghan and Mark's (1984) algorithm for flow direction determination, coupled with an arbitrary constant value for the minimum contributing area needed to form and maintain a channel. The common problem with drainage network delineation using DEM is the presence of sinks (Nikolakopoulos et al., 2006). The most widespread method for handling depressions is sink filling, up to the level of the sink spill point, combined with routing through the resulting flat area (Fairfield and Leymarie, 1991; Planchon and Darboux, 2001; Wang and Liu, 2006). Improved sink filling methods (Grimaldi et al., 2007; Santini et al., 2009) first fill sinks, and then introduce a gradient to all flat areas to provide non-zero gradients for flow routing. Therefore, the

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sinks in the input datasets have to be removed prior to processing of DEM for drainage identification (Simon et al., 2008).

The quantitative analysis of drainage pattern is one of the important aspects in characterization of watersheds (Strahler, 1964). GIS based methods are being used increasingly to delineate channels automatically for use in hydrologic models. However, care needs to be exercised to ensure that networks are extracted from DEMs at an appropriate scale. Many authors have attempted to analyze the drainage characteristics of the basins using GIS techniques in determining the quantitative description of the basin geometry (Biswas et al., 1999; Reddy et al., 2002, 2004a; Vijith and Satheesh, 2006; Kattimani and Prasad, 2016). In the present study, in order to evaluate the performance of automatic drainage extraction thresholds, drainage network extraction was performed in TNTmips GIS software using ASTER GDEM (30 m) and Cartosat-1 DEM (30 m) at different threshold levels. The extracted drainage from two input DEMs was compared with hydrological and morphometric indices (Wen et al., 2006), which includes the relationship between thresholds, drainage characteristics and stream networking statistics (Strahler, 1964). We also examined the qualitative and quantitative comparison of the automatically extracted drainage from ASTER GDEM and Cartosat-1 DEMs to assess the influence of different thresholds.

2. Study area

The Neri watershed on basaltic terrain located in Nagpur district of Maharashtra, Central India and lies between 21°03′05″ and 21°07′24″ north latitudes and 78°48′33″ and 78°53′02″ east longitudes covering an area of about 3196.22 ha (Fig. 1). The elevation is ranging from 250 to 408 meters above mean sea level (MSL). The climate is warm sub-humid with mean annual rainfall of 1120 mm of which about 89% is received during the south-west monsoon (June to October). Geologically the area is covered by basaltic lava flow of Lower Eocene to Upper Cretaceous, commonly known as "Traps". The dentritic drainage pattern has been observed in the upper reaches, whereas in the lower reaches parallel to sub parallel drainage pattern has been observed. The study area has an undulating topography with landforms typical of a basaltic terrain. The slope of the study area ranges from level to nearly level (0–1%) in the flood plains to steep slopes (>30%) mainly along the scarp slopes. The soils in the watershed area ranges from very shallow (10-25 cm) in the upper reaches to deep (100–150 cm) mainly in flood plains and broad valley floor. Clay loam and clayey textured soils have been noticed in the upper and lower reaches, respectively. Study area is predominantly under well drained soils, however, excessively drained soils are associated with the scarp slopes (Anon., 1990). The study area is mainly under rainfed condition with cotton-fallow and cotton/pigeonpea-fallow as main land use systems.

3. Material and methods

3.1. Processing of ASTER 30 m GDEM

The freely available ASTER 30 m GDEM (version 2) of one arc-second (arcsec) grid was downloaded for the study area in GeoTIFF format with geographic lat/long coordinates (USGS, 2012). The ASTER sensor on board of the Terra spacecraft (launched in 1999) has an along-track stereoscopic capability due to a nadir-and 27.6° backward-looking telescope in the Near Infrared (NIR) spectral band. This instrumental setup allows for photogrammetric DEM generation with vertical accuracies of ±15–30 m (Toutin, 2008). The most important specifications of the ASTER stereo subsystem that govern the DEM generation capabilities include: stereo geometry; platform altitude of 705 km and base to height ratio of 0.6 (Abrams, 2000). ASTER DEM standard data products are produced with 30 m postings, and have Z accuracies generally between 10 m and 25 m root mean square error (RMSE). The GDEM is provided at a one arc sec resolution (30 m) and referenced to World Geodetic System (WGS) 1984. With reference to GDEM1, the improvements in GDEM2 include increased horizontal and vertical accuracy, as compared to both GPS benchmarks and standard DEMs, and improved horizontal accuracy and resolution (Dave, 2011). Downloaded ASTER GDEM 30 m data was reprojected to Universal Transverse Mercator (UTM) projection with zone 44 and clipped to the extent of the study area to extract various drainage properties at given thresholds.

3.2. Processing of Cartosat-1 (30m) DEM

The freely available resampled Cartosat-1 DEM of 1 arc-sec. i.e. 30 m resolution at equator, generated by sub sampling the original 1/3 arc-sec data was downloaded in *.tiff* format (http://bhuvannoeda.nrsc.gov.in/download/download/download.php, 2016). The Cartosat-1 has a pair of Panchromatic cameras having an along track stereoscopic capability using its near-nadir viewing and forward viewing telescopes to acquire stereo image data with a base-to-height ratio of about 0.63. The spatial resolution is 2.5 m in the horizontal plane giving a swath of about 27 km. The methodology adopted to produce the Cartosat-1 DEM involved stereo-strip triangulation of 500 km strip stereo pairs using high precise ground control points, interactive cloud masking, automatic dense conjugate pair generation using matching approach (Kääb, 2002). Seamless homogeneous Cartosat-1 DEM is produced by TIN modeling of irregular DEM, interpolation for regular DEM generation and automatic strip to strip mosaicing. The primary output unit is a tile of $7.5' \times 7.5'$ extents with DEM spacing of 1/3 arc-sec, and co-registered ortho-image of resolution 1/12 arc-sec. Statistically, Cartosat-1 DEM is meeting the specification of vertical accuracy i.e. 8 m at 90% confidence (Radhika et al., 2007; Van Zyl, 2001). The processed Cartosat-1 DEM of 30 m resolution was clipped to the study area in order to extract various drainage properties at given thresholds. Before processing, it was ensured that the two input DEMs are errors free like removal of data voids, which could normally found in DEMs. Besides, the remotely sensed DEMs, the topographic data on 1:50,000 scale of the study area has been used as reference data.

3.3. Automated detection of drainage network at different thresholds

With increasing computer capability and availability of DEMs in public domain enable the researchers to extract drainage networks from DEMs through computer programs (Lashermes et al., 2007). But, the suitable drainage network extraction depends primarily on the accuracy of the DEM and the channel initiation identification. The more accurate the channel initiation points provided, the more suitable the drainage network generated (Wen et al., 2006). We used ASTER GDEM 30 m and Cartosat-1 DEM 30 m datasets and followed different drainage area thresholds ie., 0.05 km^2, 0.125 km^2, 0.25 km^2, 0.50 km^2 1.0 km^2 and 2.0 km^2 to determine the number of upstream elements. Watershed process tools in TNTmips software (ver. 7.7) (TNTmips, 2012) were used to extract drainage channels at different thresholds. In the study, the Tarboton et al. (1989) method was used to remove all sinks in the input datasets. Then, 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 Watershed process tools in TNTmips create a series of temporary vector and raster objects that present different aspects of the results. In order to generate flow paths, the Watershed pro-

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