Geoscience Frontiers 5 (2014) 893–909

Contents lists available at ScienceDirect

China University of Geosciences (Beijing)

Geoscience Frontiers

journal homepage: www.elsevier.com/locate/gsf

Research paper

Sensitivity of digital elevation models: The scenario from two tropical mountain river basins of the Western Ghats, India

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ARTICLE INFO

Article history:
Received 18 March 2013
Received in revised form
18 October 2013
Accepted 16 December 2013
Available online 11 January 2014

Keywords:
DEM
ASTER
SRTM
GMTED
Tropical mountain river basins
Western Ghats

ABSTRACT

The paper evaluates sensitivity of various spaceborne digital elevation models (DEMs), viz., Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), Shuttle Radar Topography Mapping Mission (SRTM) and Global Multi-resolution Terrain Elevation Data 2010 (GMTED), in comparison with the DEM (TOPO) derived from contour data of 20 m interval of Survey of India topographic sheets of 1: 50,000 scale. Several topographic attributes, such as elevation (above mean sea level), relative relief, slope, aspect, curvature, slope-length and -steepness (LS) factor, terrain ruggedness index (TRI), topographic wetness index (TWI), hypsometric integral (I_{hyp}) and drainage network attributes (stream number and stream length) of two tropical mountain river basins, viz., Muthirapuzha River Basin and Pambar River Basin are compared to evaluate the variations. Though the basins are comparable in extent, they differ in respect of terrain characteristics and climate. The results suggest that ASTER and SRTM provide equally reliable representation of topography portrayed by TOPO and the topographic attributes extracted from the spaceborne DEMs are in agreement with those derived from TOPO. Despite the coarser resolution, SRTM shows relatively higher vertical accuracy (RMSE = 23 and 20 m respectively in MRB and PRB) compared to ASTER (RMSE = 33 and 24 m) and GMTED (RMSE = 59 and 48 m). Vertical accuracy of all the spaceborne DEMs is influenced by relief of the terrain as well as type of vegetation. Further, GMTED shows significant deviation for most of the attributes, indicating its inability for mountain-river-basin-scale studies.

1. Introduction

On catchment scale, topography has a dominant control on hydrology and influences spatial distribution of various environmental factors, such as climate (Singh et al., 1995; Singh and Kumar, 1997; Bennie et al., 2008), soil formation (Jenny, 1941; Amundsen et al., 1994), soil moisture patterns (e.g., Western et al., 1999), soil properties (Chen et al., 1997; Johnson et al., 2000; Seibert et al., 2007) and even biodiversity (Florinsky and Kuryakova, 1996; Renfrew and Ribic, 2002; Zinko et al., 2005). For decades, topographic maps of varying scales have been used for the estimation of topographic attributes as well as in delineation of stream networks (Chapman, 1952; Pike and Wilson, 1971; Zevenbergen and Thorne, 1987), which is labor-intensive, expensive and time-consuming. Application of remote sensing and Geographic Information System (GIS) in earth-environmental-sciences and the developments in digital terrain analysis underscore digital elevation model (DEM) as an important component of hydrologic as well as geomorphologic research (e.g., Moore et al., 1992; Tarboton et al., 1992). Significant advances in remote sensing technology since its inception more than 50 years ago (Miller and Laflamme, 1958) have led to higher quality DEMs being generated by different techniques (contour-derived-, photogrammetric-, LIDAR- and RADAR-DEMs). Even though DEMs of differing spatial resolutions are freely

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Peer-review under responsibility of China University of Geosciences (Beijing)

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http://dx.doi.org/10.1016/j.gsf.2013.12.008

available (e.g., data of Advanced Spaceborne Thermal Emission and Reflection Radiometer, ASTER; Shuttle Radar Topography Mapping Mission, SRTM; Global Multi-resolution Terrain Elevation Data 2010, GMTED), choosing an appropriate data type for specific purposes still remains an enigma in geomorphologic and hydrologic applications (de Vente et al., 2009).

It is obvious that DEM errors adversely affect the accuracy and thereby modeling of natural processes (Lopez, 1997; Florinsky, 1998a). In addition, Vaze et al. (2010) demonstrated that the accuracy and resolution of the input DEM have serious implications on the hydrologically important spatial indices derived from the DEM. Hence, access of better quality input data is a major factor determining the successful application of environmental models at regional scale (Renschler and Harbor, 2002; Merritt et al., 2003). However, the only information regarding any global DEM provided is the global estimate of root mean square error (RMSE) and thus DEM accuracy at specific location needs to be estimated by the user. Several factors, such as source of data including collection techniques, location and density of samples, methods used for generation of DEM, spatial resolution and topographic complexity of the landscape affect the accuracy of DEM (Florinsky, 1998a; Thompson et al., 2001; Chaplot et al., 2006). Aguilar et al. (2005) suggested terrain morphology as the most important factor (compared to sampling density and interpolation techniques) determining the DEM accuracy. Compared to flatter terrains, mountainous topography has larger DEM errors contributed by terrain complexity, dense-vegetation-canopy and snow cover (Rodriguez et al., 2005; Nelson et al., 2009). However, recently, several researchers (e.g., Kervyn et al., 2008; Sharma et al., 2010; Prasannakumar et al., 2011; Darnell et al., 2012; Kia et al., 2012; Suwandana et al., 2012; Yamazaki et al., 2012; Zani et al., 2012; Elmahdy and Mostafa Mohamed, 2013) illustrated the expediency of spaceborne DEMs in geomorphometric and hydrologic applications in tropical environments.

In the regional context, Prasannakumar et al. (2011) demonstrated the suitability of SRTM data for geomorphometric analysis in parts of the Western Ghats, a prominent high-elevation passive margin with a well-defined escarpment extending for about 1500 km in NNW–SSE direction, parallel to the west coast of India (Ollier, 1990; Gunnell and Radhakrishna, 2001). Recently, Kale and Shejwalkar (2007, 2008), Magesh et al. (2011, 2013), Jayappa et al. (2012), Thomas et al. (2012) and Shinde et al. (2013) also employed either SRTM or ASTER data for various geomorphometric applications in various river basins draining the Western Ghats. However, hardly any attempt has been made to evaluate the accuracy and applicability of various spaceborne DEMs for geomorphometric and hydrologic applications in the tropical mountainous regions of the southern Western Ghats. Hence, this study is an outcome of comparing the sensitivity of various topographic attributes derived from different spaceborne DEMs (ASTER, SRTM and GMTED) with DEM generated from topographic contours (TOPO) of Survey of India (SoI) toposheets of 1:50,000 scale. In this study, we examine the DEMs to identify the most suitable DEM that can be used for geomorphometric and hydrologic applications in tropical mountainous terrain of the southern Western Ghats.

2. Study region

Two mountain river basins, viz., Muthirapuzha River Basin (MRB; area = 271.75 km^2, a sub-basin of west-flowing Periyar river) and Pambar River Basin (PRB; area = 288.53 km^2, a sub-basin of east-flowing Cauvery river) in the Anaimalai-Cardamom Hills of the southern Western Ghats have been selected for the investigation (Fig. 1). The basins are a part of the Precambrian high-grade Southern Granulite Terrain of the Peninsular India and the main rock types are hornblende-biotite-gneiss and granitoids. The drainage system of both MRB and PRB is influenced by the Munnar plateau (an extensive planation surface of late Paleocene age), and highest elevated surface (i.e., 1400 m above mean sea level, msl) in the southern Western Ghats (Soman, 2002). Thomas et al. (2010, 2011, 2012) emphasized the substantial influence of Munnar plateau in the development of the drainage characteristics of the basins. Several local planation surfaces (600–2200 m above msl) and terrain with concordant summits (2200–2400 m above msl) also characterize the region (Thomas et al., 2012). The basin elevation of MRB varies between 2690 (i.e., Anai Mudi, the tallest peak south of the Himalayas) and 760 m above msl, while that of PRB ranges from 2540 to 440 m above msl.

Even though tropical monsoon is the principal contributor of rainfall in the region, a distinguishable difference in climate exists between the basins due to distinctive terrain settings (Thomas, 2012). MRB is located on the western slopes of the southern Western Ghats and hence tropical humid climate (mean annual rainfall = 3700 mm, mean annual temperature = 17 °C), whereas PRB is on the eastern leeward slopes (and therefore rain shadow region with tropical semi-arid climate; mean annual rainfall = 1100 mm, mean annual temperature = 26 °C). MRB is covered by several natural vegetation belts including southern montane wet temperate grasslands, southern montane wet temperate forests (shola), west coast tropical evergreen forests and southern sub-tropical hill forests, while dominant vegetation types in PRB include southern montane wet temperate grasslands, southern montane wet temperate forests, southern tropical thorn forests, southern dry mixed deciduous forests and southern moist mixed deciduous forests. Tea and Eucalyptus plantations are common in both the basins.

3. DEM acquisition, characteristics and processing

This study makes use of four DEMs (of varying spatial resolution), viz., TOPO (derived from SoI toposheets), ASTER (http://earthexplorer.usgs.gov), SRTM (http://glcf.umiacs.umd.edu) and GMTED (http://eros.usgs.gov) to compare the topographic attributes for geomorphometric and hydrologic analyses as well as for landform characterization. In order to compare the applicability of the spaceborne DEMs, TOPO is taken as the reference DEM.

3.1. TOPO

The SoI topographic sheets (1: 50,000 scale) have been scanned with 750 dpi in TIFF format and georeferenced to real map coordinate system. Contours (of 20 m interval) as well as spot heights from topographic maps are vectorized in ArcGIS 9.3. To ensure data quality of the digital contour data, topology is created and various topology errors are corrected. The digitally captured contour elevation data is then converted to TOPO (with a spatial resolution of 20 m) using spatial analyst extension for ArcGIS 9.3 (Reuter and Nelson, 2009).

3.2. ASTER

The ASTER is an advanced multispectral imaging system of varying spatial resolution (15–90 m). ASTER consists of three different subsystems: the visible and near infrared (VNIR), the shortwave infrared (SWIR) and the thermal infrared (TIR), where VNIR (viz., Band 3-Nadir looking and Band 3-Backward looking; 0.76–0.86 μm) is the only one that provides stereo capability. ASTER relative DEM data has a horizontal accuracy of ±15 m and better and a vertical accuracy of ±15–25 m, depending on the environmental setting of the region. In an in-depth review, Toutin