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ORIGINAL ARTICLE

Terrain characterization of small island using publicly available data and open- source software: a case study of Marinduque, Philippines

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Abstract Digital terrain attributes derived from digital elevation model (DEM) such as elevation, slope, and aspect are widely used to determine the influence of topography on different environmental and human processes. The advent of publicly available DEM data has provided a cheaper, low-cost alternative to traditional field data collection and survey. Handling, processing, and visualization of such data on an open-source software will provide researchers and specialists a better and faster way of generating digital terrain maps and creating input data for other analyses. This paper demonstrates the methodology of combining the use ASTER GDEM and SAGA functionality of QGIS, and R software to develop terrain maps for Marinduque, an island province of the Philippines.

Keywords Terrain mapping · Open-source · ASTER GDEM · QGIS · R software · Marinduque · Philippines

Introduction

Digital terrain analysis

According to Hutchinson and Gallant (2000) terrain plays an important role in regulating earth surface and atmospheric process. Understanding the nature of terrain can provide knowledge on nature and magnitude of these processes through topographic analysis and visualization (Wilson 2012). Digital terrain analysis (DTA) is the science of quantitative land-surface analysis that deals with the collection, analysis, evaluation, and interpretation of geographical information of terrain's natural and artificial features (Zhou and Zhu 2013). The analysis involves derivation of terrain attributes from digital elevation data (Wilson 2012; Zhou and Zhu 2013). Common terrain attributes include elevation, slope, aspect, profile curvature, and topographic wetness index (Kemp et al. 2008; Wilson 2012; Zhang et al. 2012; Pakoksung and Takagi 2015). These terrain attributes are used to describe the morphology of the landscape and predict the effect of the terrain on environmental or human processes (Zhou and Zhu 2013). According to Behrens et al. (2010) terrain attributes are widely used for digital soil mapping because relief is an important factor in soil formation. Bajat et al. (2011) showed how environmental factors (including elevation and slope) affect population change in Southern Serbia. Dragićević et al. (2015) provided a review on how elevation, aspect, slope, and other topographic index influence occurrence of landslide. Significance of different terrain attributes are discussed in details elsewhere (i.e., Wilson 2012).

Digital elevation model

A typical input data for DTA is the Digital Elevation Model (DEM) (Qiming et al. 2008; Wilson 2012; Cheng et al. 2012). According to Li et al. (2005), there are three ways to acquire data for DTA: (1) field surveying or direct measurement of terrain surface using total station and global positioning system (GPS); (2) cartographic digitization of existing topographic maps; and (3) use of stereo pairs of aerial (or space) images and photogrammetric instruments. Examples of space images derived DEM

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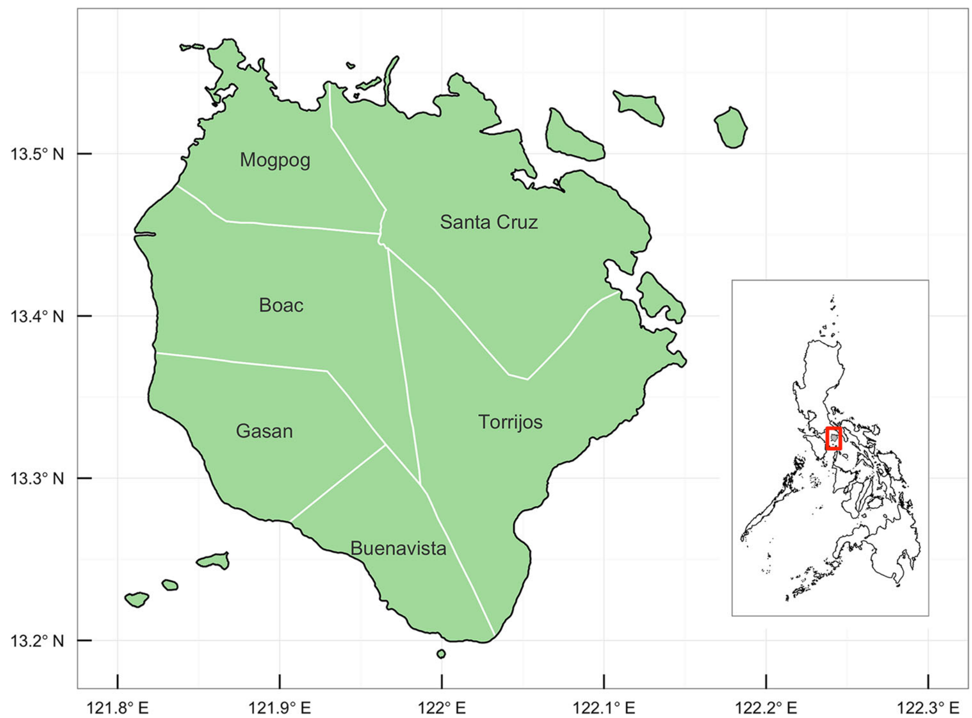

Fig. 1 Location map of Marinduque, Philippines

Table 1 Population and land area of six municipalities of Marinduque, Philippines (Data Source: NSCB 2015)

Municipality	Population (as of 2010)	Area (hectares)
Boac (Capital)	52,892	21,270
Buenavista	23,111	8,125
Gasan	33,402	10,088
Mogpog	33,384	10,806
Sta. Cruz	55,673	27,077
Torrijos	15,833	17,892

include the shuttle radar topography mission (SRTM) (Farr et al. 2007) and advanced spaceborne thermal emission and reflection radiometer (ASTER) global digital elevation model (GDEM) (Abrams et al. 2015).

ASTER GDEM

According to Abrams et al. (Abrams et al. 2015), ASTER GDEM is the most up-to-date, complete, and high spatial resolution (30 m), digital topographic data set of the Earth

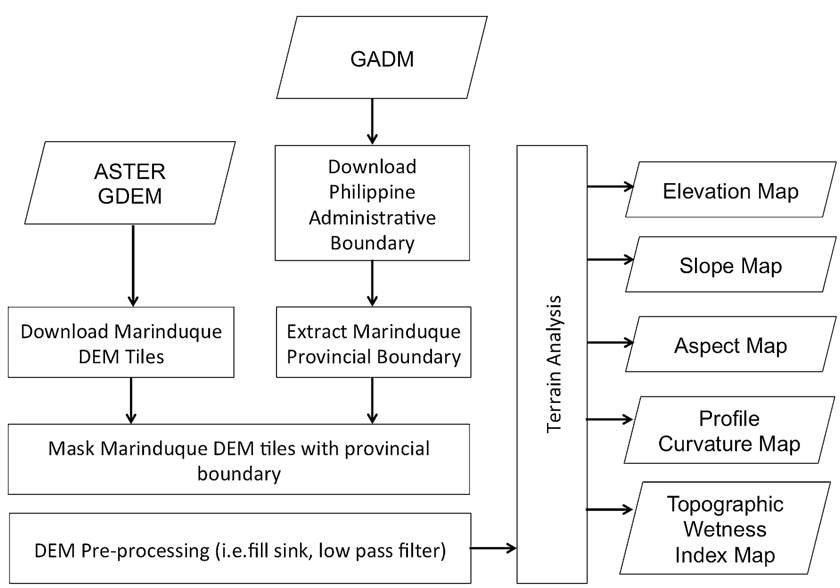

Fig. 2 Terrain mapping workflow

freely available (at no cost) to the public (Abrams et al. 2015). It is one of the many products of ASTER, a joint project between U.S. National Aeronautics and Space Administration (NASA) and Japan's Ministry of Economy, Trade, and Industry (METI). Operating on NASA's terra satellite, ASTER has been acquiring data (since March 2000) to produce other products such as the ASTER Emissivity Database (ASTER GED), the ASTER Global Urban Area Map (AGURAM), the ASTER Volcano Archive (AVA), ASTER Geoscience, and the Global Ice Monitoring from Space (GLIMS) (Abrams et al. 2015). Before the release of ASTER GDEM, SRTM was the most complete DEM data available to the public (Abrams et al. 2015). Several researches have utilized ASTER GDEM. Phillips et al. 2011 used terrain characteristic derived from ASTER GDEM along with WorldView imagery and fuzzy logic to model distribution of moulins in Sermeq Avannarleq in West Greenland. Gichamo et al. (2012) extract cross section of Tisza River in Hungary from ASTER GDEM. Kassab et al. (2013) combine ASTER GDEM with other remote sensing products to produce glacial geomorphological map of the Dalijia Shan region in the northeastern Tibetan Plateau. Sar et al. (2015) use ASTER GDEM along with other geospatial data to map the risk of water-logging disaster in Keleghai river basin, India. Recently, Mokarram and Hojati (2015) suggested that ASTER DEM is superior over areal photographs in delineating drainage network.

Quantum GIS

Quantum GIS (QGIS) (http://www.qgis.org/en/site/index.html) is a free, open-source, and user friendly GIS software

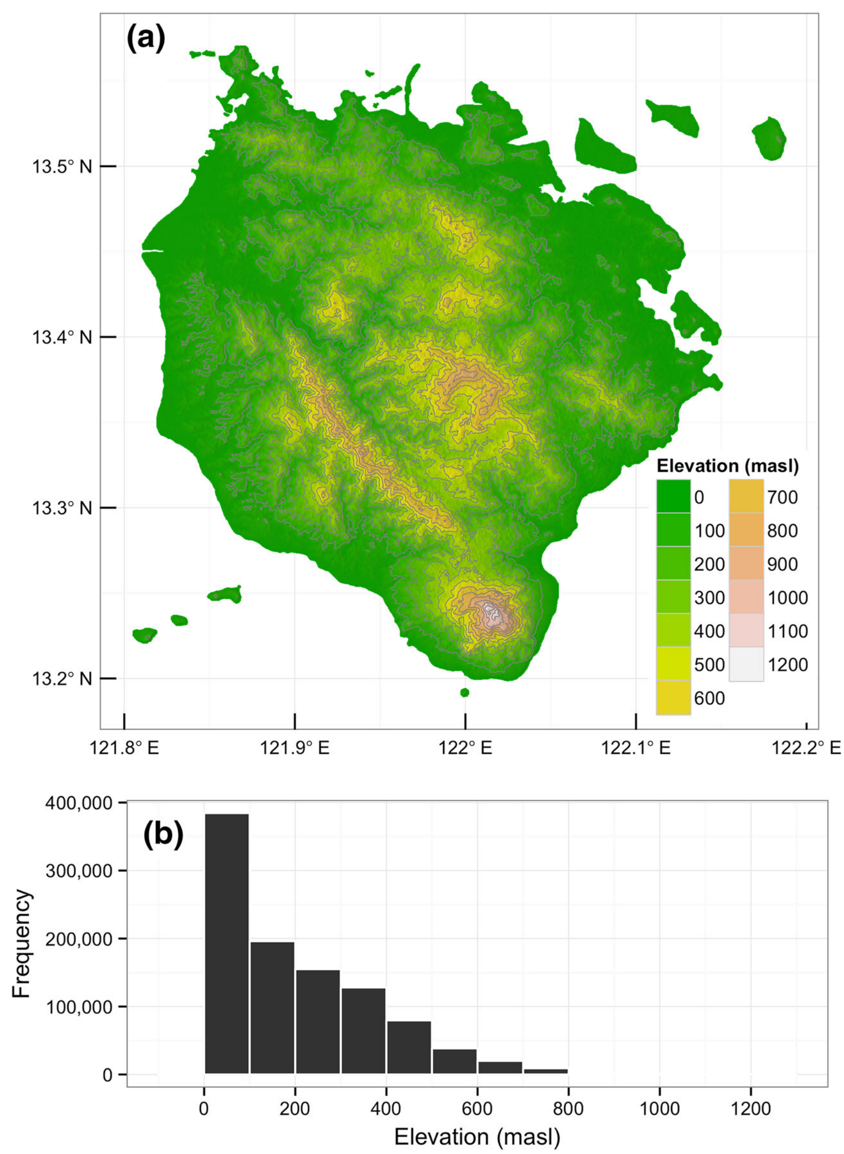

Fig. 3 Elevation **a** map and **b** distribution of elevation across Marinduque Province

licensed under the GNU General Public License (http://www.gnu.org/licenses/gpl-3.0.en.html) (Hugentobler 2008). The software is written C++ and based on C++ cross platform library enabling it to run on different operating systems such as Linux, Unix, Mac OS X and Windows (Hugentobler 2008). In addition, QGIS has a suite of terrain analysis functions from geographic resources analysis support system (GRASS) (Neteler and Mitasova 2008; Neteler et al. 2012) and system for automated geoscientific analyses (SAGA) GIS (Conrad et al. 2015). Furthermore, QGIS provides has a plug-in mechanism, which enables researchers and developers to extend the software functionality (Hugentobler 2008). Several researchers have adopted the use of QGIS on their study. Mantovani et al. (2010) combined QGIS with WebGIS to develop landslide geomorphological maps for the Olvera area in Cadiz, Spain. Yu et al. (2015) integrate QGIS with bayesian maximum entropy (BME) to map particulate matter concentration across Taiwan. Landuyt et al. (2015) mapped ecosystem services in Grote Nete basin in Belgium using QGIS.

R software

The R software is a free statistical computing and graphics environment that runs on wide variety of UNIX platforms, Windows and MacOS (Ihaka and Gentleman 1996; R Core Team 2014). Aside from statistical computing, R also has a large number of contributed packages or libraries for handling, analyzing, and visualizing spatial data (Bivand et al. 2013). Packages such *sp* (Bivand et al. 2013), *rgdal* (Bivand et al. 2014), *maptools* (Bivand and Lewin-Koh 2014), and *raster* (Hijmans 2014) are the common R packages used to handle spatial data.

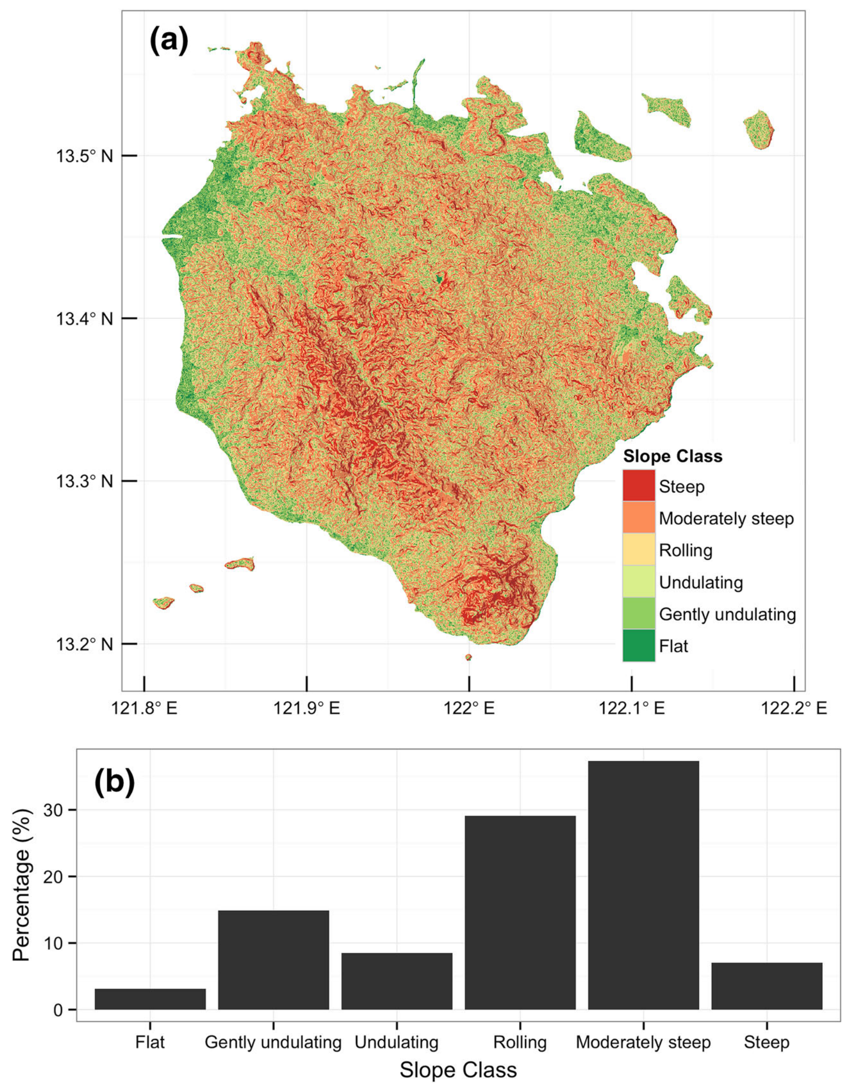

Fig. 4 Slope **a** map and **b** distribution of different slope class across Marinduque Province

Marinduque Island

Marinduque is an island province of the Philippines situated around 200 km south of the country's capital (Manila) (Fig. 1). It is considered the heart of the Philippine archipelago because of its geometric shape and location (Salvacion and Magcale-Macandog 2015). There are six municipalities that consist the province covering around 96,000 hectares of land (Table 1).

Methodology

Data

Provincial boundary map of Marinduque was downloaded from Global Administrative Areas (www.gadm.org) through the *getData* function of the *raster* (Hijmans 2014) package in R. The GADM is a spatial database of the world's administrative areas, which include countries and lower subdivisions such as provinces, departments, bibhag, bundeslander, daerah istimewa, fivondronana, krong, landsvæðun, opština, sous-préfectures, counties, and thana (GADM 2015). Digital elevation data of Marinduque was downloaded from ASTER GDEM website (http://gdem.ersdac.jspacesystems.or.jp/).

Processing and analysis

The DEM data of Marinduque was downloaded manually from ASTER webpage while its provincial boundary was extracted from Philippine provincial administrative boundary downloaded from GADM website. Then, the DEM data was subjected to pre-processing (i.e., low-pass filter and pit-removal) prior to terrain analysis to remove any artifacts and depressions from the data. Next, different terrain (i.e., slope,

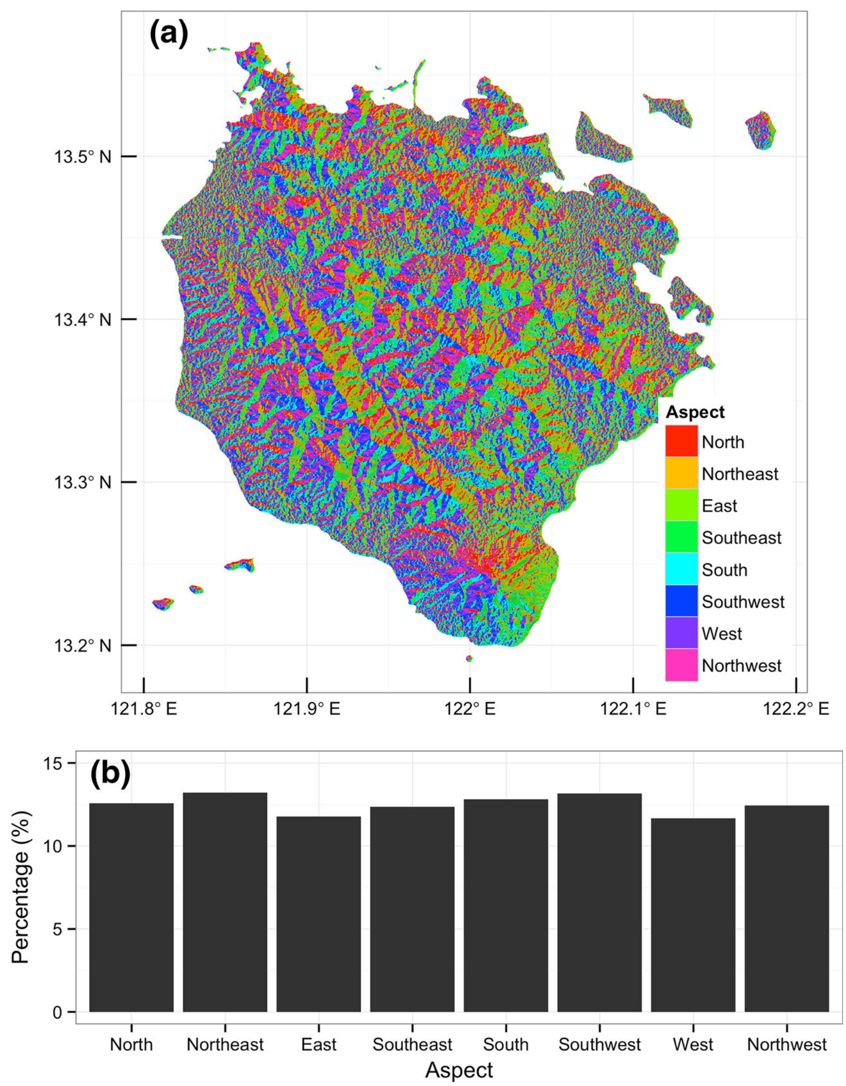

Fig. 5 Aspect **a** map and **b** distribution of different aspect class across Marinduque Province

aspect, profile curvature, and topographic wetness index) characteristics were calculated from the processed DEM in QGIS. Figure 2 shows the schematic diagram used for terrain analysis. Further data analysis and visualization were using R (Ihaka and Gentleman 1996; R Core Team 2014) environment using the *ggplot* (Wickham 2009) and *RColorBrewer* (Neuwirth 2014) package.

Results and discussion

Elevation of the province ranges from 0 to 1187 m above sea level (masl) with an average elevation of 204 masl. Elevation map (Fig. 3a) of the province showed high elevation regions on its inner portion and low-lying areas on its outer part. Histogram of the elevation (Fig. 3b) reveals that majority of the island (93 %) is below 500 masl. Elevation information about an area is very important because of the altitudinal effect on precipitation and temperature, at higher elevation rainfall amount is higher while temperature is lower (Ishida and Kawashima 1993; Basist et al. 1994; Diaz and Bradley 1997; Sevruk 1997; Brunsdon et al. 2001; Qing et al. 2011). In addition, based on the study of Dragićević et al. (2015), risk of landslide susceptibility increases within the range of 250–750 masl. In terms of slope, the province is dominated by rolling to moderately steep (approximately 66 %) slopes (Fig. 4a), which is distributed all over the area (Fig. 4b). Data on slope of an area is an indication of its vulnerability to different geohazards such as landslide and erosion, the steeper the area the higher is its risk (Balasubramani et al. 2015; Biswas and Pani 2015; Dutta et al. 2015; Pal 2015; Shit et al. 2015a, b; Dragićević et al. 2015; Chen et al. 2016). In fact, slope information is among the major input for different geohazard models (Lamelas et al. 2009; Cheng et al. 2013; Chen et al. 2016). On the other hand, aside

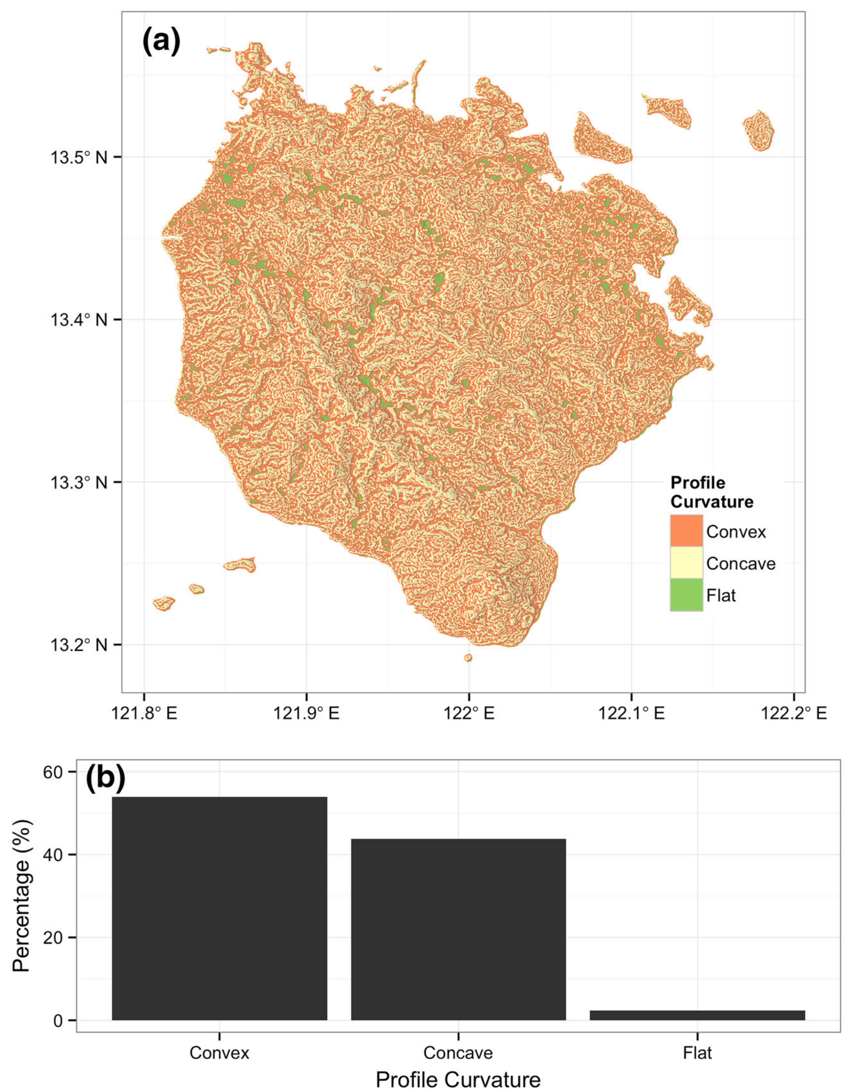

Fig. 6 Profile curvature **a** map and **b** distribution of different curvature class across Marinduque Province

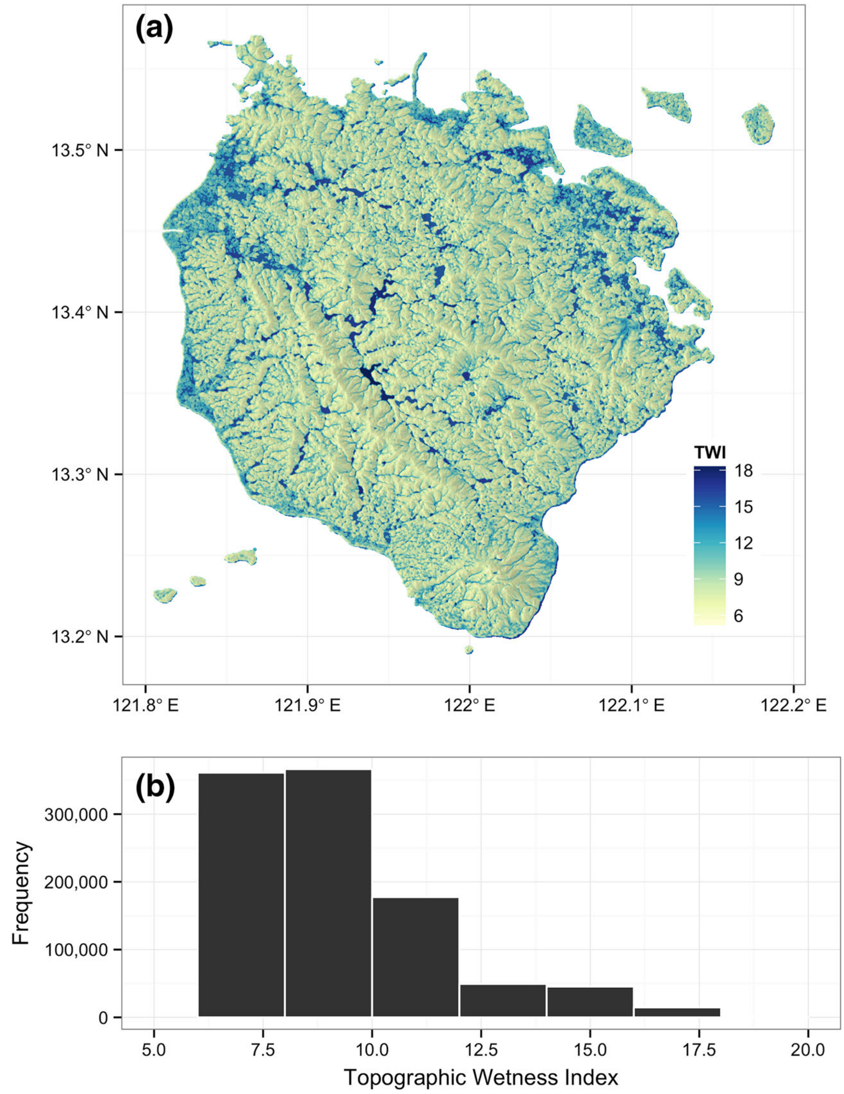

Fig. 7 Topographic wetness index **a** map and **b** distribution of topographic wetness across Marinduque Province

from slope angle, slope length and orientation (aspect) (Balasubramani et al. 2015; Biswas and Pani 2015; Dutta et al. 2015; Shit et al. 2015a; Xing et al. 2016). No distinct aspect class dominates the entire province. Based on the aspect map (Fig. 5a), the different aspect classes are distributed across the province (5b). According to Guan et al. (2013) aspect (slope orientation) is an important factor influencing solar radiation and air temperature of an area, a west-facing slope tends to have higher daily maximum temperature tan east-facing slope because daily maximum temperature occurs in the afternoon when the sun is in the west. Profile curvature map (Fig. 6a) of the province showed that the province is dominated by convex and concave profile (Fig. 6b). Profile curvature influence the velocity of flowing water in a surface affecting erosion and deposition (Alkhasawneh et al. 2013). Erosions were likely to occur under convex profile or deposition in the case of concave profile (Alkhasawneh et al. 2013). In terms of topographic wetness (Fig. 7a), low TWI values were calculated for most part of the province (Fig. 7b). The TWI can serve as index for surface saturation zones and spatial distribution of soil water, and quantify effect of topography on runoff (Qin et al. 2009). In the study of Zinko (2004) TWI was found to be positively correlated with ground water depth and soil pH. The use of TWI varies from studying spatial scale effect of hydrological processes, geochemical, and biological processes (Hjerdt et al. 2004; Sørensen et al. 2006; Qin et al. 2009).

Conclusion

This paper demonstrated the use of publicly available DEM data from ASTER GDEM using open-source software (i.e., QGIS and R) for terrain mapping and characterization of a small island. These terrain maps can be used on different scientific application and research within the island (e.g., landform characterization, landslide mapping, etc.). In addition, the methodology from this paper can be replicated to other places or studies that require terrain information as inputs or reference data on their analysis.

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