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Integrating historical topographic maps and SRTM data to derive the bathymetry of a tropical reservoir

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SUMMARY

This paper proposes a fast and inexpensive method for estimating the bathymetry of hydroelectric reservoirs. Brazil has more than 30 large hydroelectric reservoirs with a combined volume exceeding one billion cubic meters. The hydroelectric sector is responsible for 97% of the energy production in Brazil and is the largest hydroelectric park in the world. Among the variables affecting the environmental impacts of reservoirs, depth plays a major role because it influences the aquatic system hydrodynamics. Reservoir depth distribution (i.e., the bathymetry) is also a fundamental factor controlling the physical–chemical and biological properties of the system. However, the acquisition of bathymetric information for the large reservoirs in Brazil is not a simple task because: (1) most of the topographic maps available in the area of the lake have a very small scale (1:100,000 and smaller), (2) larger charts are the property of the hydropower companies and are classified, and (3) the size of the reservoirs prevent the use of bathymetric surveys. The proposed method of integrating historical and Shuttle Radar Topography Mission (SRTM) topographic data allowed for the estimation of the bathymetry of the Itumbiara reservoir with $R^2 = 0.98$ ($n = 100$, $\rho = 0.00$) and RMSE = 3.78 m. For researchers who need a rapid and simple method to develop bathymetric maps of hydroelectric reservoirs, the proposed method can provide a simple and fast alternative to more data intensive methods.

1. Introduction

The World Commission on Dams (WCD) states that up to 60% of the 227 largest rivers in the world are fragmented by dams, deviated or canalized, causing effects on inland water ecosystems and their surroundings (WCD, 2000). According to Baxter (1977), the environmental impacts caused by dammed rivers are associated with their size, volume, time of residence and geographical localization. The main effects include flooding of agricultural areas, alteration of fish migration, loss of aquatic flora and fauna, change of hydrological regime, sediment yielding, dissemination of disease vectors, loss of historical and cultural sites, negative social effects and changes in local economical activities. Bathymetry is one of the key parameters in characterizing and understanding many processes in aquatic systems.

Bathymetry is a necessary input parameter in many studies and is important for determining sediment deposition through time (Rowan et al., 1995; Gaytán et al., 2008), water quality modeling (Tufford and McKellar, 1999), circulation and thermal structure modeling (Beletsky and Schwab, 2001), modeling of macrophyte distribution (Lehmann, 1998), fish ecology (Jepsen et al., 1999), management (Awulachew, 2006), embankments dams (Charles, 2009), and others.

Moreover, the bathymetry inventory of reservoirs is often determined by echo sounders and is based on the time passed between sending pulses and the reception of these pulses after their reflection from the bottom of reservoir (Barbosa et al., 2006). Measuring the bottom depth conventionally is often an expensive procedure and is also time consuming (Wilcox and Huertos, 2005; Merwade, 2009). Some authors have developed methods based on remote sensing to map the bottom depth (Lafon et al., 2002; Krug and Noernberg, 2007; Brando et al., 2009) and volume (Gupta and Banerji, 1985), with relatively high success in shallow water bodies and low turbidity. However, an extensive sampling delineation is required to validate the developed models when using this method. Therefore, if the use of low precision topographic charts from the period previous to reservoir filling can be combined with Shuttle Radar Topography Mission (SRTM) data to obtain a bathymetric map that can be used to plan echo-bathymetric missions,

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this may reduce both the cost and time of data acquisition and processing. Thus, the objective of this work was to develop an inexpensive method to map the bottom depth of a tropical hydroelectric reservoir.

1.1. Study area and background

The Itumbiara hydroelectric reservoir (18°25′S, 49°06′W) is located on a tropical grassland savanna between Minas Gerais and Goiás States (central Brazil). The reservoir was formed by damming the Parnaiba River. This resulted in the backwards flood of its main tributaries, the Araguari River and Corumbá River. The basin geomorphology resulted in a lake with a dentritic pattern covering an area of approximately 814 km^2 and volume of 17.03×10^9 m^3 (Fig. 1).

The reservoir was built in 1979 and started operating in 1980 (Mello, 1980). Fig. 2a shows the reservoir area before the flooding and Fig. 2b shows the river after flooding. As a result of the flooding, there were environmental, social and economic impacts caused by the dam.

2. Methodological approach

The methodological approach was based on the integration of historical and satellite derived topographic data to estimate the depths within the reservoir.

2.1. Cartographic data

A topographic map from 1979 at the scale of 1:250,000 with contour lines spaced every 50 m was used (DSG, 1979). This map was created before reservoir construction and allowed an overall understanding of the topography of the area to be submersed by the reservoir.

2.2. Remote sensing data

A Shuttle Radar Topography Mission (SRTM) from 2000, with spatial resolution of 90 m (Farr et al., 2007) and resized to 30 m using the approach proposed by Valeriano et al. (2006), was used

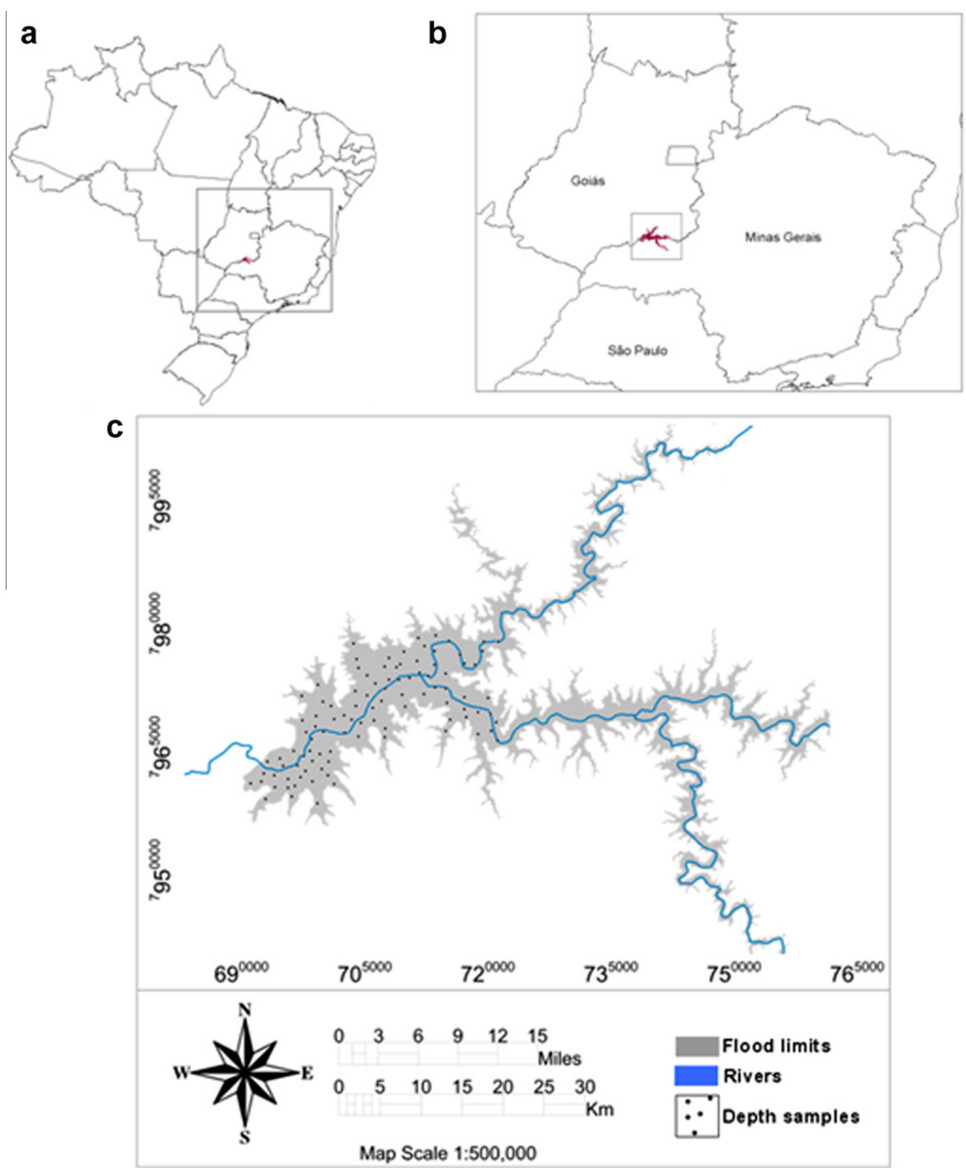

Fig. 1. Location of the Itumbiara hydroelectric reservoir in central Brazil (a), in the context of its surrounding states (b) and on a regional scale (c).