

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

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Abstract

This paper proposes a cheap and fast method for estimating the bathymetry of hydroelectric reservoirs. Brazil has more than 30 large hydroelectric reservoirs with volume exceeding one billion cubic meters. The hydroelectric sector is responsible for 97% of energy generation being the largest hydroelectric park in the world. These dams, however, cause a series of environmental, social and economic impacts, which need to be monitored. Among the variables affecting the environmental impact posed by reservoirs, depth has a key role because it acts on the aquatic system hydrodynamics. Reservoir depth distribution, the bathymetry, is also a fundamental factor controlling physical-chemical and biological properties of the system. In Brazil, the acquisition of bathymetric information for the large reservoirs, however, is not a simple task, because: 1) most of the topographic maps available in the area covered by the lake have very small scale (1:100 000 and smaller); 2) larger charts are property of the hydropower companies and are classified; 3) the size of the reservoirs prevent the use of bathymetric surveys due. The challenge therefore is how to combine the use of low precision topographic charts from the period previous to reservoir filling, SRTM data to obtain a bathymetric map which could be used for planning echo-bathymetric missions so as reducing both cost and time of data acquisition and processing.

Keywords: hydroelectric sector, echo-sounder, geoprocessing, water resources.

Introduction

In accordance to World Commission Dams (WCD, 2000) up to 60% of 227 largest rivers of the world was hard or moderate fragmented by dams, deviated or canalized, causing effects on inland water ecosystems and surroundings.

The environmental impacts caused by dammed rivers (Tundisi, 1994) are associated with their size and volume, time of residence and geographical localization, being the main ones: 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, social effects and on local economical activities. One of key parameter to characterize and understanding a lot of processes in aquatic systems is the bathymetry.

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

Moreover, often the bathymetry inventory of reservoirs is realized by echo-sounders that are based on time pass between sending pulses and the reception of these pulses after their reflection by bottom (Barbosa et al. 2006). The conventional measuring bottom depth is generally a expensive procedure and consuming time. Some authors developed methods based on remote sensing to map the bottom depth (Krug & Noernberg, 2007, Lafon et al. 2002, Brando et al. 2009) with relatively success in shallow water bodies and low turbidity. However, using this type of method an extensive sampling delineation is required to validate the developed models.

Thus, the objective of this work is to develop a cheap method to map the bottom depth of a tropical hydroelectric reservoir.

Study Area and background – The Itumbiara hydroelectric reservoir (18°25'S, 49°06'W) is located on tropical grassland savanna, between Minas Gerais and Goiás States (Brazil's central). The reservoir was formed by damming the Parnaíba River which resulted in the backward flood of its main tributaries, Araguari River and Corumbá. The basin geomorphology resulted in a lake with a dentritic pattern covering an area of approximately 814 Km² and volume of 17.03m³ (Figure 1).

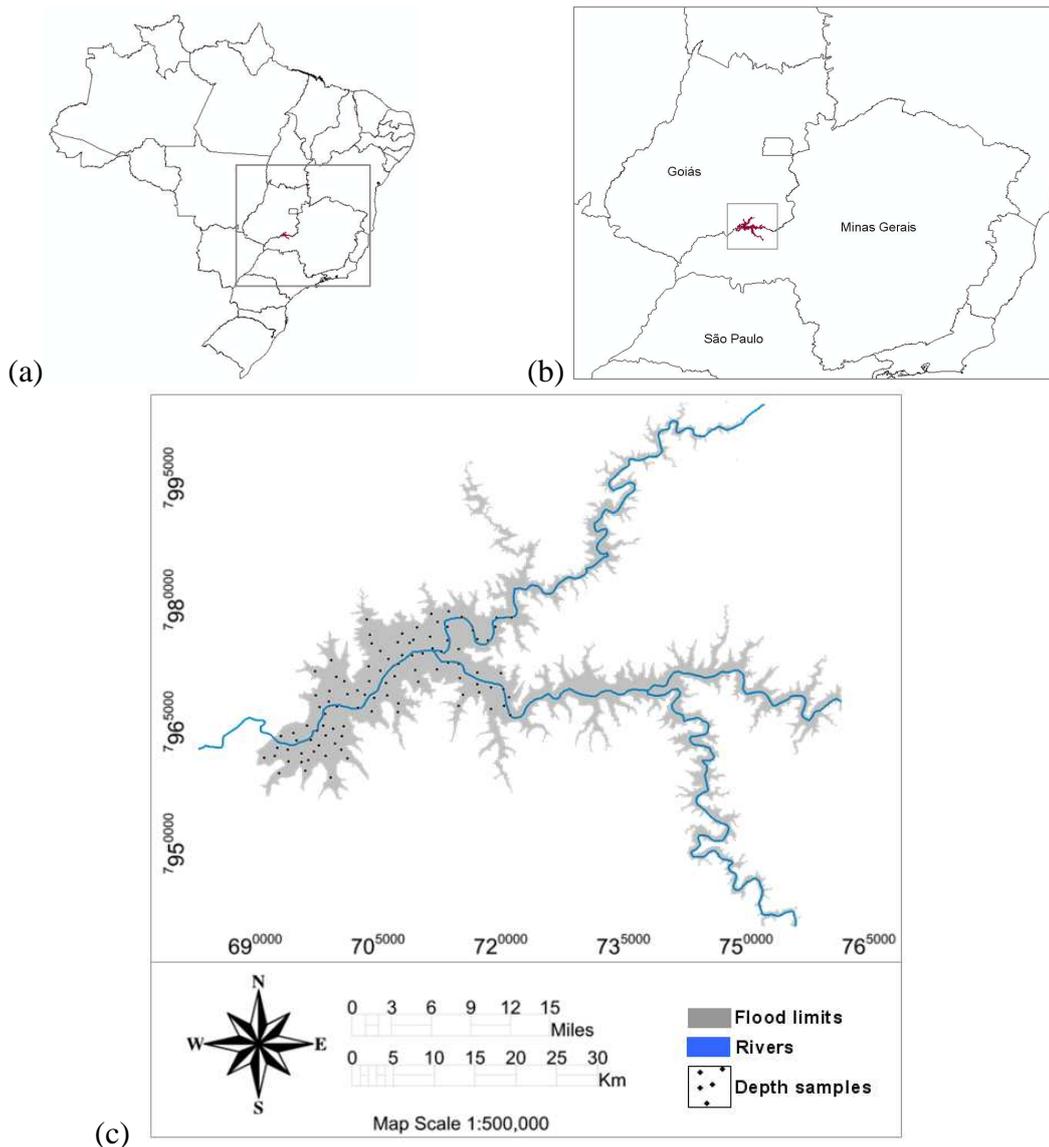


Figure 1: Localization of Itumbiara hydroelectric reservoir on Brazil's central (a), on state context (b) and on regional scale (c).

The reservoir was building in 1979 and starts your operation on 1980 (Mello, 1980). The figure 2 shows the reservoir area before the flooding (Figure 2-a) and after (Figure 2-b). As can be observed in Figure 2 it is easy to imagine the environmental, social and economic impacts caused by the dam.

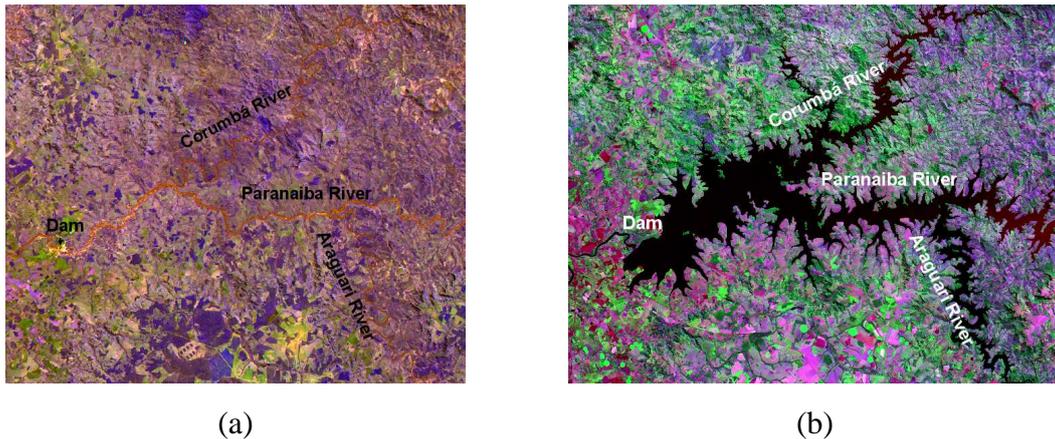


Figure 2: (a) MSS-Landsat-3 imagery from 11-08-1978 show the area before inundation; and (b) TM-Landsat-5 imagery from 26-05-2007 actual period. The figure also shows the position of dam on reservoir.

The following section provides all methodological bases to reach the objective proposed here.

Methodological approach

Cartographic Data – a topographic map from 1979 at the scale of 1:250.000 (SE-22-Z-a) with contour lines spaced every 50 m was used (DSG, 1979). This map was produced before reservoir construction and allows an overall idea of the topography of the area to be submersed. .

Remote Sensing Data – A SRTM (Shuttle Radar Topography Mission) from 2000, with spatial resolution of 90m (Farr et al. 2007) and resized to 30m using the approach proposed by Valeriano et al. (2006) was used to refine the information on the topographic chart. A Landsat-5 TM image from May 26 2007 was also acquired to represent the maximum water level in the Itumbiara reservoir and to define the land/water limit.

Water Level Data – The water level was record from 1993 to 2008 in each hour measured by ‘FUNAS Centrais Elétricas S.A.’ (Figure 3). These data was collected near the dam structure (18°24’22,83’’S, 49°05’48,25’’ W).

Depth Data – A field campaign was carried out using a Lowrance LMS-480 sound from may 11-15 2009 to measure water quality data and depth data in 25 stations in whole reservoir (see Figure 1-c for samples location).

Method

Water Level Dynamics and Water Mask – A monthly mean water level from 2003 to 2008 was used to classify the periods of rising, high, falling and low water regime and the rate of variation ($\frac{dC}{dt}$), see Figure 3. These classifications are in accordance to methodology proposed in Barbosa et al. (2006).

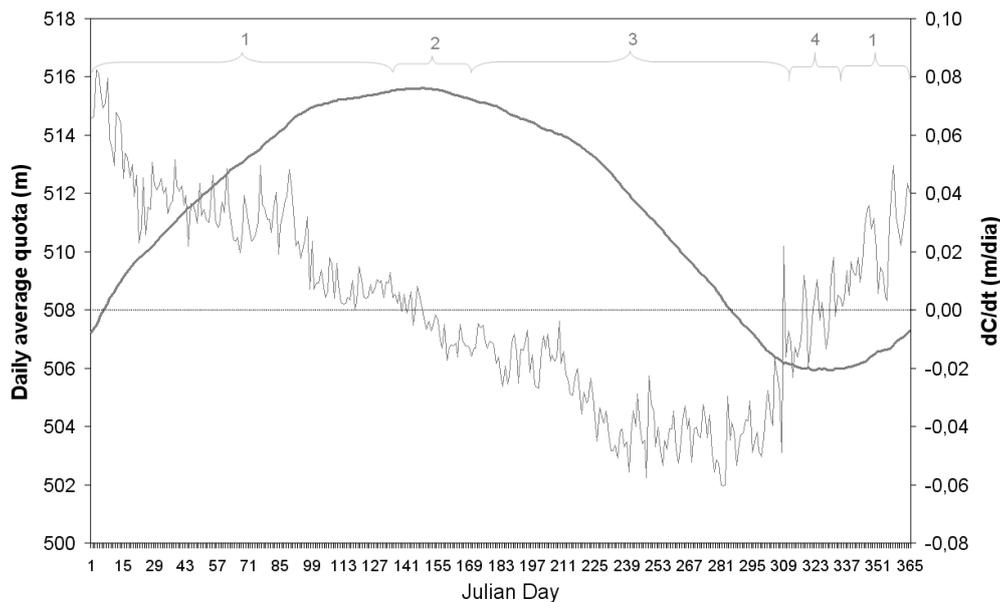


Figure 3: Daily mean variation and rate of water level variation: rising (1), high (2), falling (3) and low water level (4).

According to the water level fluctuation (Figure 3) the best period for carrying out the bathymetry is from April 21 to June 07, because it corresponds to the smallest time change in quota. Based on this the water mask was built using the Landsat-5 TM image acquired May 26 2007 which was the only date available in the period. The mask was built using the NDWI (Normalized Difference Water Index) algorithm proposed by McFeeters (1996).

Estimating the bottom depth – The topographic map from 1979 was digitized (Figure 4-a) using the *Computer-Aided Design* (CAD) software to generate a digital topographic map. The contour curve interval was 50 m providing a very poor display of the terrain (Figure 4-a and b). A SRTM image with contour curve intervals of 20m (Figure 4-c and d) shows the lack of information in the flooded area since it was acquired in 2000. The backscattering from the water surface is almost zero because SRTM sensor operates in bands C and X and is only sensitive to differences in water surface roughness. In the

area surrounding the reservoir, however, SRTM displays a much finer representation of the terrain topography (Figure 4-d) as compared with that displayed by the topographic map (Figure 4-b)

By merging the two data sets, using the SRTM to improve the vertical resolution of the topographic map in the region bordering the reservoir, it was possible to generate a hybrid map with an improved quality. This procedure allowed generating a third contour map (Figure 4-e) and its image (Figure 4-f) with a clear improvement of the vertical resolution and much better display of the terrain even inside the flooded area

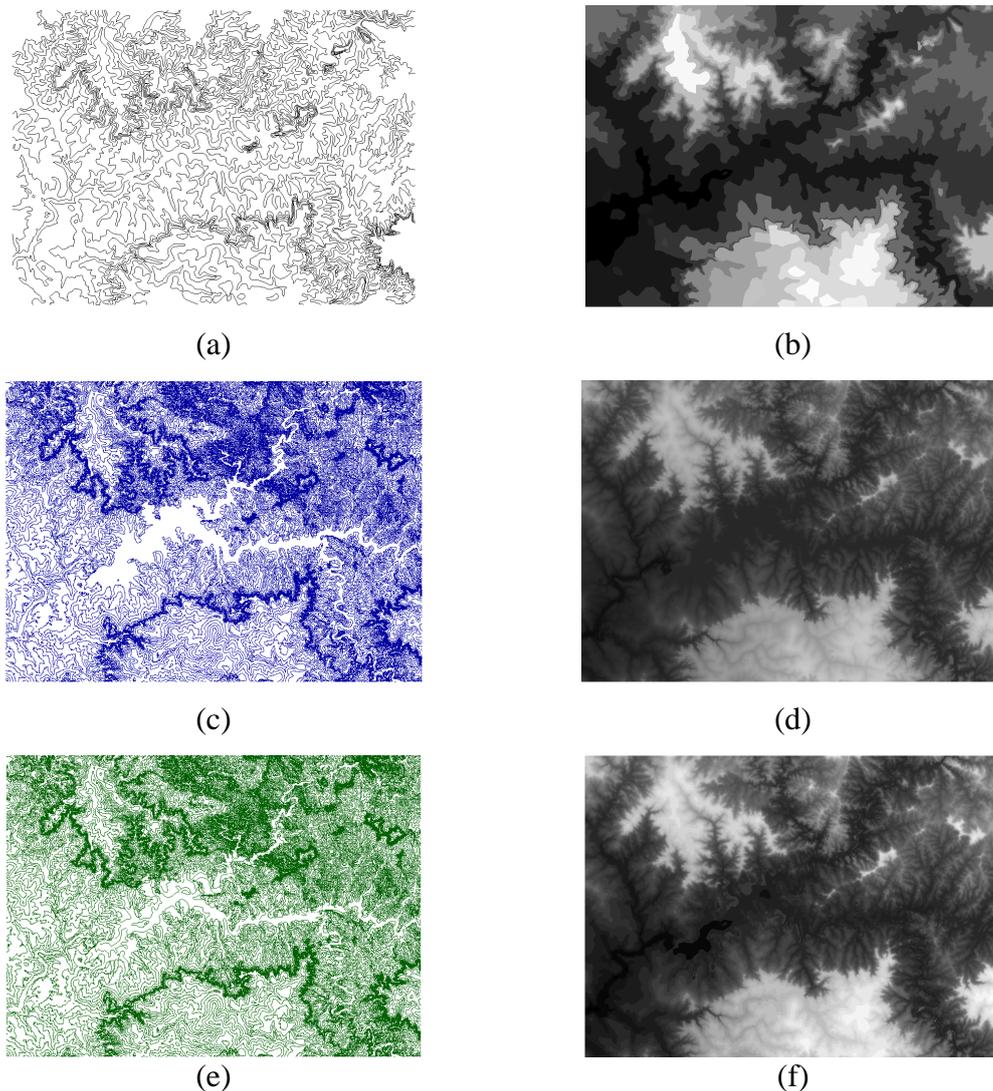


Figure 4: Methodological approach used to enhance the topography map of flooded area of Itumbiara reservoir. (a) Curve levels of 50 m derived from topography map of 1979 and the image (b); (c) curve level of 20 m derived from SRTM from 2000 and their image (d); and the enhanced curve levels (e) and their image (f).

From topography to bathymetry – The hybrid map was then used to transform the enhanced topography map (see Figure 4-f) in bathymetry. This transformation consisted of an operation of pixel subtraction from the known reference water level ($h_w=515m$) for the highest quote (Figure 5).

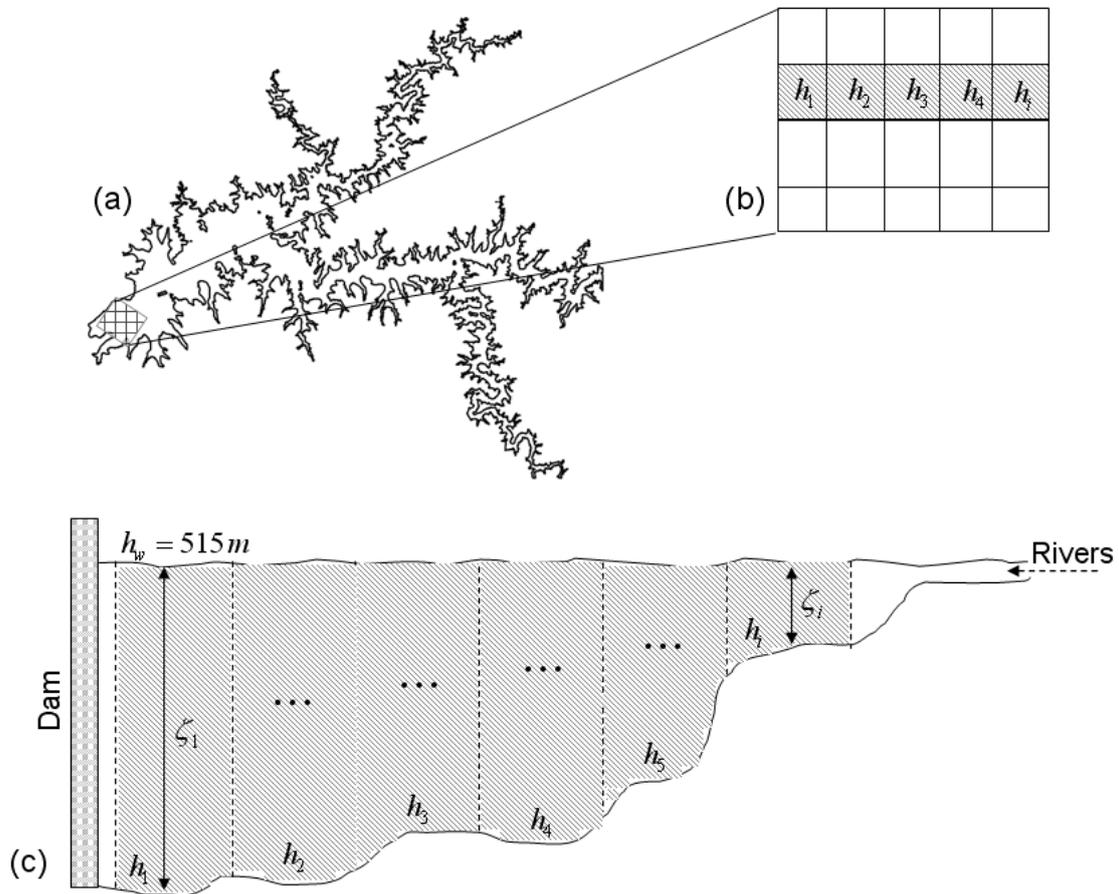


Figure 5: Simplified scheme used to transform the enhanced topography map in bottom depth: (a) water-land limit showing a small test area and (b) the detail of how the topographic level in a small area is organized allowing the transformation of the reference level $h_w = 515m$ differences to topographic height (h_1, h_2, \dots, h_n) for each pixel into depth information.

The equation used in this transformation is:

$$\zeta_i = h_w - h_i \quad (1)$$

Where ζ_i is the bottom depth at the i^{th} pixel of the image (m), h_i is the height in the i^{th} pixel of the image and h_w is a constant equal to the reference level for the highest quota.

Sensitivity analysis of the method – The sensitivity analysis was carried out using 25 depth measurements (see Figure 1-c for sample location) and confronting with the depth estimated by the method at the same geolocation.

Results

Figure 6 shows estimated bottom depths for the entire reservoir. Depths near the dam are approximately 70 m (region 1). This region seems to be the deepest of the reservoir in conjunction with region 2 with 65 m. Both are near the main river (see Figure 1 for location of the rivers before the inundation). The region 3 represents the areas with depth between 25-40 m occurring mainly in the central body of the reservoir. The regions 4 and 5 represent the shallow areas in the first order channels running straight into the reservoir.

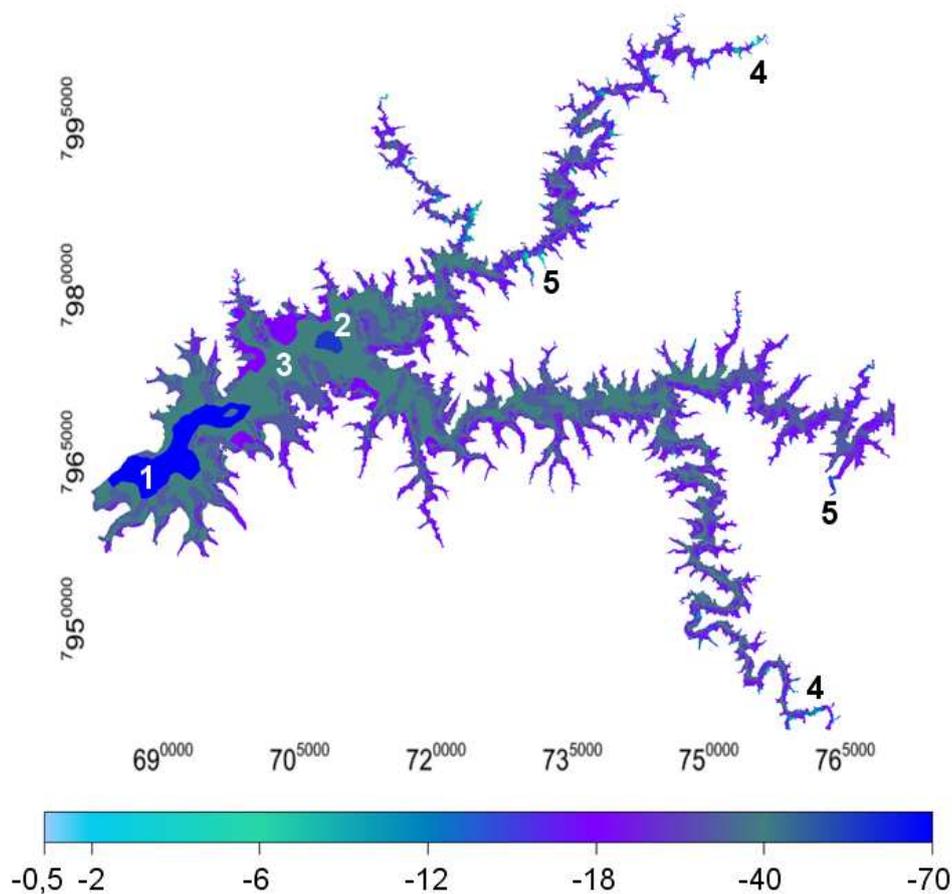


Figure 6: Estimated bathymetry (m) by the proposed method.

According to Figure 6 the shallow areas are in the regions 4 and 5 corresponding to the first order channels running straight into the reservoir. These results agree with the literature (Tundisi et al., 2002), that is, the deepest regions near the dam and shallowest region in the small channels.

Figure 7a renders a quantitative assessment of the method. The scatterplot of measured and estimated depths display a $R^2=0.98$ ($n = 100$, $\rho = 0.00$). The highest errors were observed depths higher than 70m. This failure was already expected because the topographic surveys do not include information on river depth. In spite of that, these results are very useful for planning the bathymetric survey in the reservoir, focusing the data collection on the river channel which is the main source of error, and limiting the number of sampling sites in the regions where the hybrid topographic chart renders a good display of reservoir depth distribution.

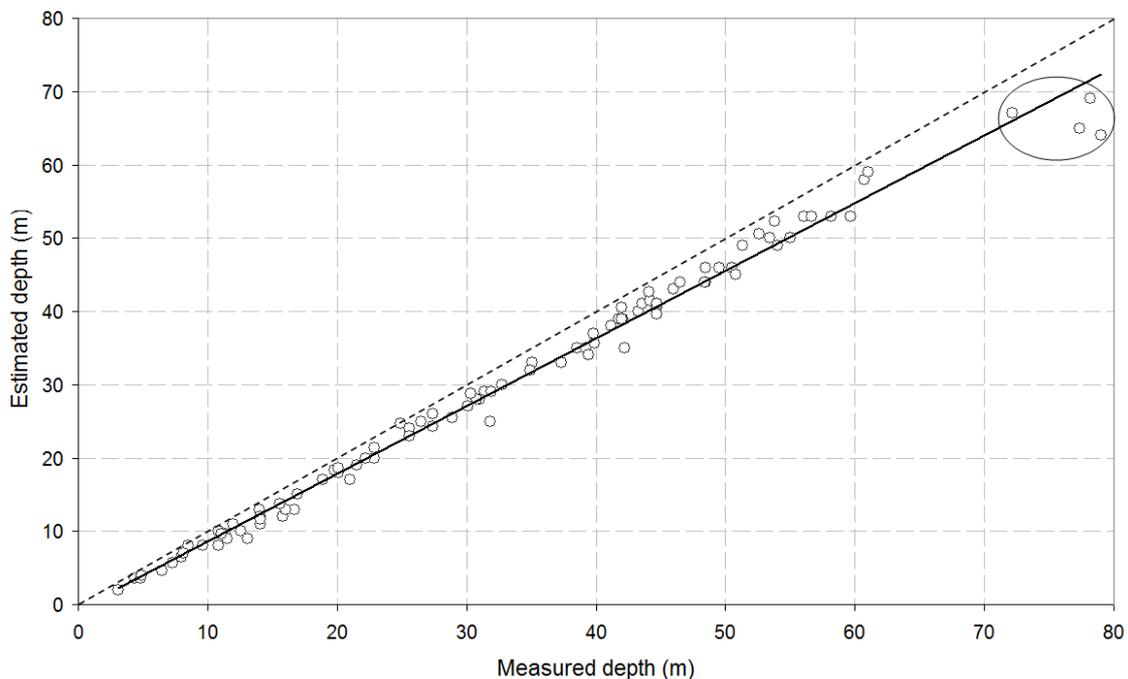


Figure 7: Evaluation of the proposed methodology: (a) measured versus estimated depth (m) and (b) the residuals.

In a country as Brazil where the hydroelectric energy is responsible for 97% of the total generated energy and considering the valuable information generated by the bathymetric map for reservoir operations the methodology should be applied with relatively success with economy of time, people for surveying and financial resources.

Final remarks

We present a new method to estimate the bottom depths in hydroelectric reservoirs using cartographic maps and satellite topographic data. Our approach allows the following applications:

- Planning field campaigns;
- Decision making by the engineers;

- Bathymetry using sonar;
- Water quality sampling;
- Modelling the sedimentation processes in reservoirs over time.

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