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PERFORMANCE ANALYSIS OF DIGITAL ELEVATION MODELS: A CASE STUDY OF BASIN LOW MIDDLE SÃO FRANCISCO RIVER

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Abstract

The performance assessment of digital elevation models, from the handling of the mission SRTM elevation data , ASTER imager instrument , and project TOPODATA compared to elevation data obtained in the field from GPS was the aim of this work, in view the adequacy of the best model for use in studies of morphometric analysis of watersheds , as well as applications in hydrological models . To conduct this study we used the ArcGIS 9.3 software. The results demonstrate that the elevation data extracted from SRTM , ASTER and TOPODATA are extremely satisfactory for presenting high correlation with the data collected by GPS (r = 0.97 , 0.96 and 0.97 , respectively) , was also observed that the smallest errors associated were obtained for the SRTM DEM , being observed PBIAS equal to 2.71 % and MAE of 11.45 m . Finally from the index c Camargo & Sentelhas be excellent in the criterion of model performance. In conclusion it was observed that the DEM SRTM showed the best results, possibly due to the lower number of cells to compose your image, thus generating more homogeneous areas than other models.

Keywords: Altimetry; geoprocessing remote sensing.

Introduction

In recent decades, interest in studies of environmental impacts caused by human activities have moved a considerable number of researchers studying new tools, including those that seek to simulate the changes occurred through changes in water use and soil, taking into account the issue of spatial distribution within the basin under study (Santos et al., 2005).

Through the GIS may be a detailed description of spatial variable region linked to hydrological models in the study, thus contributing to know in greater detail the complex processes which when analyzed together, converge to a higher precision analysis phenomenon (Wegehenkel et. al., 2006). The integration of GIS with hydrological models allows performing several operations related to hydrological modeling easy and efficient way, such as the physical properties of the watershed boundary, drainage network generation, dividing the watershed into homogeneous areas, etc.

With respect to input data, Machado & Vettorazzi (2003) reports that they may originate from different sources (satellite imagery, topographic maps, soil maps, hydrography, etc.) and at different scales and whose results are commonly generated in the form of maps. Data processed in GIS whose main characteristic is the diversity of generating sources and formats presented. There are at least three ways to use a GIS: as tools for the production of maps; as support for spatial analysis of phenomena and how geographic database with functions of storing and retrieving spatial information Vettorazzi & Machado (2003).

A digital elevation model (DEM) provides sufficient information for a GIS environment in the land slope, set the direction of the surface flow and therefore generated drainage network for the basin (Melo, 2008) are analyzed. From the knowledge of exutório a bowl can be easily bounded. Also by classifying satellite image, you can analyze the changes in vegetation cover of an area and also predict and locate the impacts caused by human action, allowing management more efficient and effective basins (Melo, 2008). Also according to this author, the relationship between the data rate the coupling between subsystems according to the proximity of the data. The integration with sharing occurs when a subsystem directly accesses the data stored as the model data structure and the other subsystem. Already in the seamless integration of data sharing is not observed the existence of a single database for the coupled system, resulting in the need for an external tool for data exchange, making the GIS manager of such data. While there is data exchange between tools, which enhances the performance of the model on data sharing.

With the advent of satellite sensors, elevation models, which allow the determination of the drainage network could be extracted by interferometry. This process is the mode of operation of some imaging microwave sensors, such as the SRTM - Shuttle Radar Topographic Mission, or stereoscopy through optical

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sensors that acquire images with reprocessing, like the ASTER / Terra - Advanced Thermal Emission Spacebone and Reflection Radiometer (Fuckner et al., 2009).

The SRTM mission was conducted to acquire data from altimetry entire globe from active sensors (radar). The original resolution of the generated images is 30 meters; however, for South America NASA released images with a resolution of 90 meters. The product is georeferenced to the WGS84 datum, in decimal geographic coordinates and can be obtained via the Internet. The SRTM Images of Brazil have been treated by

The ASTER GDEM are produced through a consortium between METI - Ministry of Economy, Trade and Industry of Japan and NASA - National Aeronautics and Space Administration, United States, for construction of a digital elevation model of global free access. Starting on June 29, 2009, digital elevation models, built from stereo pairs of images derived from the EOS AM-1 platform with the ASTER instrument, VNIR sensor was available for free and unrestricted (Rodrigues et al. 2010).

The objective of this work the performance of digital elevation models was to evaluate when compared to data obtained by global positioning systems (GPS), through analysis of the coefficients of determination (R2), correlation coefficients (r), the square root of the square average of the standard error (RQMDN), the percent Bias (PBIAS), mean absolute error (MAE), Willmott index (d) (Willmott et al., 1981) and performance index (c) (Camargo & Sentelhas, 1997).

Material and Methods

Study Area

The Lower Basin of the São Francisco River Valley covers areas of the States of Bahia and Pernambuco, stretching from the town of Backwater to the city of Paulo Afonso both in the state of Bahia (Figure 1), 110.446,00 km2, or 17% of area of the São Francisco Basin. It is 440 km long and its population is 1.944 million people. The region consists of the sub-basins of Pontal, Herons, Bridget, Pajeú, Moxotó Xingó and rivers from the left margin; while on the right bank are the sub-basins of Tourão Salgado, Vargem, Curaçá, Macuru Long and Well (CODEVASF, 1999).

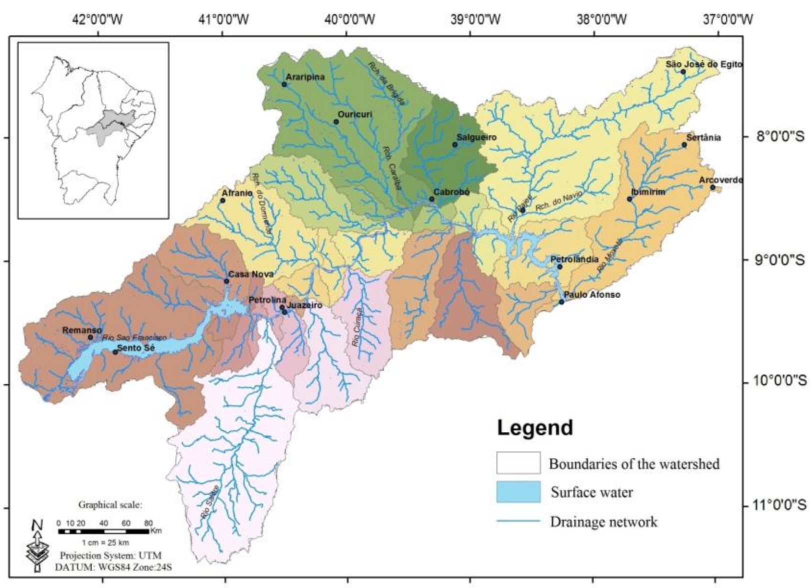

Figure 1. Map of the study area.

The climate of the region is semi-arid, with average annual temperature of 27 ° C, rated Bswh by Koeppen. Depending on the characteristics of climate and temperature associated with the intertropical geographical location and atmospheric clarity most of the year, the potential evapotranspiration is very high, especially in the northern part of the Valley, being of the order of 3.000 mm annually CODEVASF (1999). Heat stroke is high and the relative humidity is low. The dry period is prevalent, with about 6-8 months and may reach up to 11 months in areas of greater aridity CODEVASF, (1999). The average annual rainfall is around 400-650 mm, which occurs irregularly and concentrated form in 2-3 months of the year, heavy rainfall (120-130 mm) may occur within 24 hours CODEVASF, (1999).

For this work 38 control points were collected in the study area through GPS (GARMIN E-TREX 10) and then inserted into the GIS ArcGIS 9.3, were also obtained images of remote sensing for composition of digital elevation models (DEM), characteristics of the spatial resolution of each model are shown in Table (1). In this study, three different sets of DEMs were used. The first generated from SRTM data, the second of Aster GDEM and the last data that is to be Topodata improving the SRTM (Valeriano 2004). All SRTM and ASTER images TOPODATA were referenced to the WGS84 Datum Zone 24 and UTM projection system.

Table 1. Characteristics of the spatial resolution of digital elevation models.

DEM	spatial resolution
Aster	30x30m
Topodata	30x30m
SRTM	90x90m

When are related by the regression, the estimated values with observed values, one can obtain information precision and accuracy, which together indicate the consistency of the estimates with observed data. The accuracy, ie, the degree of dispersion of values around the mean, as the coefficient of determination, indicates only the degree of dispersion of the data obtained, the random error, not systematic considering. The coefficients of determination and correlation were obtained using EXCEL from direct construction of graphs and their regressions. For evaluating the performance of the models we used regression analysis and coefficients of determination (R^2), correlation coefficients (r), percent BIAS (PBIAS), mean absolute error (MAE), the square root were obtained normalized mean square error (RQMDN), the index of Willmott (d) (Willmott et al., 1981) and performance index (c) (Camargo & Sentelhas, 1997). Statistical indices are described and formulated as follows:

a) The accuracy, ie, the degree of dispersion of values around the mean, as the coefficient of determination (R^2) indicates only the degree of dispersion of the data obtained, the random error, not systematic considering.

Obtained from Equation (1) represents the linear regressions between the observed and estimated values:

$$R^2 = 1 - \left[\frac{\sum_{i=1}^{n}(E_i - O_i)^2}{\sum_{i=1}^{n}(O_i - \bar{O})^2}\right] \quad \textbf{(1)}$$

b) The square of the normalized mean square error (RQMDN) according to Equation (2):

$$RQMDN = \frac{\left[\frac{1}{n}\sum_{i=1}^{n}(E_i - O_i)^2\right]^{0,5}}{\frac{1}{n}\sum_{i=1}^{n} O_i} \quad \textbf{(2)}$$

The RQMDN ranges from 0 to infinity and that the smaller, the better the estimate, however, this index makes no distinction as to be underestimated or overestimated (Jacovides & Kontoyiannis, 1995) data.

c) The mean absolute error is the magnitude of the difference between the observed value and the estimated value. Whereas Oi is the observed value, Ei represents the estimated models from n represents the number of values, the MAE value was determined by Equation (3):

$$MAE = \frac{1}{n}\sum_{i=1}^{n}|O_i - E_i| \quad \textbf{(3)}$$

Also to RQMDN, the lower the value of the mean absolute error of MAE best estimate but positive values indicate the average amount of overestimation of the models, and negative otherwise.

d) The Percent Bias (%) refers to the percentage of bias of simulated values compared to those observed. The closer to zero the value of this ratio the better the model represents reality, that is, the lower the tendency in the estimates and, moreover, it also serves as an indication that the model is poor representation (Moriasi et al. 2007). Liew et al. (2007) presented the following classification: | PBIAS | <10%, very good; 10% <| PBIAS | <15% good; 15% <| PBIAS | <25%, and satisfying | PBIAS |> 25%, the model is inadequate. The Percent Bias is obtained by Equation (4):

$$PBIAS = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{O_i - E_i}{E_i}\right| \times 100 \quad \textbf{(4)}$$

To verify that, indeed, the altitude values estimated by the models differ significantly between the measured values of altitude, we used the t-test derived from the R^2 (Stone, 1993; Togrul & Togrul, 2002) according to Equation (5):

$$t = \frac{r\sqrt{n-2}}{\sqrt{1-r^2}} \quad \textbf{(5)}$$

The critical value of t can be obtained from the statistical table (Student-t), with a significance level (α) and (n - 1) degrees of freedom. A model will be considered statistically significant (accepting the null hypothesis, Ho: Ei = Oi) in the range (1 - α), the calculated t value is greater than the critical value. In the present study the significance levels used were $\alpha = 0.01$ and $\alpha = 0.05$ with varying degrees of freedom as the number of observations.

The d index quantifies numerically the accuracy, with a coefficient of agreement (Willmott et al., 1981). It also shows how the model simulates the observed values, reflecting, on a scale 0-1, being obtained by Equation 6:

$$d = 1 - \frac{\sum_{i}^{N}(X - X')^2}{\sum_{i}^{N}(|X' - \bar{X}| + |X - \bar{X}|)^2} \quad \textbf{(6)}$$

The performance index c (Equation 7) is given by the product of the correlation coefficient (r) and the index of Willmott (d) (Camargo and Sentelhas, 1997) the interpretation of the results is shown in Table 2.

$$c = r \times d \quad \textbf{(7)}$$

Table 2. Values of the coefficients of performance (c) as Sentelhas & Camargo (1997).

C value	Performance Rating
> 0.90	great
0.81 - 0.90	very good
0.71 - 0.80	good
0.51 - 0.70	median
0.41 - 0.50	poorly
0.31 - 0.40	bad
≤ 0.30	terrible

Results and Discussion

From Figure 2 there is the points of extraction of information collected by the GPS altitude, 38 samples were obtained in Basin Low Middle River São Francisco - BHSRSF.

It is observed that the central part of the basin has greater distribution of points, mainly along the San Francisco River.

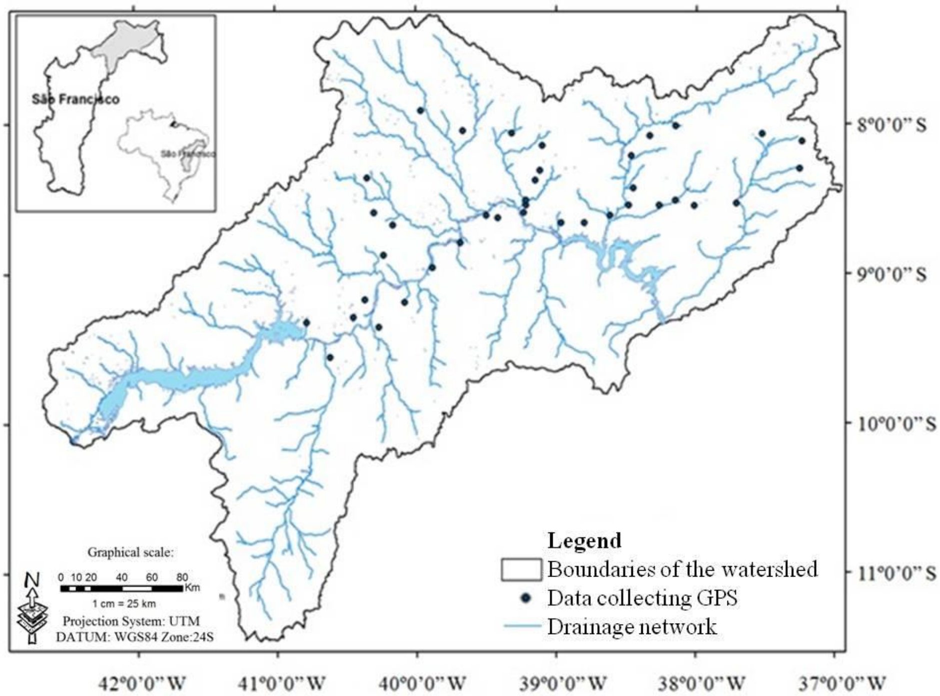

Figure 2. Distribution of points for obtaining altimetry data in the Basin Low Middle River São Francisco - BHSRSF.

According to Figure 3 it is possible to verify the topographic profile of the sampling site of altitude data via GPS, as well as the distribution of points extracted from DEM through GIS ArcGIS 9.3, however it is observed in most small tendency to underestimate values coming from the DEM, this fact can be explained by the spatial resolution of the images of remote compared with the accuracy of the data obtained by the GPS sensor.

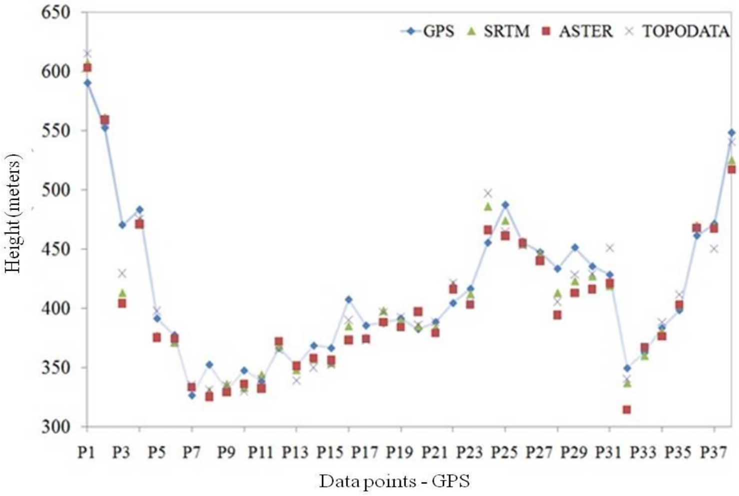

Figure 3. Topographic profile stretch of data collection.

Through Figures (4A to 4C) is possible to evaluate the efficiency of the methodologies used in this study to estimate the altitude data from DEM in BHSRSF, taking as reference the data obtained by GPS, as previously mentioned. Figure 4A shows the relationship between the GPS data and DEM aster, it is possible to observe that the DEM aster obtained slope of 1.13 and intercept 0,97m. Through the coefficient of determination (R^2) appeared that the relation between the values obtained for the two methods is relatively high (0.926), ie, the dispersion of the points is very small compared to the straight setting. The relationship between the GPS data and DEM topodata is observed in Figure 4B, was found (R2 = 0.941) demonstrated high ratio between the values estimated by the two methodologies. The slope was -9.9 and the interception was in 1,016m. The largest relation between the methodologies for estimating the altitude was through GPS data and the DEM srtm (Figure 4C) was observed (R2 = 0.945). In SRTM (90m) model have fewer cells for image composition when compared with Aster and Topodata (30m) models, this feature makes it more uniform, making small relief features are suppressed, ie for each cell of the DEM srtm have had nine cells for DEM aster and topodata. Estimates show how the values of R^2 are significant at the 0.01 and 0.05 and the t-test derived from the values presented R^2 t> t99 and t95, namely parameters have been adjusted.

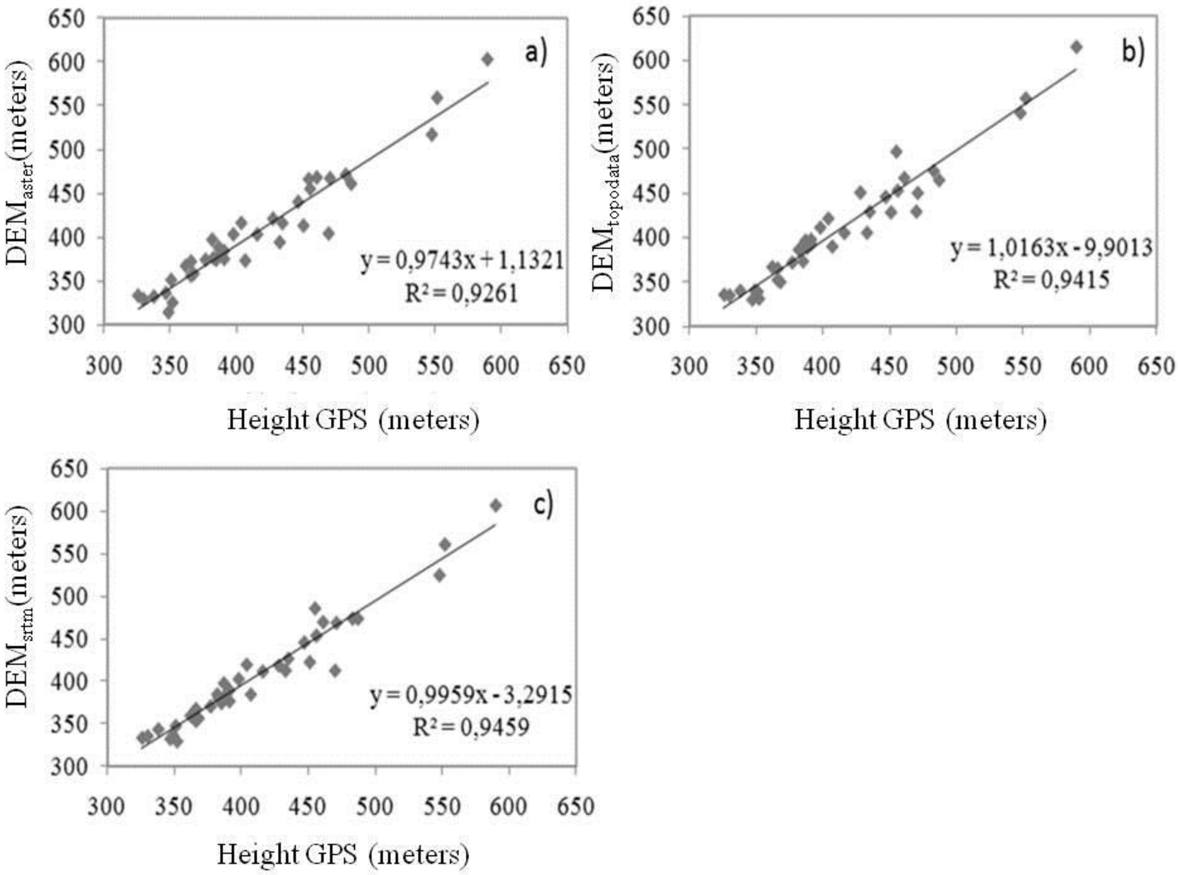

Figure 4. Relationship between the GPS data and the data obtained by DEM aster (a) DEM topodata (b) and DEM srtm (c).

From table 3 it can be seen the percent pbias (PBIAS) and mean absolute error (MAE) from the data used in the methodology. Results indicate PBIAS and MAE of 3.37% and 14.18m, respectively, to the values estimated from data from DEM aster. For the DEM topodata values of 2.98% and 12.53m, being related to PBIAS and MAE, respectively are checked. Smaller errors associated were obtained for the DEM srtm, being observed PBIAS equal to 2.71% and MAE 11.45m, RQMDN presented the value of 2.1%. According to Liew et al. (2007) this result indicates good model fit DEM srtm this basin.

Table 3. Statistical analysis of digital elevation models.

DEM	Height (meters)			R^2	MAE (m)	PBIAS (%)	RQMDN (%)
	Mean	Max.	Min.				
Aster	404.5	603.0	314.0	0.926*	14.18	3.37	4.7
Topodata	410.8	615.0	329.8	0.941*	12.53	2.98	2.2
SRTM	409.0	607.0	330.0	0.945*	11.45	2.71	2.1

From table 4 we can see that the performance index c ranged from 0.94 to 0.96, being classified as excellent for all models. From this, it follows that the methodology can be employed as an alternative in the absence of good data from the gps, or as a form of additional data for generation of letters and hipsometric slope. Errors encountered can be considered negligible in view of the accuracy achieved.

Table 4. Values of coefficient of performance (c) as Camargo & Sentelhas (1997).

DEM	r	d	c	Performance index c
Aster	0.96	0.97	0.94	great
Topodata	0.97	0.98	0.95	great
SRTM	0.97	0.98	0.96	great

Conclusions

Evaluating the potential use of DEMs from SRTM, ASTER and TOPODATA products, to determine the altitude, there was an extremely satisfactory approximation in relation to the data obtained in the field from the GPS. It was also observed that the SRTM DEM showed the best results, possibly due to the lower number of cells to compose your image, thus generating more homogeneous areas than the other models.

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