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Spatial analysis on the watershed of Goiana River – PE: comparison with the use of geoprocessing and ANA data

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Abstract

The recognition of a watershed is extremely important for the planning of the water resources, the geotechnology contributes for a better comprehension of the natural forms in computational environment with a higher level of details, lower time-demanded precision, therefore this research aims to use computational techniques to delimit the watersheds, especially Goiana River one, in Mata Norte Zone of Pernambuco, and, at the end, to establish a relation with the watersheds data of the Oriental Northeastern Atlantic watersheds published in 2013 by ANA (Agência Nacional de Águas) and made available on GeoNetwork platform. It was made use of the Digital Elevation Model with resolution of 30 metres in the Software environment ArcGis 10.3, as well as a sequence of data processing available on the ArcHydrotools. The result of the obtained delimitation with the methodology applied in this paper approached the ANA data fairly enough.

Keywords: Digital elevation model, Arc Hydro Tools, morphometry.

1. Introduction

The watershed can be understood as a natural catchment area of water from precipitation, delimited through strands and cut by a drainage network which converges towards only one watercourse (Tucci, 1997). Barrella (2001) highlights that the water which soaks into the soil makes water tables and sources. The Federal Law n. 9.433/97 in Brazil establishes the watershed as a territorial unit for the application of the National Policies of the Water Resources (PNRH) (Sobrinho, T. A.; Oliveira, P. T. S.; Rodrigues, D. B. B.; Ayres, F. M., 2010).

The state of Pernambuco has got several watersheds, along its territory, its water courses show an enormous importance to the state, being present in the economy and culture of the Pernambuco people.

Therefore, the knowledge about morphometry of the watershed is considered to be highly important to the control and management of it, as the morphometrycal characteristics influence directly in the water cycle, thus, they interfere in the infiltration, evapotranspiration and in the superficial and sub-superficial flow (Elesbon, 2011).

Accordingly, the first step to manage a watershed is through its delimitation, and the SIG's (Sistema de Informações Geográficas) tools help with managing the watersheds (Duarte, 2007). It can be stated that the evolution of the geotechnology provide the planning with new and more efficient techniques to manage the natural resources, making it easier to obtain data for a better understanding of the natural forms in computational environment counting on a higher level of details, lower time-demanded precision. Thus, the study about the watersheds demonstrates its importance on the economical field as well as the sociocultural one, and the use of geoprocessing softwares has been explored more and more.

The process of delimiting a watershed uses the data of the terrain which, according to Sobrinho et al. (2010), can be understood as a structure of numerical data related to the altitude and surface of the ground, called Digital Elevation Model (MDE). The generation of the MDE can be used through level curves or through images of remote sensors, which is the case of this paper that use images obtained by Shuttle Radar Topography Mission (SRTM).

MDE is generated from interpolation in environment SIG, from vectored information (shapefile) extracted from topographic letters containing level curves, elevation points, watershed network and water mirrors. However, it is important to look carefully at the fact that the superficial watershed network along the time, due to constant urbanization, changes and climatic periods such as droughts or raining, can present considerable change in the location and outline of the vectors. To reach better precision, an alternative is interpreting this information from updated geo-referenced and high definition spatial images (Camargo, 2016; Silva and Moura, 2013).

The use of MDE obtained through SRTM have been showing better elevation results than the ones which from the topographic letter in a scale 1:100.000, as demonstrated by Santos et al. (2006), enhancing, thus, the reliability on the use of geoprocesssing to the watershed studies and management. That goes along with Oliveira & Paradella (2008 apud Oliveira, P. T. S.; Sobrinho, T. A.; Steffen, J. L. and Rodrigues D. B. B., 2010) who demonstrated that the use of MDE from the STRM followed the cartographic standards to a scale 1:100.000, when used to analyze flat and hilly regions in the Amazon.

According to Silva (2015), the tool ArcHidro is a geospatial model to water resources constituted by a group of goals which fill in the features in the structure used by it which interconnects features in different layers, allowing water delimitation. This procedure helps with delimiting the watershed more precisely, on ArcHydro Tools to a delimitation of the watershed (Camargo, 2016).

In this sense, this paper aims at exploring the use of a delimitation methodology of watershed from geoprocessing techniques, especially the watershed of Goiana River, Permanbuco Mata Norte, using the ArcHydroTools, place of the Software ArcGis 10.3, and from the results obtained, to establish a relation with the official data of the watershed.

2. Materials and methods

Characterizing the study field

The watershed of Goiana River is located between the coordinates 07º 22'20" and 07º 54' 47" latitude southwards, and 34º 49' 06" and 35º 41' 43" latitude westwards, presenting a direction from west to east, from Agreste to Mata Norte Zone of Pernambuco. It is 2.847,45 km big, corresponding to 2,90% of the total area of the state (Figure 1).

Goiana River is formed from the confluence of Capibaribe Mirim and Tracunhaém Rivers. It is 19 km long and by its last 10,5 km, it is found the limit between Paraíba and Pernambuco states (CONDEPE/FIDEM, 2005). According to APAC (2005), the main water courses are from Capibaribe-Mirim, Sirigi, Tracunhaém and Goiana, Within a rich drainage network, Sirigi River is one of the most important, its watershed occupies 30% of the total area of Goiana River watershed. It is a perennial river, and its water volume is bigger during the rainy periods, concentrated in autumn – winter. This period is when the Northeastern region of Brazil has generally a bigger rainfall index along the year. It is a sub intercontinental watershed which has its source in Sao Vicente Férrer – PE and its mouth in Condado – PE, where it unites with Capibaribe-mirim River which, previously, unites with Tracunhaém River, a big part of the watershed of Goiana River (Vasconcelos, 2005).

In the middle of the water courses, the watershed includes 26 cities, according to SEMAS (2001):

Goiana River watershed includes lands from Araçoiaba, Aliança, Buenos Aires, Bom Jardim, Camutanga, Carpina, Casinhas, Condado, Ferreiros, Goiana, Igarassu, Itaquitinga, Itambé, João Alfredo, Lagoa do Carro, Limoeiro, Macaparana, Machados, Nazaré da Mata, Orobó, Paudalho, Salgadinho, São Vicente Férrer, Timbaúba, Tracunhaém and Vicência cities.

The watershed is limited by the estate of Paraíba to the north and with the sixth group of watershed of small coastal rivers – GL6 (UP19); it is limited by Capibaribe River watershed to the south and the first group of watershed of small coastal rivers – GL1 (UP14); to the east, it is limited by the Atlantic Ocean and the GL6 and to the west by the state of Paraíba (CONDEPE/FIDEM, 2005; SEMAS, 2011).

The weather varies between dry and wet, as its location is between Agreste and Mata Norte Zone, so in the westwards areas, it is predominant to see hot and dry areas with some rainy periods from February to June and in the eastwards parts it is more usual to have hot and wet weather with rainy periods from March to July. The vegetation in the central areas is mostly deciduous and in some parts to the north, hipoxerophilic caatinga, to the eastwards areas, the vegetation of the Atlantic forest in the coastal areas, there are mangroves. Its terrain has mostly altitudes lower than 100 metres, except in the northwest part of it, because it presents a variation from 100 metres to 700 metres. Most of the parts are constituted by crystalline rocks, its soils have dark-read podzols, non-calcium Brunos in the most fertile areas, yellow Latosols, Litholics, Alluvials, Gleissoles and Salodic Planosols, in the coastal areas, Marine Quartz Sands (CONDEPE/FIDEM, 2005).

When it comes to the river course along its all watershed, the use and occupation of the soil happens through urban and industrial occupations (most of the times sugar-cane mills), spoilt areas for sugar-cane cultivation, polyculture, livestock, closed arboreal vegetation, open and shrubby arboreal – closed arboreal. In the region near the coast, there is shrimp farming, which is a technique to farm shrimp and seafood in nurseries (Figure 3 and 4). The presence of the mangrove, the sand dams for extracting sand mainly reserved to civil construction. The use of water by the shrimp farming, the human and animal consumerism, public supply, tourism, recreation and leisure; besides the industrial use, watering, cleaning and fishing, it occurs the reception of domestic, agribusiness (Shrimp farming) and industrial effluents (CONDEPE/FIDEM, 2005).

In the relation between mankind and nature, the manmade impacts on the environment are clear. The Water Planning Unit UP1, which corresponds to the watershed of Goiana River (APAC, 2017), the environmental impacts linked directly to the watershed are many. The CONDEPE/FIDEM (2005) identified that the main impacts are:

Sprayers washing, sprinklers and harmful agricultural packages in the water of the rivers; flushing of domestic effluents; withdrawal of sand from the riverbed of many rivers in the watershed; construction of buildings (houses, among others), near the water courses and the dam protecting areas (in the riverside); atmospheric pollution produced by the emission of soot originated from the burning of the rest of sugar-cane in the sugar mills; the planting of sugar-cane and other cultures by the riverside; effluent discharge originated from public and clandestine slaughterhouses located by the riverside of rivers in several cities; disorganized captures of water from the rivers; the use of agrotoxin for the planting of sugar-cane by the riverside; deforestation in the source areas and ciliary forests; the presence of dumps near the water course; pigs, cattle and poultry nurseries in the bordering areas, being its detritus discharged into the rivers; the discharge of domestic garbage, by the population, directly into the channel of rivers and streams; discharge of effluents from vehicles washing (jet wash) near the water course; discharge of the public sewer into the spring; and effluents from tannery discharged into the rivers.

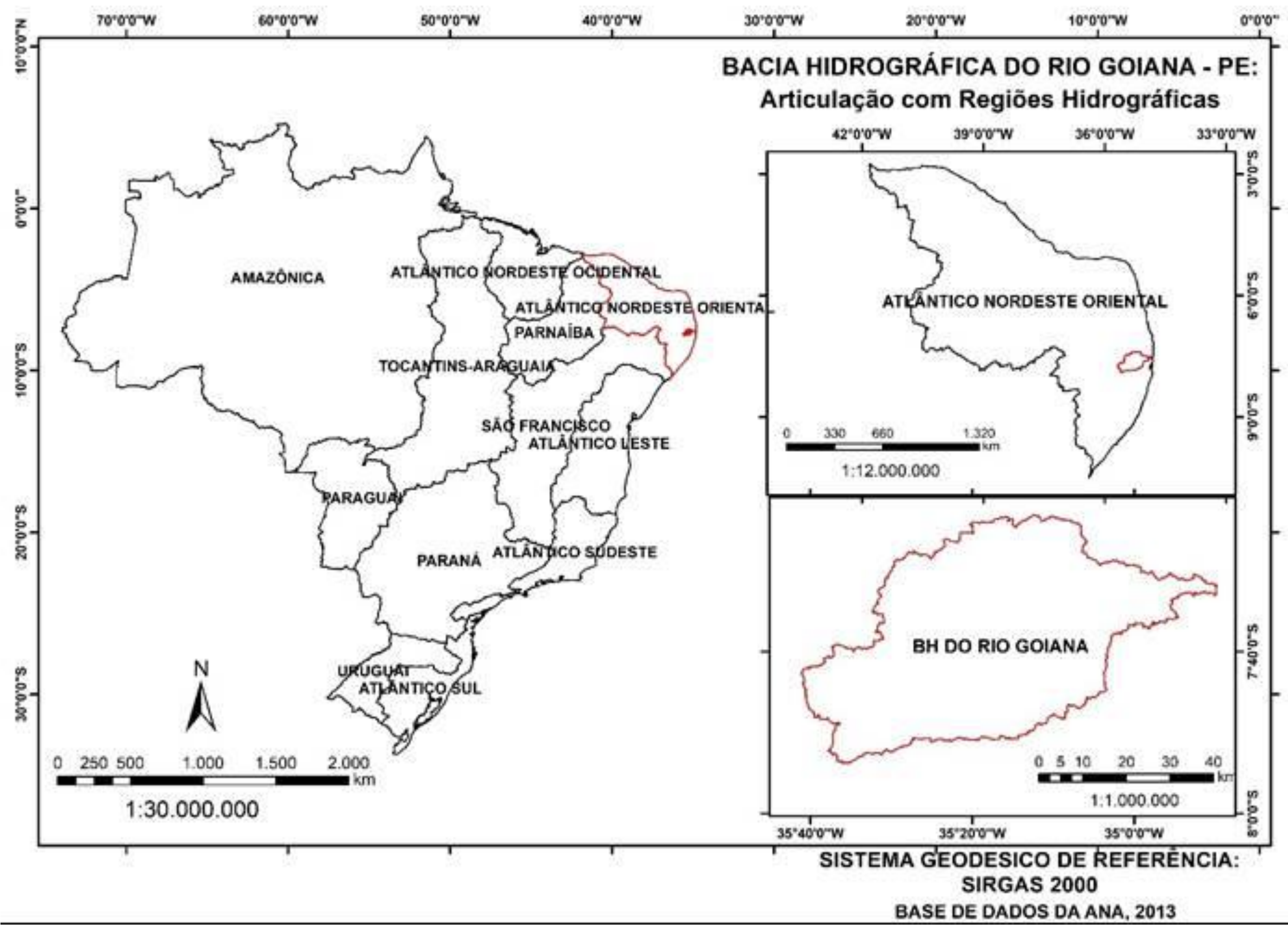

Figure 1. The Location of watershed of Goiana River

Delimitation of the Watershed

For this paper, the Digital Elevation Model SRTM (Farr et al.; 2007) was obtained, counting on a resolution of 30 metres (07236_ZN). Luedeling, E.; Siebert, S.; Buerkert, A., (2007) accounts that this MDE can contain more frequent imperfections in areas which the surface slope is bigger than 20 degrees, exactly because of the shading caused by the radar. Considering this the Software ArcGIS 10.3, it was used a sequence of processing from available data on ArcHydroTools, a free extension from Software ArcGIS (Figure 02).

On ArcHydroTools, it was used the Fill Sinks modules for the filling of depressions. Novais (2015) “This function allows correction on MNT/MDE, in a way that it considers the altitudes neighbouring pixels to fill in the ‘sinks’, softening the consistency on the map from MNT/MDE”.

After the correction on the MDE, we moved on to the analysis of the superficial flow. The Flow Direction was used to calculate the direction of the flow. Novais (2015) the Flow Direction function, which originates a regular grid defining the direction of flow, taking the line of greater slope of the ground as the basis. That new numerical grid determines the direction of greater slope of a pixel in relation to its eight neighbouring pixels. The Flow Accumulation module was used to define where the superficial flow is accumulated in the ground. That accumulated flow refer to the watershed network, however it is possible to obtain a new grid containing the respective values of the water accumulation inside each pixel. From the direction of the flow, the accumulated flow is obtained by adding the cell areas (amount of cells) in the direction of the flow (Novais, 2015).

After the definition of the superficial flow, we moved on to the delimitation of the drainage network, with the Stream Definition module. The processing demands a value which defined a threshold for the number of cells, on this paper it was used the value 1000 for the cells of the flow accumulation Raster. The Stream Segmentation module defines the confluences which generate the hierarchy of the drainage, by using the Flow Direction Rasters and the drainage network. For the vectorisation of the drainage network it was used the Drainage Line Processing.

. Having the superficial drainage and the contributing areas defined and the vector, we moved on to the proper delimitation of the watershed. The Adjoint Catchment Processing tool was used to refine the micro watersheds having the vectors of the drainage network and the contributing areas as a parameter. The Drainage Point Processing modules aims at defining, by using points, where the segments of the superficial drainage start and finish, that is, the sources, the confluences and the mouth of the watersheds. Having the points of segments defined, the Batch Point Generation tool was used to select the point which shows the mouth of the watersheds destined to the study, showing the software where the watershed starts. Lastly, to delimit the watershed, the Watershed Delineation tools was used, besides the parameter defined with the Batch Point Generation tool, it uses other data which were generated until then.

At the contributing areas delineation phase, the Catchment Grid Delineation module was used, which delimits the contributing areas or micro watersheds by using the flow direction Rasters and the superficial drainage. Afterwards, the Catchment Polygon Processing module was used, that one did the automatic vectorisation of the micro watershed.

The morphometric data were also used as a way of comparing the obtained result with the ABA data. One of the main reasons for working with watershed is its management, to do so, the manager use data which are capable of describing and predicting possible phenomena in the watershed. Consecrated indexes in Literature were used:

Index of Circularity which tends to the unit as the watershed approaches the circular form and reduces as the form becomes elongated (Tonello, 2005). As described in equation 1:

$$Ic = \frac{12{,}57 * A}{P^2} \quad (1)$$

In which: Ic is the Index of Circularity; A is the Area of the watershed in square kilometer and P is the Perimeter of the watershed in kilometer.

The Density of drainage (Equation 2), on the other hand, demonstrates the highest and the lowest speed in which the water leaves the watershed, so the index points to the level of development of the drainage network (Villela and Mattos, 1975)

$$Dd = \frac{Lt}{A} \quad (2)$$

In which: Dd is the density of drainage in kilometer/square kilometer; Lt is the total length of the annals in kilometer and A is the area of the watershed in square kilometer.

The coefficient of Compactness, according to Villela and Mattos (1995), varies according to the form of the watershed, regardless of its size, the more irregular it is, the bigger the coefficient of compactness will be, that is, the closer to the unit, the more circular the basin will be and it will be subject to flooding, in order to calculate it, the equation 3 was used.

$$Kc = \frac{0{,}28 * P}{\sqrt{A}} \quad (3)$$

In which: Kc is the coefficient of compactness; A is the Area of the watershed in square kilometer and P is the Perimeter of the watershed in kilometer.

The results were compared with data from the watershed of the Oriental Northeastern Atlantic published in 2013 by ANA and made available on GeoNetwork platform. This database looks on the representation of parts of the drainage and the delimitation of areas of watershed contribution for all the Oriental Northeastern Atlantic watersheds, in which Goiana River watershed is part of. The methodology used by ANA for the construction of this base was the “vectorisation of the topographic charts in scale 1:100.000 of the Brazilian systematic mapping, followed by topological amendments in the parts of drainage and ottocoding procedures. The areas of watershed contribution were defined from a hydrologically consistent digital elevation model, as a result of data processing ASTER” (ANA, 2013)

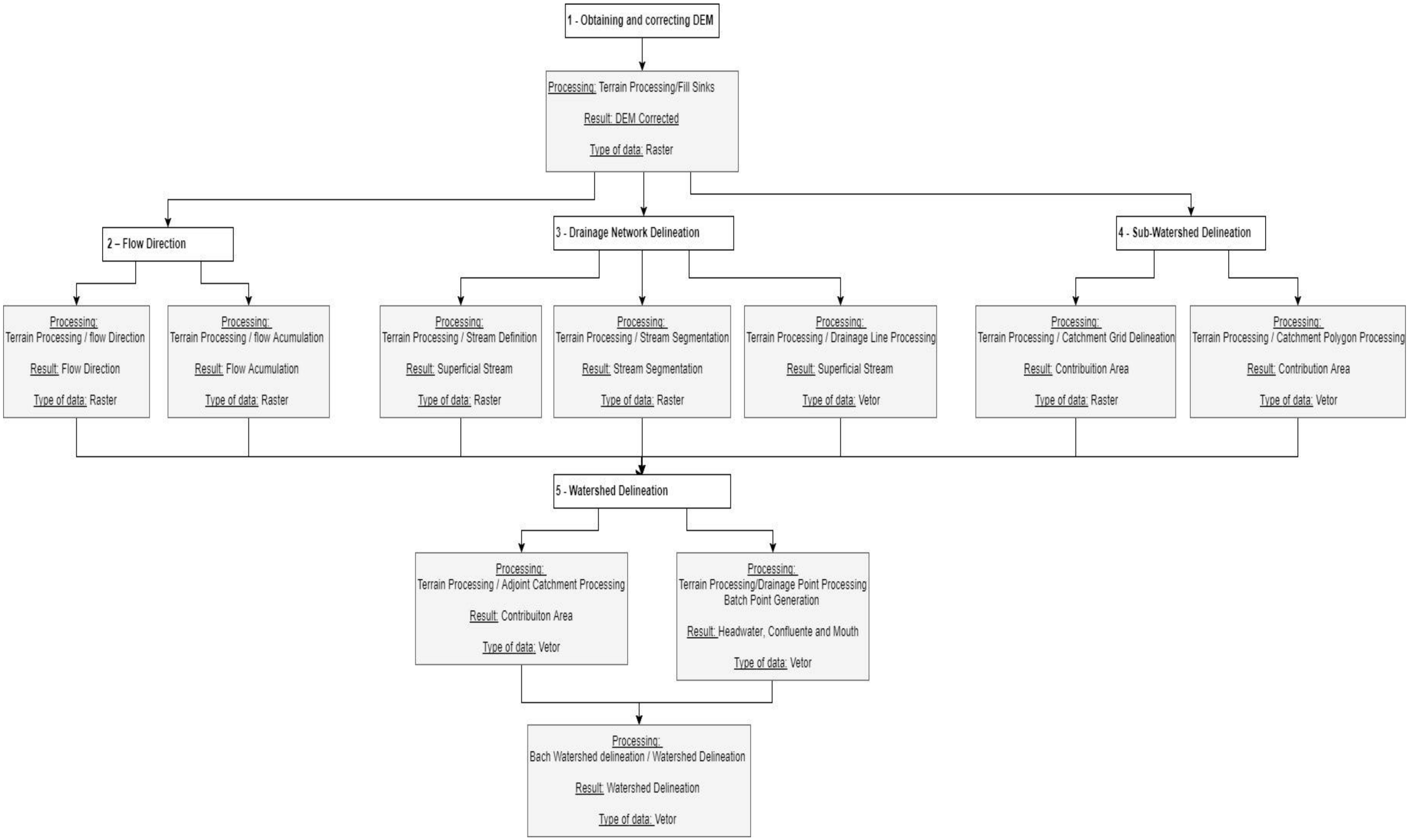

Figure 2. Flow Chart with the Processing used with ArcHydrotools.

3. Results and discussion

The results obtained through the methodology used show enough agreement when comparing with the official data from ANA (Figure 3).

Results Obtained and Comparison with the Data from ANA

The result f the delimitation obtained with the methodology applied in the paper approaches the data from ANA. To reach a better comparison, it was delimited with the same methodology to Sub-watershed of Siriji River, which composes and occupies a big part of Goiana watershed, 471,9 square kilometers, sharing the same geographical context.

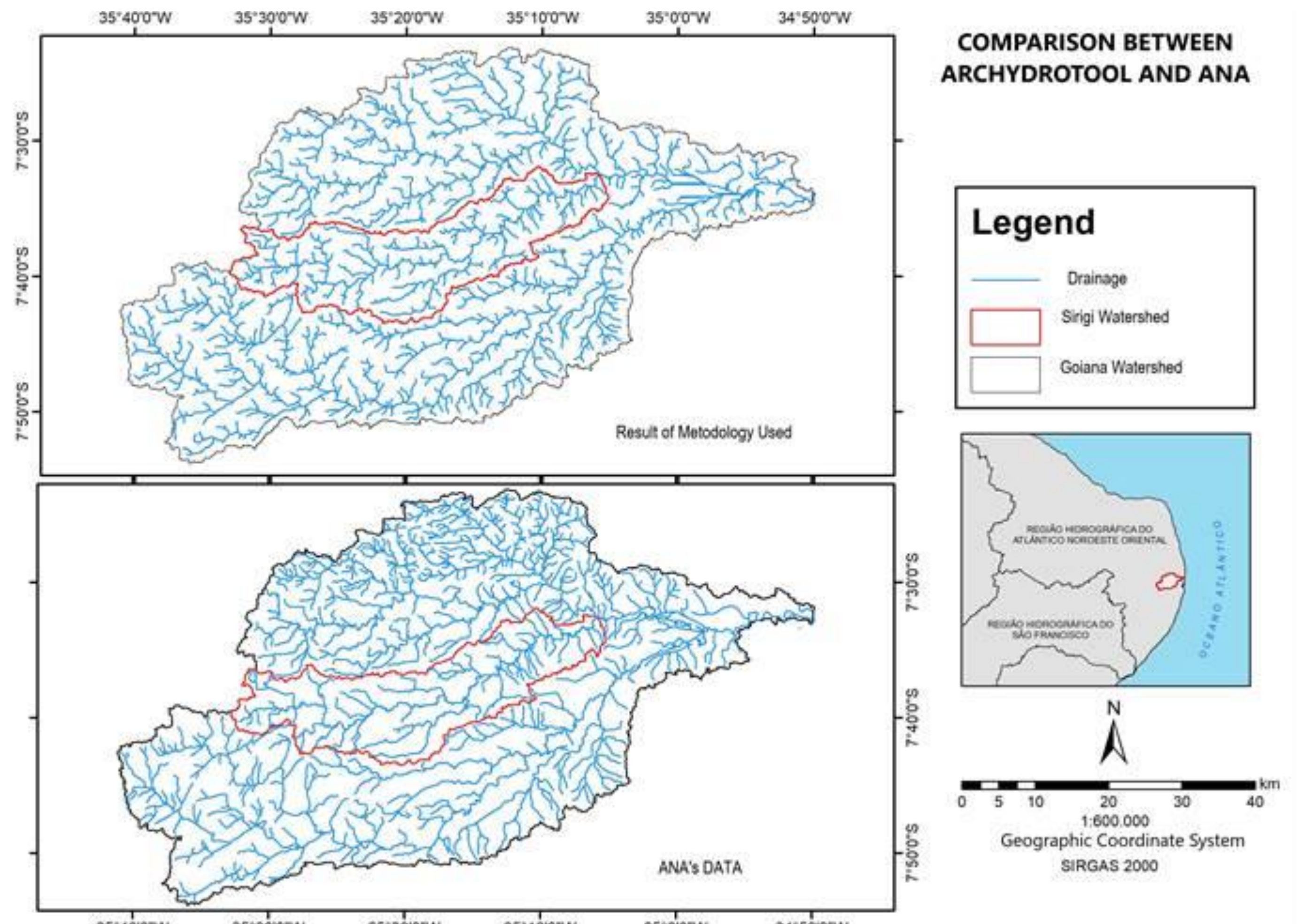

Figure 3. Comparison between the Result obtained through ArcHydroTool (above) and the offical data from ANA (Bellow).

The sub-watershed of Sirigi River shows more similarities with the data from ANA than the Goiana River Watershed, which seems to have some differentiation in its mouth (Figure 4). Two hypotheses can explain why. The first is a possible alteration in the watershed, from natural or manmade origin, which can occur between the data collection done in 2000 which resulted to MDE SRTM and the generation of the database of

ANA published in 2013. The second, simpler and more probable, are the errors from MDE itself.

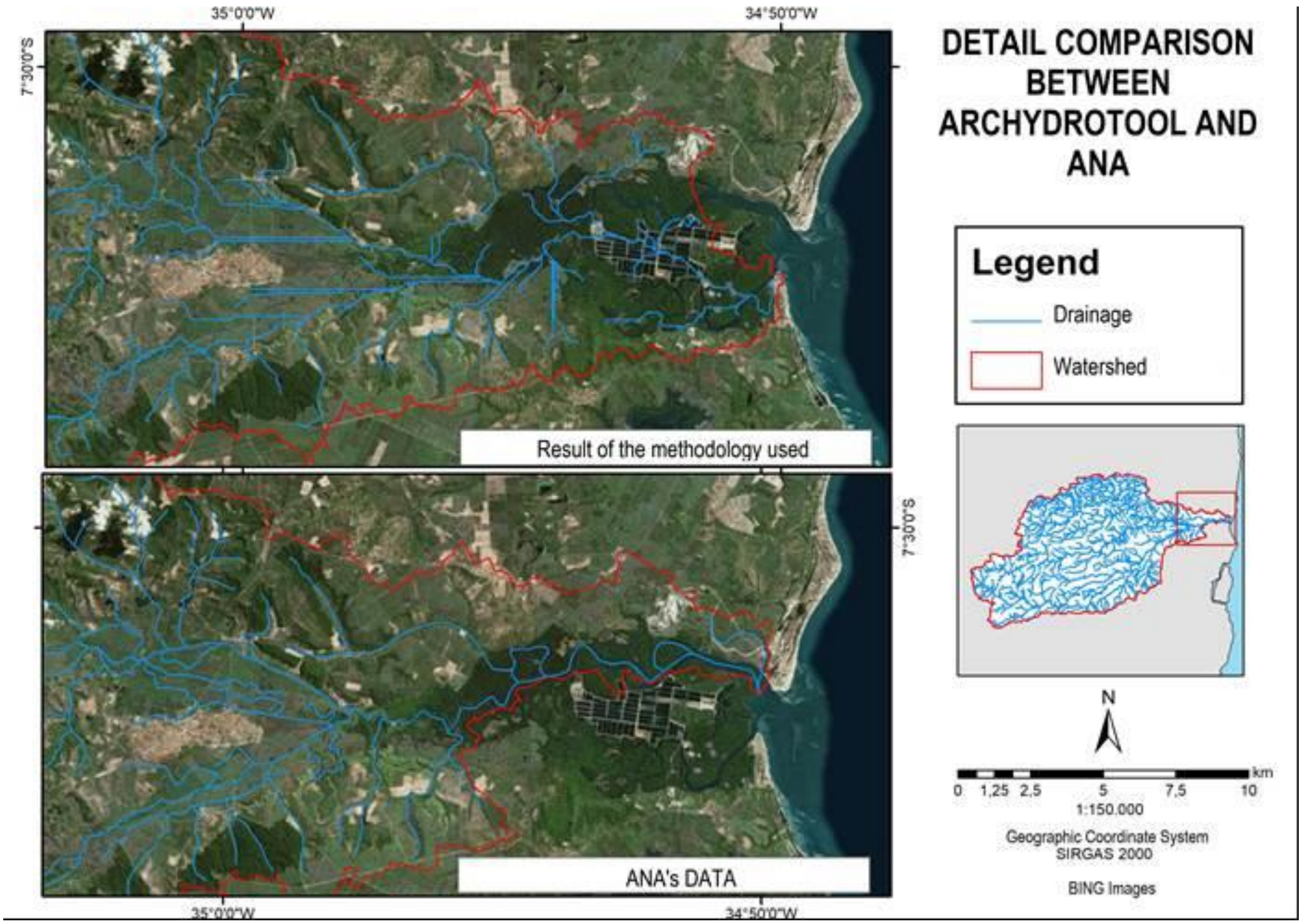

Figure 4. Detailed comparison of the Goiana River estuary between the Result obtained through ArcHydroTool (above) and the Official data from ANA (below).

Hypotheses of the Result

In order to measure if some modification in the Goiana River estuary has occured, to be able to have influenced this result, it was made use of satellite images as proposed by Camargo, (2016) and Silva et al. (2013) which compared the Landsat 7 satellite image with the false colour composition R5G4B3 from 2000, when it was done a data collection which results in SRTM and a Landsat 8 satellite image with false colour composition R6G5B4 from 2013, referring to the date of the publication of the ottocoding watershed database in the Oriental Northearsten Atlantic published by ANA (Figure 5). Both images were obtained on the U.S. Geological Survey Earth Explorer (USGS).

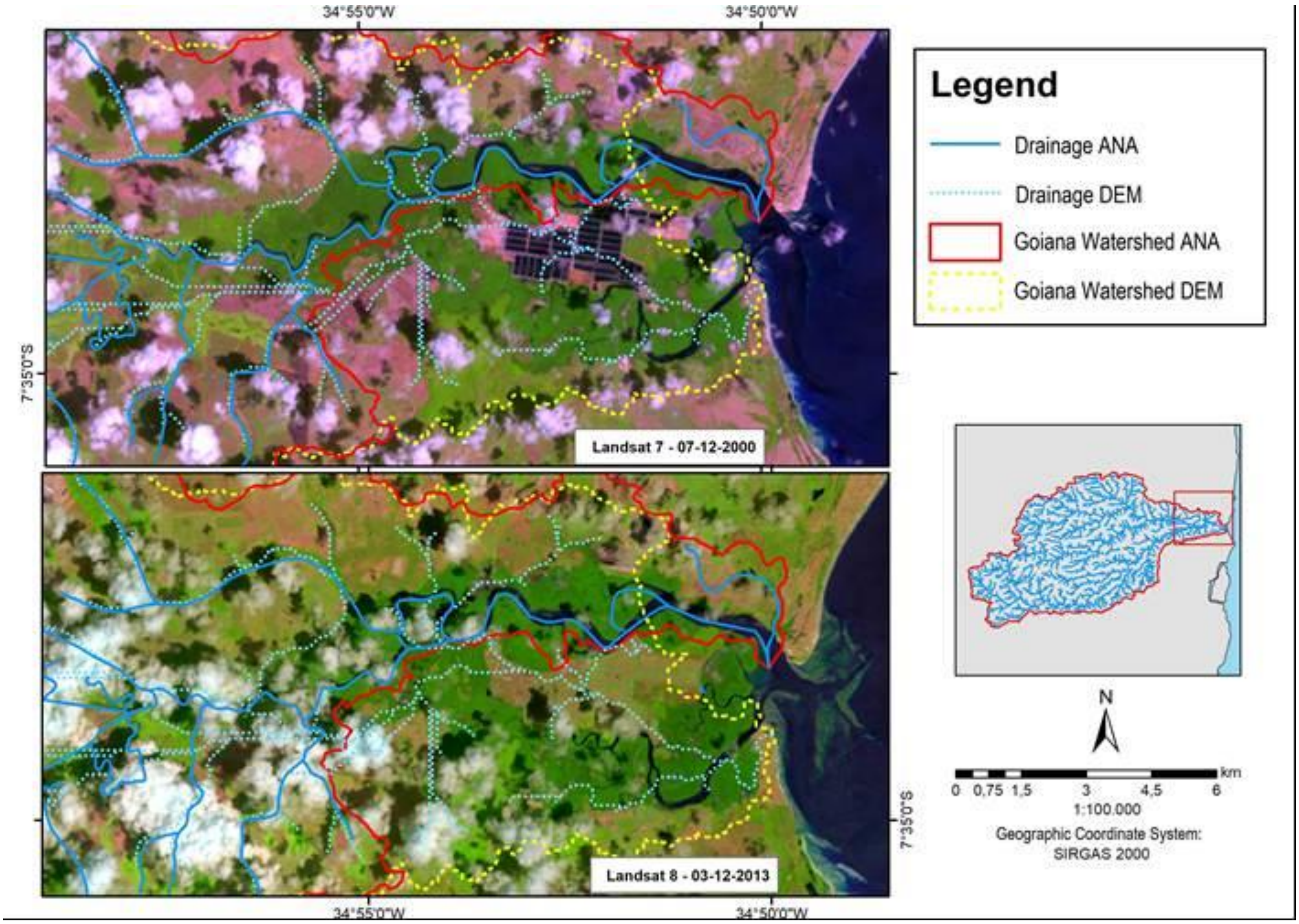

Figure 5. Detailed comparison of the Goiana River estuary between the Landsat 7 images from 2000 (above) and Landsat 8 from 2013 (bellow).

Some changes were identified in figure 5, in a spatial form for land use between 2000 and 2013 in the Goiana River mouth. However, those changes are not of such magnitude that justifies that result difference. By the way, it is observed that the drainage obtained by MDE through the methodology explained in figure 2 is confused with the drainage of Megaó River which shared the same estuary, as it is reported by Silva, J. B.; Galvíncio, J. D.; Corrêa, A. C. de B.; Silva, D. G. da and Machado, C. C. C. (2011).

Then, we started considering that the result of the differentiation between the data compared comes from failures of the MDE used. Analysing the altimetry of the mouth, we noticed that MDE shows little difference in the altitude (Figure 6). That occurs due to the fact that Goiana River mouth is classified, according to Silva et al. (2011), as a Coastal Plain-like estuary. The estuaries are transitional environment between the continent and the ocean, in the areas of the mouth causing dilution in the salty water from the sea by the dilocarcinus of the river. Silva, J. B.; Galvíncio, J. D.; Corrêa, A. C. de B.; Silva, D. G. da and Machado, C. C. C. (2011) defines a Coastal Plain Estuary as:

[…] estuaries are found in the coastal plains which originated during the marine transgression in the Holocene, flooding the river valleys. The flooding process was more heightened than the sedimentation one, making the current topography of the estuaries similar to the river valley. They are generally shallow, barely going beyond 30 meters deep.

The processing, in its automated routine, ends up generating the drainage features and the capture areas from altimetric data from MDE which is the bases for every processing. This situation confirms the fact that the delimitation of the sub-watershed of Siriji River in figure 3 shows a better performance, because of its exhilarating inside the continent, where the MDE is more precise, because it is not confused with the sea.

Even though Santos, P. R. A.; Gaboardi, C.; Oliveira, L. C. (2006) and Oliveira and Paradella (2008 apud Oliveira, P. T. S.; Sobrinho, T. A.; Steffen, J. L. and Rodrigues D. B. B. 2010) have shown the precision of the MDE obtained through SRTM for the flat and hilly areas of the Amazon region, for the estuarine watershed in coastal plains its efficiency was not proved, for automated routines.

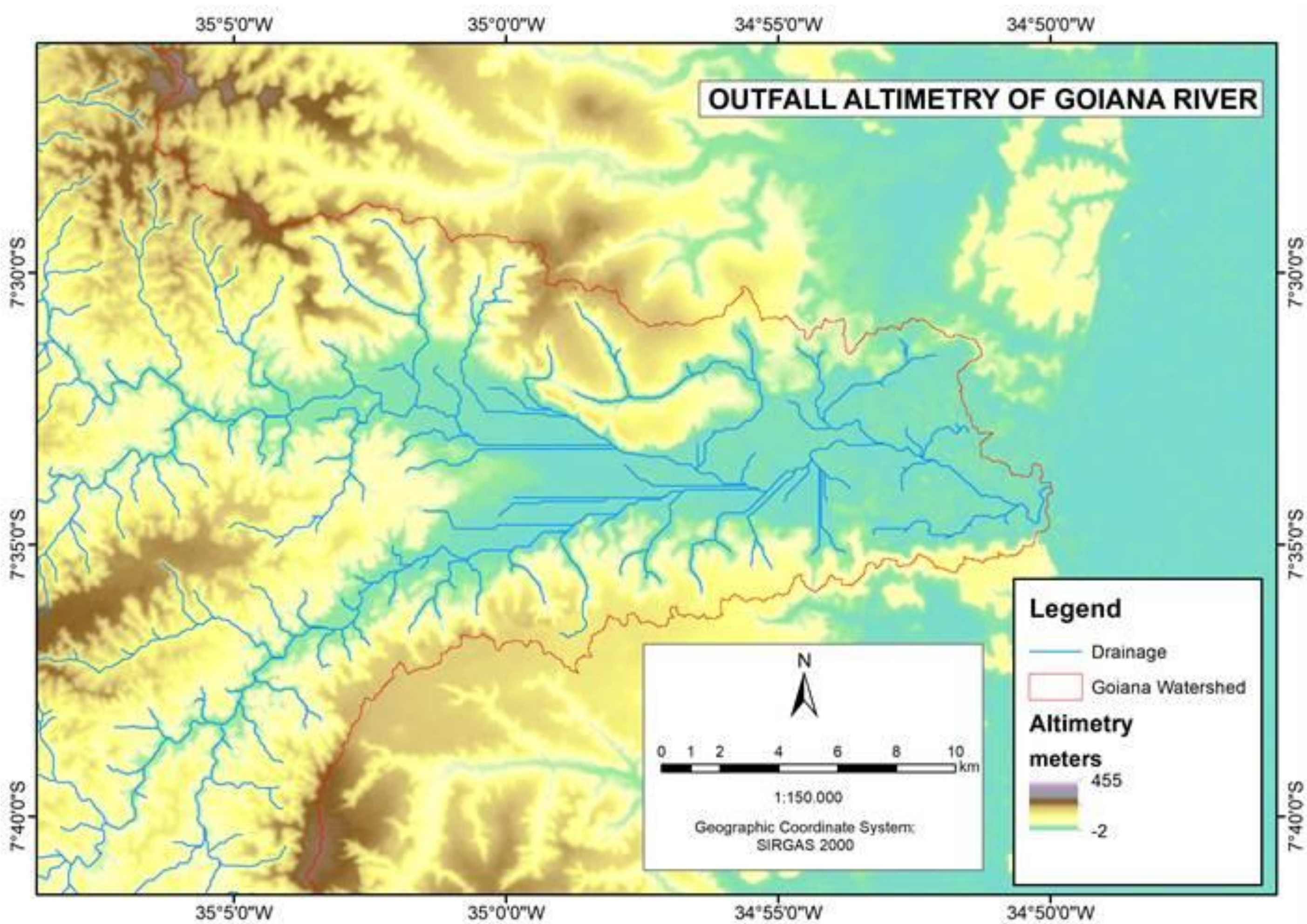

Figure 6. Altimetric Map of Goiana/Megaó River estuary compared with vectorial results of the delimitation Goiana River watershed.

Morphometry

The results obtained for the morphometric analysis aims at assessing if even having a clear alteration in figure 3, the indexes could indicate the same situations to the watershed. The areas and perimeters found have not changed that much, those are the two main variables that define the indexes (Chart 1). The coefficients of compactness show that, even though that is slightly different, having the result obtained equal Kc 2,3752 and the data of ANA equal Kc 1,9117, still show, according to Silva and Mello (2008) who report that the watershed present an elongated format. This index, along with the results of circularity of the water (Ic) confirms that the watershed is efficient for the water flows in the channel in rainier periods, that is, there are less chances for flooding to occur in this watershed.

The index of density of drainage for both data were the closest. According to Villela and Mattos (1975), the density of the watershed drainage varies between <0,5 kilometer/square kilometer (for the poor-drained watersheds) and 3,5 kilometer/square kilometer or more (for exceptionally well-drained watershed). That classifies Goiana River water as a having a regular watershed drainage.

Chart 1. Comparison between the Morphometric datas.

Index	Data of the Result	Data from ANA
Area	2864,94 km²	2837,46 km²
Perimeter	454,066 km²	363,692 km²
Index of Circularity (Ic)	0,1747	0,2696
Density of drainage (Dd)	0,7959 km/km²	0,7896 km/km²
Coefficient of Compactness (Kc)	2,3753	1,9117

4. Conclusions

The delimitation of the watershed originated from the methodology applied is efficient, however, for the watershed with coastal plain estuary, especially the Digital Elevation Model. As well as, it is highlighted the importance of the operator of Geographical Information Systems.

When it comes to Goiana River watershed, even though it has occurred differentiations in the Morphometric Indexes. For the diagnosis of the watershed, both methodologies compared move towards the same interpretations, confirming once more the methodology efficiency towards the watershed planning.

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