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Application of the SMAP hydrological model in the determination of water production in a coastal watershed [1]

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R E S U M O

A bacia hidrográfica do rio Almada é um importante manancial para o abastecimento público regional, e se sobressai como um dos principais sistemas naturais regional, contudo, sofre forte pressão antrópica a oeste com a expansão de atividades agropastoris e leste com intensa pressão de especulação imobiliária. Diversos trabalhos ressaltam que a conversão do uso e ocupação da terra interfere nos processos hidrológicos naturais alterando de forma significativa a disponibilidade e qualidade da água, neste contexto, este trabalho objetivou realizar a modelagem hidrológica das sub-bacias hidrográficas do rio Almada com intuito de correlacionar os dados de vazão de cada uma das sub-bacias hidrográficas do Rio Almada com o uso e ocupação da terra. Para tanto, a metodologia empregada foi o modelo hidrológico *SoilMoistureAccounting Procedure*, e a aplicação de técnicas de Sistema de Informação Geográfica. Os resultados demonstraram que as sub-bacias do alto curso do Almada possuem as menores vazões ocasionadas pela conversão do uso da terra de mata para pasto e solos exposto. As sub-bacias do curso médio, apresentaram as maiores vazões por possuírem as maiores áreas dentro da bacia em estudo e por estarem cobertas com mais de 65 % de suas áreas sob mata e cabruca. E as sub-bacias do baixo curso do Almada irrigam áreas fortemente antropizadas, contudo são paisagens com alta produção de água. Apesar de apresentarem paisagens distintas os resultados evidenciam que as sub-bacias do rio Almada em análise não possuem variação muito grande entres as vazões.

Palavras-chave: Bacia Hidrográfica; planejamento ambiental; modelagem hidrológica

Application of the SMAP hydrological model to determine water production in a coastal catchment area

A B S T R A C T

The hydrographic basin of the Almada river is an important source for the regional public supply, and stands out as one of the main regional natural systems, however, it suffers strong anthropic pressure to the west with the expansion of agropastoral activities and east with intense pressure of real estate speculation. Several studies have emphasize that the conversion of land use and occupation interferes with natural hydrological processes, significantly altering water availability and quality. In this context, this work aimed to perform the hydrological modeling of the hydrographic sub-basins of the Almada river in order to correlate the flow data of each of the sub-basins of the Almada River with the use and occupation of the land. For that, the methodology used was the Soil Moisture Accounting Procedure, and the application of Geographic Information System techniques. The results showed that the sub-basins of the upper course of Almada have the lowest flows caused by the conversion of land use from pasture and exposed soils. The sub-basins of

[1]Data extracted from the doctoral thesis of Danusa Oliveira Campos

the middle course had the highest flows because they had the largest areas within the basin under study and because they were covered with more than 65% of their areas under forest and cabruca. Also, the sub-basins of the lower course of Almada irrigate the heavily anthropized areas, yet they are landscapes with high water production. Although they present distinct landscapes, the results show that the sub-basins of the Almada river in analysis do not have very large variation between the flows.
Key words: Watershed, environmental planning; hydrological modeling.

Introduction

Natural hydrological processes have been affected by human activities that have significantly changed the availability and quality of water around the world (Padovesi-Fonseca et al., 2010). These problems, as well as their origin, have become the focus of world attention (Samson and Charrier, 2011).

Modeling techniques enhance the understanding of hydrological processes and are shown as essential tools for environmental planning. Hydrological models are defined by Rennó and Soares (2000) as a mathematical representation of the flow of water and its constituents on some part of the surface and / or sub-surface. These models have a framework formed by a set of equations that correlate input data with outputs, so it is an approximation of the real system, where its inputs and outputs, functions of time and space are measurable variables (Castilho, 2005).

The hydrological models are based on the processes that operate in the hydrological cycle, characterizing the natural behavior of the water in relation to its events, changes and antropic intervention (Villela and Mattos, 1975). The models are designed to describe and quantify the processes that form the runoff caused by precipitation over a river basin, based on historical data, and provide an estimate for future flows (Vélez, 2001).

It is important to remember that the watershed constitutes an extremely complex physical system, usually with different physical properties, as well as heterogeneous variables in time. Any attempt to represent it through a mathematical model, however complex and detailed, is always an approximation of reality. Their adequacy to the studied problem can only be judged by comparing the calculated results with the field observations (Santos, 2010).

The attempt to represent a simplified version of the complex system results in limitations in the quantity and quality of hydrological data, in the difficulty of mathematically formulating some of the processes and in the simplification of the spatial behavior of some variables and phenomena (Barbosa, 2006). The choice of the hydrological model depends on the objectives of the work, quantity of data available, basin properties and their use, proposed methodology, model knowledge, budget and schedule (Tucci, 2009).

There is a great diversity of models used in the management of water resources, among them is the precipitation-flow of hydrologic models. The rainfall-flow models simulate the flow from precipitation data, through algorithms that represent the terrestrial phase of the hydrological cycle and encompassing processes of temporary storage of water, its circulations and state transformations (Vendruscolo, 2005). Its structure is based on the discretization of the river basin, input variables, process integration, physical data acquisition of the basins and the determination of the parameters (Tucci, 1998).

Tucci (1998) and Coelho (2006) stated some obstacles of the rainfall-rainfall models: the precariousness of rainfall data representative of the region and climate, the estimation of evapotranspiration, the doubt of connection of aquifers to the river, the characterization of soil type, definition of the key curve (of the adjustment data, if any), process simplifications adopted in model elaboration, uncertainty in the transfer of model parameters, as well as function that may be nonlinear, unknown and complex.

Despite the limitations, Mota (1995) mentioned mathematical models as tools capable of providing quantitative answers of the physical phenomena that help to interpolate, simulate and predict the physical phenomenon under study; assist in the definition of methodologies; characterize the influence of the variables that participate in the model and help to suggest research priorities.

Examples of hydrologic precipitation-flow models include, the HEC-HMS-Hydrologic Modeling System (Peters, 1998) developed by the Hydrologic Engineering Center used in the design of drainage systems and quantifies the effect of land use change on floods; the Hydrological Model for Large Basins MGB-IPH (Tucci, 1998) developed by the Institute of Hydraulic Research, Système Hydrologique Européen - SHE one of the most detailed (Abbott et al., 1986), Stream flow Synthesis and Reservoir Regulation models-SSARR (Rockwood, 1968), Soil and Water Assessment Tool - SWAT (Arnold et al., 1998), TOPMODEL (Beven and Kikrby, 1979).

Moreira (2005) pointed out that at the national level, the rainfall-flow models MGB-IPH and SMAP are examples of well-publicized conceptual models.

SMAP was developed in 1982 by Lopes, Braga and Conejo, presented at the International Symposium on Rainfall-Runoff Modeling, Mississipi, U.S.A., and published in Water Resources Publications (Lopes et al., 1982). It was created based on the experience of applying the Stanford Watershed IV and Mero models in works carried out in the Department of Water and Electric Power of the State of São Paulo.

It presents a simple structure, for continuous series, and uses the Soil Conservation Service - SCS (USDA, 1986) method for the separation of runoff. It is a conceptual and concentrated model that seeks to represent the storage and water flows in the basin through fictitious linear reservoirs. It is considered a model that requires the obtaining of few parameters and low computational demand (Castanharo et al., 2007, Lima; Alves, 2009). The model uses as input data, the total precipitation and evaporation heights in the desired time interval, the drainage area of the basin and the initial conditions of the basin (Lopes et al., 1982).

The SMAP was initially developed for daily time interval, after which adaptations were made in its structure presenting hourly and monthly versions. In its monthly version, the concept of field capacity and the surface reservoir are suppressed, since damping occurs at shorter intervals than the month (Lopes et al., 1982). The monthly version of this model uses in its physical scheme, two linear reservoirs representing the soil (upper layer) and the aquifer (lower layer). Its application has shown good results in different regions of Brazil (Paiva et al., 2006, Nascimento et al., 2009; Caponi, Silva, 2013).

Paiva et al. (2006) developed a methodology to determine natural outflows in the Vacacaí Mirim River Basin, and observed the difference between the flow demanded for the flooding of the rice fields and the available flows. For the study, the hydrographic basin was subdivided into 14 sub-basins and 14 characteristic points and the estimation of the flows occurred through the model of hydrological simulations SMAP implemented in environment MATLAB.

Lima and Alves (2009) evaluated the applicability of the SMAP in estimating the average flow for the Cachoeira Manteiga and Porto de Extrema hydrographic basins, located in the Upper São Francisco Basin (MG). In order to do so, it fed the model with simulated precipitation data by hydroclimate downscaling and performed automatic calibration, assuming as its objective the sum of the root of the quadratic error between the observed and calculated flows. For validation of the calibration used, the coefficient of efficiency of Nash and Sutcliffe was used. Only after correction of the simulated precipitation data using Probability Density Functions technique were better results obtained in the simulation of the estimated flows.

Caponi and Silva (2013) tested the usefulness of genetic algorithms in the calibration of the SMAP model with monthly discretization of 6 parameters. The performance of the genetic algorithm was applied in three sub-basins of the São Francisco River. The genetic algorithm performed well in seeking the global minimum of tthe objective function, revealing itself as an extremely capable and robust search technique. The authors have emphasized that the proposed genetic algorithm is even more useful when interactivity with the user occurs.

The evolution of the techniques used for research on water resources requires the use of instruments that analyze hydrological processes in a qualitative and quantitative way (Melo, 2010). Geographic Information Systems (GIS) have been used worldwide in hydrological studies, since they are able to store, manipulate and process large databases, as well as variables in time and space (Camara, Davis; Monteiro, 2001). Numerous studies (Melo, 2010; Pereira, Kayser and Collischonn, 2012) have addressed the topic, hydrological modeling of the catchment area integrated to the Geographic Information System.

All over the world, studies correlating vegetation and hydrological cycle corroborate the results obtained by Albuquerque (2010), which correlated the specific flow (liters / second / Km^2) of three microcatchments with the same rainfall regime, but different soil uses. In the rainy season, the main inflow of the microbasin used integrally for short cycle and pasture agriculture was up to seven times greater than the microbasin covered by native forest. In the dry season, the flow of the river under forest use was always higher than that of the river with agriculture. The results showed a direct relationship between the attenuation of the flow peaks and the vegetation complexity, that is, the microcatchments with greater natural coverage had a more efficient flow regulation. The author concluded that the vegetal cover provides an essential hydrological environmental service for the preservation of water sources.

When analyzing data on a world scale, Bradshaw et al. (2007) concluded that forests are correlated with flood risk and flood-related disasters, reinforcing the need to conserve forests on a large scale to protect human well-being. Ziegler et al. (2004), Makarieva and Gorshkov (2007), Maes et al. (2009) corroborate with Ellison et al. (2012), who concluded his research pointing to the inappropriate use and management of the earth as factors that can interfere in the hydrological cycle and consequently, in forest ecosystems.

In Brazil, the research developed by Coleridge (2006), Smaniotto (2007), Balbinot et al. (2008), Tundisi and Tundisi (2010), Germer (2010), Bezerra et al. (2011) and Fernandes et al. (2011) concluded that the vegetation cover maintains the regularity of the flow of a river basin by means of regulation, through the flow in the low flow periods of drought.

In Southeastern Bahia, the hydrographic basin of the Almada River (BHRA) is an important source for the regional public supply, and stands out as one of the main natural systems of the Cacao Region of Bahia, which protects native forest formations. However, anthropogenic activities to the west with the expansion of agropastoral activities and to the east with strong pressure of real estate speculation, since it is occupied by districts of Ilhéus like São Domingos and São Miguel, and the subdivisions are subjected to constant deforestation.

In this context, this work aimed to perform hydrological modeling of the Almada river basin, considering the geoenvironmental characteristics of ways to evaluate the water production capacity in the different subunits and correlate them with land use and occupation.

Materials and Methods

Localization and characterization of the area

The water catchment area of the Almada river, is located in the South Coastal region of Bahia, between the coordinates of 14° 26 'and 14° 50' S and 39° 03 'and 39° 44' W, being limited to the north and west by the hydrographic basin of the De Contas River, to the south by the watershed of the Cachoeira river and to the east by the Atlantic Ocean (Figure 1).

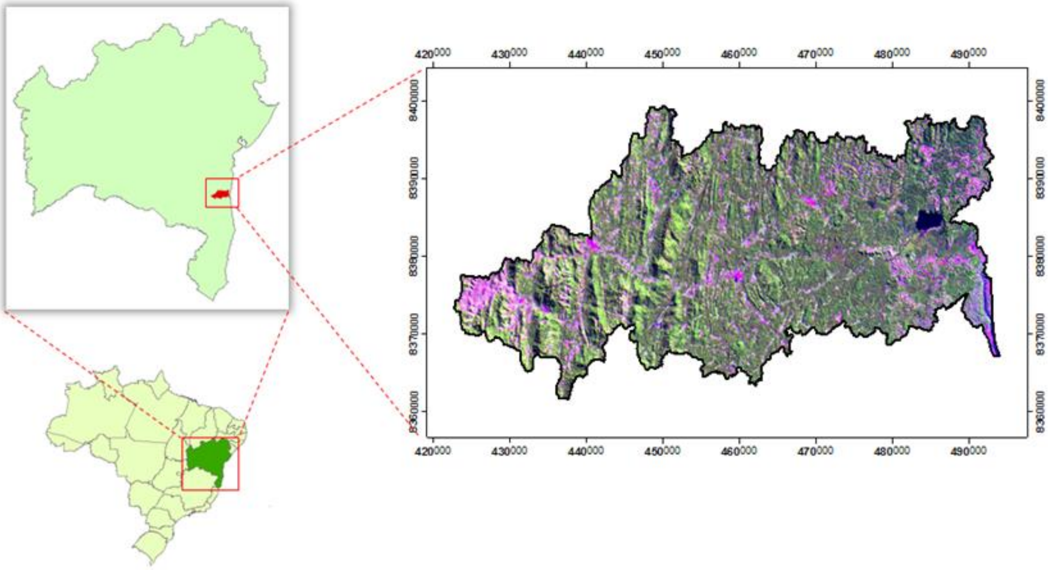

Figure 1. Location of the hydrographic basin of the Almada river, southeast of Bahia.

The hydrographic basin is cut by the BR-101 while the interstate and intermunicipal highways have an area of 1,572.5 km² and perimeter of 332.4 km. The Almada river, the main tributary of this basin, has its source located in the Serra do Chuchu, in the municipality of Almadina, and its mouth in Barra de Itaípe in the municipality of Ilhéus, covering about 138 km. It includes part of municipalities of the Ilhéus-Itabuna microregion, namely: Almadina, Coaraci, Floresta Azul, Ibicaraí, Barro Preto, Itajuípe, Itabuna, Ilhéus and Uruçuca.

The upper reaches of the BHRA are represented by the Alto do Almada and Macacos river sub-basins, which together represent a total area of 265.35 km^2 covering about 16.9% of the whole territory. The average Almada course has a greater number of sub-basins comprising 6, and among them is Ribeirão do Braço Norte, the sub-basin with the largest area of the territory and the sub-basin of Ribeirão Juçara with the smallest area (67.28 km^2); still, in this stretch there are important tributaries like the Braco river that supplies municipalities of the region. The low course stands out for presenting sub-basins with greater population density and therefore, greater water demand.

Analytical Method

BHRA cartographic documents, such as thematic maps, satellite images, radar images, aerial photographs and topographic charts produced by the Northeast Development Authority (SUDENE) covering all areas of BHRA were developed: Ibicaraí (SD-24-YBV), Itabuna (SD-24-YB-VI) and Ubaitaba (SD-24-YB-III).

The drainage network was also extracted from sheet 14_405_SN of the TOPODATA radar image obtained from the Geomorphometric Database of Brazil of the National Institute of Space Research (INPE), with quality and resolution of 30 m (Valeriano, 2008).

The data of the Climate Typologies were digitized and adapted from the work of Roeder (1975). The rainfall data were extracted from the SEI (2003), elaborated with climatological normals from the period 1961 to 1990 of the National Department of Meteorology - DNMET. Land use data were provided by Franco (2010) and were corrected in the field for the year 2015.

In order to determine the potential evapotranspiration of the BHRA, the data used were obtained from the EMBRAPA site, referring to the National Institute of Meteorology (INMET) stations located in the municipalities of Ilhéus, Canavieiras, Salvador and Vitória da Conquista; its seasonal distribution was calculated by means of the isohyetal method, through the interpolation of stations data by the Inverse Distance Weighting (IDW) method using the ArcGIS 9.2 program.

The calculated flow of the main sub- basins of the BHRA were obtained from the Soil Moisture Accounting Procedure - SMAP (Lopes, et al., 1982) in its monthly version. For this hydrological model, the input data used were: (1) monthly precipitation of six rainfall stations (located near and within the boundaries of the BHRA) obtained on the National Water Agency (ANA) website; (2) flow data were obtained from the ANA site; (3) and evapotranspiration was calculated by the Thornthwaite method (1948), the temperature data used were those of the CEPLAC / CEPEC meteorological station.

The calibration phase that aims to determine the values of the model parameters was performed by trial-error; therefore, different sets of parameters were examined until reaching a vector of parameters that could represent the natural response of the basin to that precipitation (Moreira, 2005).

Results and Discussion

Environmental variables

Through the geometric, relief and drainage network parameters, eleven hydrographic sub-basins (Figure 2) were mapped: Alto do Almada, Ribeirão dos Macacos, Ribeirão Papaia, Ribeirão Braço Norte, Ribeirão Juçara, Ribeirão Vai-Quem-quer, Rio do Braço, Rio Água Preta do Mucambo, Rio Comprido, Lagoa Encantada, Riacho das Sete Voltas and rio Tiriri.

The delimitation of sub-basins allows a more detailed analysis of the territory, identifying diffuse environmental problems, punctuating the areas of environmental degradation, facilitating the understanding of the processes and the degree of commitment of the landscape (Souza and Fernandes, 2000).

The upper reaches of the Almada river basin are represented by the Alto do Almada and Rio dos Macacos sub-basins, which together show a total area of 265.35 km^2, covering about 16.9% of the entire territory. Almada's middle course has a greater number of sub-basins comprising six, has an area of 823.6 km^2, among which is the Ribeirão do Braço Norte sub-basin, with the largest area of the territory and the sub-basin of Ribeirão Juçara area; still, in this stretch there are important tributaries like rio do Braço that supplies municipalities of the region. The low course stands out for presenting sub-basins with greater population density and therefore, greater water demand.

The flows of the sub-basins were obtained with the entry of monthly precipitation data from six rainfall stations, located near and within the limits of the BHRA (Table 1 and Figure 3), as well as evapotranspiration data (Table 2).

The basin area of influence of each pluviometric station, determined by the method of Thiessen, resulting in 6 different zones (Table 3), can be observed in Figure 3.

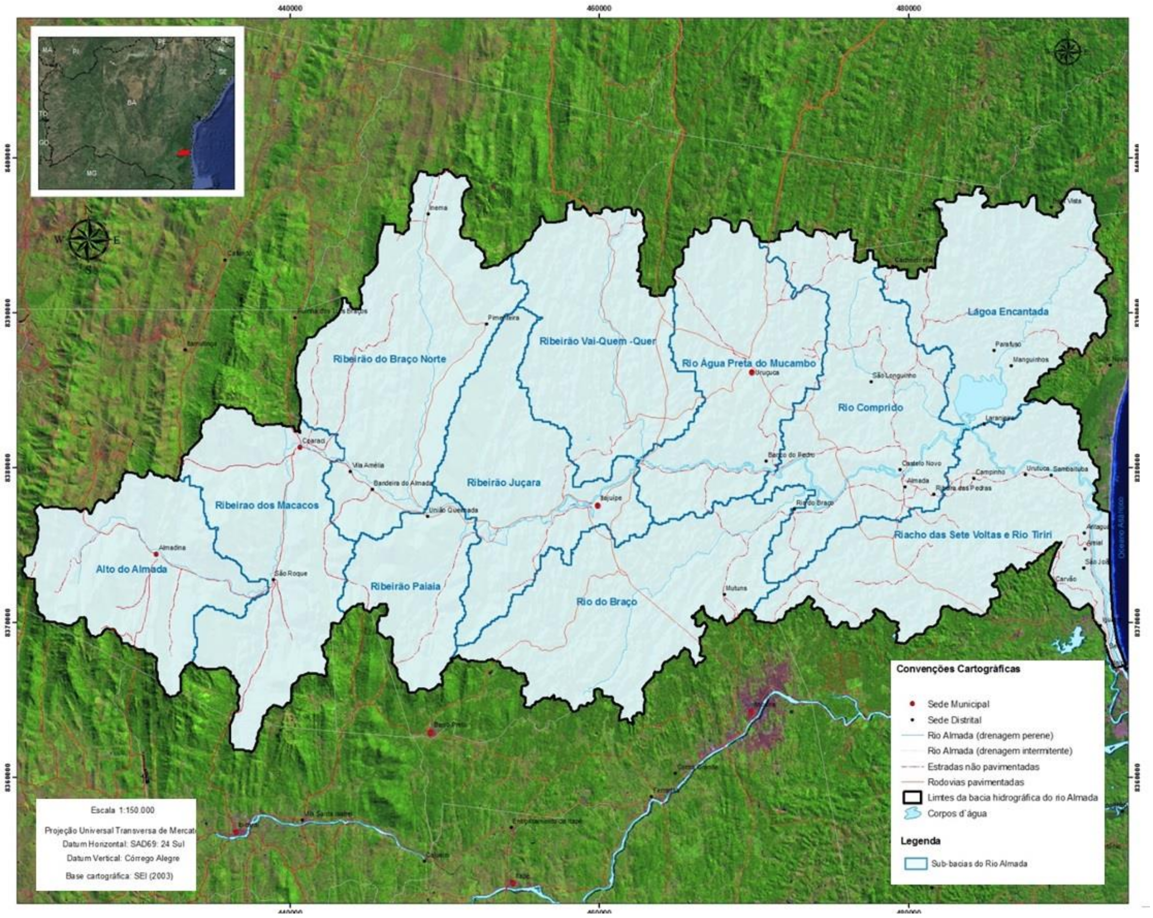

Figure 2. Location of the hydrographic sub-basins of the Almada-BA river.

Table 1 – Monitoring stations used in the hydrographic modeling of the Almada river basin

Nome	Código da estação	Tipo	Entidade	Latitude	Longitude
Coaraci	639009	Pluviométrica	CEPLAC	-14° 38’ 26’’	-30° 33’ 12’’
Floresta Azul	1439002	Pluviométrica	ANA	-14° 51’ 35’’	-39° 39’ 30’’
Ibicaraí	1439089	Pluviométrica	ANA	-14° 52’ 10’’	-39° 35’ 00’’
Itajuípe (Piranji)	1439023	Pluviométrica	ANA	-14° 40’ 40’’	-39° 23’ 22’’
Lomanto Junior	1439001	Pluviométrica	ANA	-14° 48’ 37’’	-39° 28’ 17’’
EMARC- Uruçuca	638034	Pluviométrica	CEPLAC	-14° 35’ 00’’	-39° 16’ 00’’
Provisão II	53091000	Fluviométrica	ANA	-14° 38’ 00’’	-39° 07’ 00’’
CEPEC	638047	Climatológica	CEPLAC	-14° 45’ 23’’	-39° 13’ 57’’

Source: ANA (2013), CEPLAC (2014).

Table 2 – Climatological stations used in the hydrographic modeling of the Almada river basin

Nome	Entidade	Latitude (S)	Longitude (W)	Altitude (m)
Ilhéus	INMET	14,80	39,07	60
Canavieiras	INMET	15,67	38,95	4
Salvador	INMET	13,02	38,52	51
Vitória da Conquista	INMET	15,95	40,88	839

Source: EMBRAPA (2014).

Table 3 – Monitoring climatological stations used in the hydrographic modeling of the Almada river basin

Número	Nome	Área	Área/Área Total
1	Coaraci	374,4	0,238192105
2	Floresta Azul	37,2	0,023711144
3	Ibicaraí	20,3	0,012968025
4	Itajuípe (Piranji)	381,3	0,242451211
5	Lomanto Junior	77,3	0,049138643
6	EMARC- Uruçuca	682,0	0,433538872
	Total	1.572,5	1

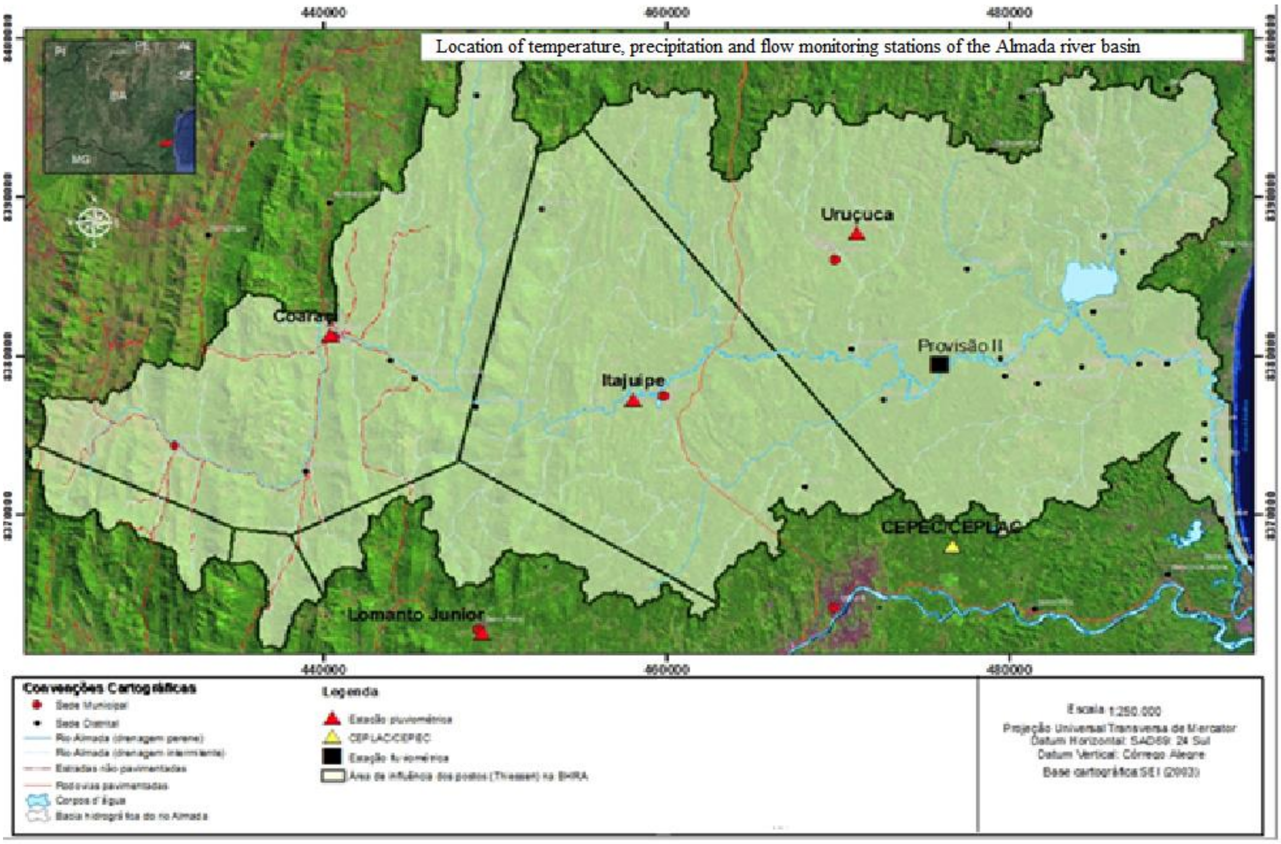

Figure 3. Location of temperature, precipitation and flow monitoring stations.

The average hydrological behavior of the flow in the section of Provision II (Figure 4) shows that the peak of flow occurs in April (month 4), as of May, there is a decay of the flow until the month of September (month 9) followed by the month of October. The flow, precipitation and evapotranspiration data were integrated into the SMAP beginning with the hydrological year of the Almada river basin, which starts in September and ends in August of the following year.

Calibration was carried out for the entire catchment area of the Almada river (1,572.5 km^2). The parameters were calibrated within the variation range suggested by Lopes et al. (1982). The calibration of the model parameters was performed in a conventional manner, where the historical data are divided into two periods, one for calibration and one for validation. The period of data used for the calibration was from September 2000 to August 2005, and the historical data for the validation were from September 2005 to August 2012. The selected periods corroborate with Lopes et al. (1982) which indicates that the period for monthly calibration is 2 to 9 years and Canedo (1989), who evaluated the ideal sample size in the calibration phase and concluded that a period of 5 years could be considered as ideal.

The result of the calibration can be observed in Figure 5, which shows the hydrogrammed flow observed at the fluviometric station and the calculated flow estimated by the simulation.

The quality of the calibration adjustment was analyzed by observing the adherence of the calculated flow chart to the observed flow rate, Pearson's linear correlation coefficient (R2), determination coefficient (R2) as well as the Nash and Sutcliffe efficiency index. The validation of the flow rates obtained by the calibration obtained high values of linear correlation of 0.90, the coefficient of determination of 0.78 and the coefficient of Nasch 0.90 presenting, therefore, good final results of the calibration.

Collischonn (2001) pointed out that the representativeness of the model is considered adequate for Nasch values above 0.75. The values of the parameters used in the calibration are presented in Table 4.

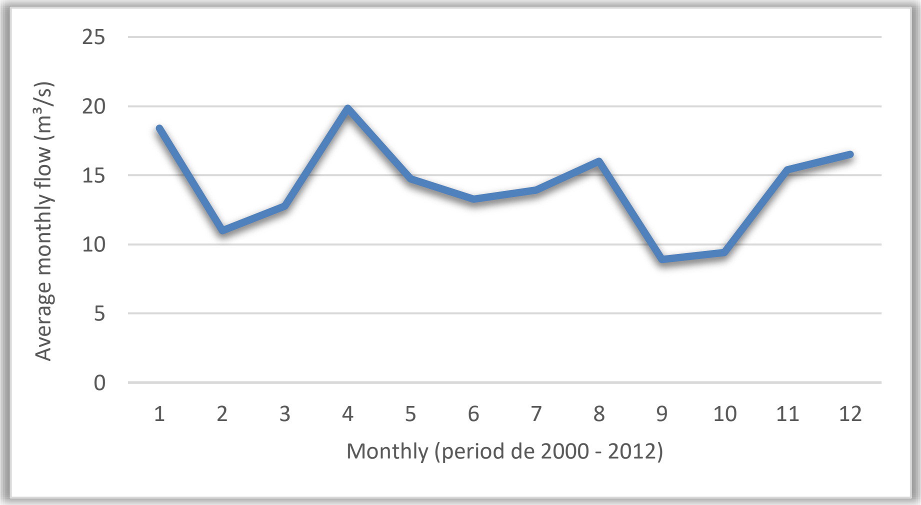

Figure 4. Average monthly hydrograph of the Almada River for the period from 2000 to 2012 at Provision II station.

Table 4 – Range of values used in the calibration of the SMAP model for the Almada river basin

Parameter		Values
Soil saturation capacity (mm)	Str	900
Surface runoff recession constant (dias)	Pes	7
Underground Recharge (%)	Crec	0,1
Basic flow recession constant	kkt	1
Initial soil moisture	Tuin	2,0
Initial baseline	Ebin	0,1
Área de drenagem (km^2)	Ad	1.572,5

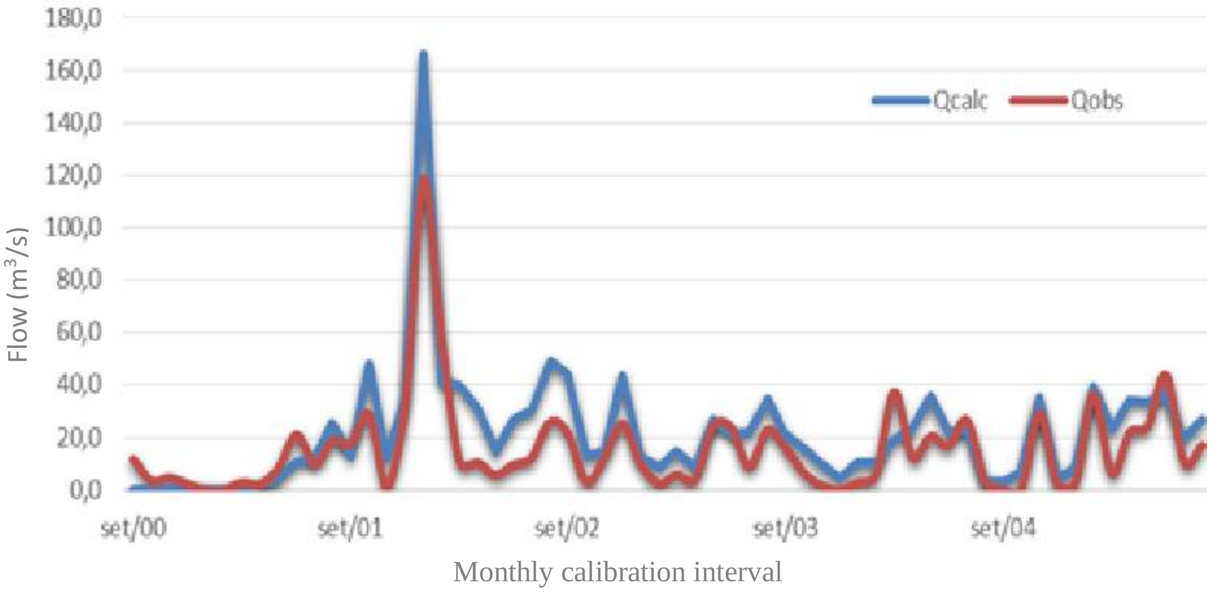

Figure 5. Observed flow series and flow calculated for monthly calibration interval between September 2000 and August 2005.

After validation of the parameters used in the calibration, the flow simulation of each of the 11 sub-basins of the Almada River was performed using the period from September 2006 to August 2012.

The flows obtained from the sub-basins can be observed in Figure 6, which presents a smaller water production in the Alto do Almada and Ribeirão Papaya sub-basins, located in the upper course, the highest flows were determined in the sub-basins of the Braço river and ribeirão Braço do Norte

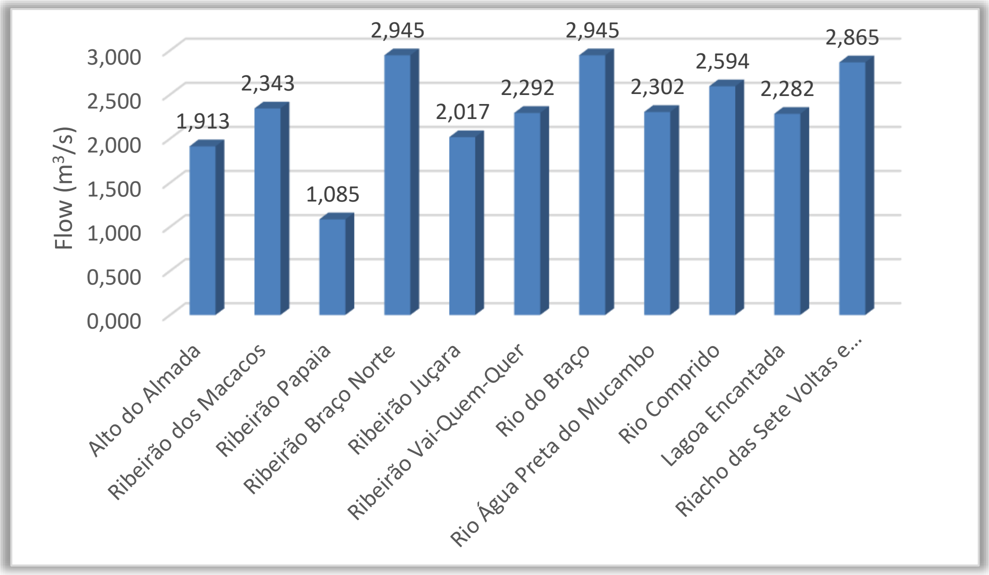

Figure 6. Average flow of the sub-basins of the Almada river.

Land use in the studied river basin has the following categories delimited by Franco (2010) (Figure 7):

• Wetlands: flat, low, periodically flooded areas usually covered by hygrophilous vegetation of várzea or mangrove;

• Restinga: herbaceous, shrub or forest formations on quaternary sandy sediments of marine, fluvial, lagoon or wind origin;

• Urban Area: the cities of Almadina, Coaraci, Itajuípe, Uruçuca and Ilhéus;

• Soil Exposure: composed of areas devoid of vegetation or crops, areas eroded with landslide processes, degraded by inappropriate agricultural management, mineral extraction; areas of land and land lending.

• Pasture and Subsistence Cultivation: areas covered by brachiaria grass, among others, with intense infestation of herbaceous invasive species and without investment in pasture formation, known as "pasture", besides planted pasture;

•Cabruca: areas where there is cocoa cultivation in the shade of the remaining native trees;

• Atlantic Rainforest: an area that preserves forest remnants of the Atlantic Forest with low anthropization or that remains in its most primary state..

The data presented in Table 5, show that the cabruca covers more than 55% followed by the forest areas that are present in about 23% of this basin. These data corroborate with the data published by Franco (2010) and IESB (2007) that despite presenting different scales show that the most used in the BHRA is the cabruca agroforestry system, followed by forest remnants.

Table 5 – Land use of the Almada River watershed, southern Bahia, in the year 2015

Land use	Area (Km^2)	Area (%)
Wetlands	6,11	0,39
Restinga	6,57	0,42
Urban area	11,51	0,73
Soil Exposure	41,92	2,66
Pasture and subsistence	273,63	17,39
Atlantic raindforest	357,69	22,74
Cabruca	867,45	55,15

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The BHRA vegetation cover is conserved, mainly by the implantation of cacao cultivation in the cabruca system adopted for more than two centuries, this use of the soil was realized through the planting of cocoa in the shade of the remaining native trees conserved important fragments of forests and consequently fauna, soil and water resources (Andrade et al., 2013). This assertion corroborates the floristic survey carried out in the municipality of Uruçuca by Thomas and Carvalho (1998), which resulted in the occurrence of 458 tree species in a single hectare, this great floristic diversity resulted in the recognition of the national and international scientific community for the importance of the remnants located in the south of Bahia, being considered one of the main hotspots of biodiversity.

The largest and most preserved Atlantic Forest remnants are found mainly in the top areas of hills and hills to the west of the BHRA, in regions associated with the high slopes of the geomorphological domain of the Serras and Maciços Pre-Litorâneos (Silva; Gomes, 2010) and in the rugged reliefs located in the eastern portion of the basin near the Enchanted Lagoon, where the difficulty of access may have contributed to conservation (Viana, 2011).

Moraes et al. (2012) analyzed the fragmentation of the landscape of the Almada river basin considering only forest fragments with areas greater than 3 ha, using landscape metrics (size, shape, border effect, isolation and connectivity). The results showed that this watershed contains representative fragments, however many of them mainly located in the interior of the basin are susceptible to the edge effect probably due to the advance of the extensive cattle raising in recent years. This factor, according to the authors, increases erosive processes, soil leaching and silting of rivers.

In order to protect and discipline the occupation process, ensuring the sustainable use of the natural resources of this region that stands out for having scenic beauty and great biological diversity, in 1993, the Government of the State of Bahia created the Environmental Protection Area of Lagoa Encantada with an area of 11,800 ha. After a decade, several studies have highlighted the importance of its expansion, which was established by State Decree No. 8,650 of September 22, 2003.

With the expansion of the area to 157,745 ha this APA encompassed a large part of the Almada River Basin, so it became known as the Environmental Protection Area of Lagoa Encantada and the Almada River.

In this, BHRA is part of the Serra do Conduru State Park (PESC), an important conservation unit in the Southern Region of Bahia, which preserves remnants of the Atlantic Forest and springs that supply the Lagoa Encantada, one of the most important tourist attractions of the municipality of Ilhéus (Viana, 2011).

The flows estimated by the SMAP of the sub-basins of the river Almada can be observed in Table 6.

Data from the upper-level sub-basins of Almada show that the Alto do Almada and Ribeirão Papaya sub-basins have the lowest BHRA flows.

This low flow was caused by anthropic interference, through the conversion of land use from grassland to pasture and exposed soils in a landscape composed of poorly developed soils in steep relief, with steep declivity. There is the presence of deforested hillsides and slopes, depleted pastures and areas classified with low environmental capacity of water production (Campos, 2014).

The Ribeirão Papaya sub-basin presents a landscape similar to the Alto do Almada sub-basin, with conversion of land use and occupation in more than 70% of its area.

Ribeirão Braço Norte, Rio do Braço and Riacho Seven Voltas and Rio Tiriri, sub-basins of the middle course, presented the largest flows due to having the largest areas within the BHRA and being protected with coverage of more than 65%, 90% and 73% (respectively) of their areas under forest and cabruca. This use conserved important fragments of forests and consequently fauna, soil and water resources (Andrade; Marques; Souza, 2013) maintaining a significant biological biodiversity (Thomas and Carvalho, 1998). The conflicts observed in the middle course are the thinning of the forest due to cocoa shading, burning, hunting and use of agrochemicals.

The Braço River is of great importance for the region because it contains the main water catchment responsible for the supply of eight municipalities: Lomanto Júnior and Itabuna.

The sub-basins present in the lower course of Almada irrigate heavily anthropized areas that are in urban sprawl, industrial district and the Itariri dump. However, they are in an area characterized by high rainfall, very porous soils originating from sedimentary rocks or quaternary sediments, areas with groundwater near the surface, well irrigated by streams, which favors landscapes with high water production, corroborated by the results found by Campos (2014).

Table 6– Flow and location of the hydrographic sub-basins of the Almada river

Localização	Sub-Bacias	Área (km^2)	Vazão (m^3\s)
Upper course of the Almada	Alto do Almada	119,2	1,913
	Rio dos Macacos	146,2	2,343
	Ribeirão Papaia	67,3	1,085
Middle course of the Almada	Ribeirão Braço Norte	183,4	2,945
	Ribeirão Juçara	125,7	2,017
	Ribeirão Vai-Quem-quer	142,9	2,292
	Rio do Braço	161,1	2,945
	Rio Água Preta do Mucambo	143,6	2,302
	Rio Comprido	161,9	2,594

Lower course of the Almada	Lagoa Encantada	142,3	2,282
	Riacho das Sete Voltas e rio Tiriri	178,9	2,865

Conclusion

The results obtained using the SMAP model from the observed rainfall and flow data have revealed a good applicability of the methodology used. In spite of presenting different landscapes with land use and occupation, rocky substrates and diverse soils, the results show that the sub-basins of the upper course of Almada present a smaller flow caused by the presence of exposed soils and degraded pastures. The sub-basin flows of the middle course presented the highest flows because they have protected their area with forest cover and cabruca. Although the present sub-basins of the lower Almada course suffer a strong impact generated by the anthropic activities, they present considerable discharges when compared to the other sub-basins present in all the watershed of the river Almada.

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