Methodological Proposal for the Prediction of Hydrological Responses to Land-Uses and Land-Cover Changes in a Brazilian Watershed

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1 Introduction

Over the years, the land-use/land-cover (LULC) is undergoing significant changes due to the fast growth of population density. Thus, continuous urbanization together with the cited changes is a major challenge for the management of water resources [17]. In this context, the hydrology and hydrological cycle of a watershed can be altered considerably due to land-uses and land-cover changes (LULCC), agricultural practices, economics, cultural alternations, among other factors [6]. The hydrological changes can be noticed in the evaporation, evapotranspiration of the ecosystem, soil infiltration capacity, surface and subsurface flux regime, peak flow and water quantity and quality, etc. [10]. Therefore, to plan and manage water resources in the medium and long term, it is fundamental to understand in a broader and more detailed way the effects of LULCC on the flow in watersheds and subwatersheds [12].

Many studies show that LULCC directly affect the availability and flow of water in the hydrological cycle in a watershed [16, 20, 25, 30, 33, 34]. The researches cited are based on assessments of impacts on water resources. Increased urbanization is

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often associated with increases in maximum flows and decreases in minimum flows, and this impact of LULCC varies according to climatic conditions [20].

According to [30], LULCC in the Songkhram Watershed, Thailand, were responsible for the increase of 5.30–6.35% in the flow of the scenario considered. In the study by Kim et al. [20] in the Hoeya Watershed, Korea, flow increased in spring and winter, but decreased in summer and fall LULCC increased maximum flows in the rainy season, but decreased minimum flows in the dry periods. Thus, the authors concluded that LULCC may aggravate the problems of increasing seasonal variability in the flow due to climate change. At the Loess Plateau in China, urban sprawl accounted for 5.46% of all factors influencing LULCC in the region [33]. In a coastal watershed, Eight mile Creek, Alabama, local residential growth will continue into the near future [25]. The mathematical models showed that, due to urbanization, the maximum flows increased from 1966 to 2011 and from 2011 to 2022. In the Olifants Watershed in South Africa, [16] showed that LULCC in the region resulted in a 46.97% increase in surface runoff, with urbanization as the predominant factor for this. For the Tekeze Dam Watershed in Ethiopia, LULCC were also significant. The increase of exposed soil and agricultural areas resulted in an increase in the average annual flow rate of 6.02%.

As shown by all the authors described above, urbanization and other forms of LULCC may result in detrimental effects on the hydrology of a watershed. These effects may increase the number of hydrological incidents and/or disasters, e.g., floods. When precipitation rates are higher than infiltration capacity, the soil behaves like an impermeable surface [2]. As asserted by Noori et al. [25], the impacts of LULCC at maximum outflows may be associated mainly to low intensity but frequent precipitation events; thus, small flood events are more sensitive to urbanization than large events. To study and evaluate how LULCC occur in a region, as well as how these changes affect the flow of surface runoff, it is necessary to conduct research through field observations and/or mathematical modeling. The first method is onerous and usually has local and non-transferable results. Thus, modeling is a more viable and commonly used method to perform environmental diagnostics and prognoses of the region of interest [25]. However, it should be noted that the fieldwork is very valuable, because as such, it is possible to carry out calibration and validation of the mathematical models.

In the studies described above it is possible to observe some limitations, e.g., the prognosis of LULC because of models based on simple regressions. These types of constraints directly impact the outcome of the hydrological response because these limitations can introduce uncertainties in the assessments. To minimize this problem, the present research proposes that the prediction of LULC should be made with a dynamic model based on neural networks. Meteorological scenarios with complete hydrological cycles were chosen to represent excess and scarcity of precipitation in the region. Through all the above, the general objective of this research is to map and predict the integrated impacts of climate and LULCC on the flow of a watershed of interest for scenarios of precipitation excess and scarcity. The specific objectives are: (1) to map the pattern of LULCC in the past and present of a watershed; (2) to predict LULCC in the future of the watershed through the LULC

model; (3) to estimate the impacts on watershed discharges for each pluviometric scenario in the past, present, and future through the hydrological model; and (4) to analyze the estimated hydrological impacts for each subwatershed in the past, present, and future.

2 Methodology

2.1 Application Area

The Araruama Lagoon Watershed is at the coastal lowlands region in the state of Rio de Janeiro and covers the administrative limits of Saquarema, Rio Bonito, Araruama, Iguaba Grande, São Pedro da Aldeia, Cabo Frio, and Arraial do Cabo (Fig. 1). Its meteorological characteristics are peculiar presenting the lowest rainfall volume of the state and registering two types of microclimates, tropical in the west and semi-arid in the east, in a small extent. In the meteorological data recorded in the region, evaporation presents higher values than precipitation resulting in a water deficit, that is, a negative water balance for the most part of the watershed. In the climatology of the region, the average annual rainfall is in the range of 750 and 900 mm and average annual evaporation between 890 and 1370 mm. In the watershed in question is located the Araruama Lagoon, which is a permanent hypersaline lagoon with an average salinity of 52, this characteristic is due to the semi-arid climate previously mentioned [5, 7]. The connection of this lagoon with the sea is carried out through the Itajuru Channel, which during the years has been suffering constant shoaling, which makes it difficult for the internal waters of the lagoon to circulate and renew.

The total drainage area of the Araruama Lagoon Watershed is $430 \, km^2$, with fresh water contributing to $2.3 \, m^3$ of average volume. Its hydrographic system is composed of small subwatsheds and almost all its rivers show intermittent behavior. The most significant rivers that drain into the lagoon are, from west to east: Moças' River, Mataruna River, Salgado River, and Ubá River (Fig. 1) [7].

2.2 Land-Use and Land-Cover (LULC) Modeling

Currently the most commonly used instruments for remote sensing and combined image analysis are obtained through satellites orbiting the Earth. The data obtained by remote sensing tend to be more economical due to the possibility of phenomena monitoring in extensive and remote areas of the planet [15]. In conjunction with the use of remote sensing data, geographic information systems (GIS) are used to relate the environment and human activities. The products that result from the satellite data processed in the GIS can be LULC maps, as well as information
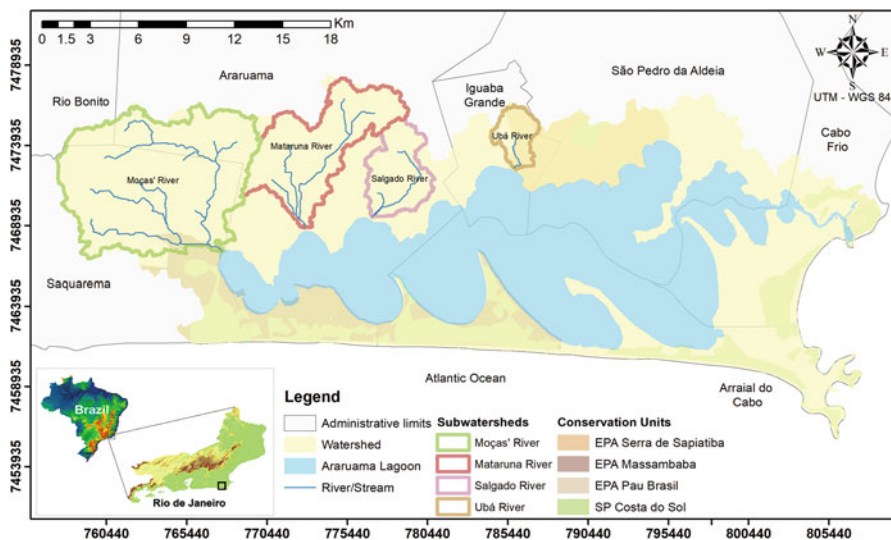
Fig. 1 Location of the Araruama Lagoon Watershed, application area considered in modeling, and its main rivers, from the lagoon system of the microregion of the lakes in state of Rio de Janeiro, Brazil (adapted from [21])

submitted to statistical and analytical procedures. Another relevant point to highlight is the quality and accessibility of data, including the availability of these images at reasonable resolution.

Through the data from the LULC's dynamics diagnosis, it is possible to predict future scenarios. To develop these prognoses, the modeling tool has been widely used for both management and environmental research [31]. The modeling of the LULC's dynamics must begin with a theoretical understanding of human behavior, through its interaction with different forms of land-use, as well as understanding how the land is distributed in the territory. These models began their development in the 1960s and since then their popularity and research have been growing significantly [18]. This growth is because changes in LULC are one of the most important ways man can directly and indirectly affect the environment in which he is inserted.

2.2.1 Land Change Modeler (LCM)

The LCM module of the TerrSet program aims to analyze and predict LULCC, as well as to improve the understanding of the system in its phenomena and effects, including influencing factors such as roads, slope, altitude, anthropogenic interferences, among others [14]. With this amplified understanding there is the possibility of achieving better support in regard to the planning and elaboration of public and private policies. In the context of LULC future projection, the model

is an effective tool to predict these changes in different scenarios, based on the trend pattern of the changes previously occurred. The performance of LCM will be through neural network and/or logistic regression, its accuracy is dependent on the variables that influence LULCC [3, 14, 28].

The input data for the model is composed of two LULC maps, one less recent and one more recent with the same LULC classes. These maps are analyzed presenting a quantitative evaluation of the changes that occurred between the chosen period. The analysis is explained through a comparative graph and maps of the losses and gains by LULC's classes and change of the contribution by class in several units as: hectare (ha), square kilometer (km^2), % of area, among others. The transition potential modeling creates maps with an acceptable degree of accuracy to perform the effective modeling by grouping a set of submodels and exploring the influence of explanatory variables, which may be either dynamic or static in time [14].

The transition structure of the submodels presents a relation of all the transitions, from the smallest to the largest, that occur between time t_1 and t_2. This modeling can be performed by both logistic regression and multi-layer perceptron neural network (MLP). The MLP neural network can model nonlinear relationships and the most robust LULCC models. The LULC's restrictions or incentives factors limit or expand the transformations to a region of interest giving it a degree of adequacy to change [28]. In this way it is possible to forecast trends for LULC, and finally to generate maps of possible future changes.

2.3 Hydrological Modeling

Over the years, many computational models have been developed to simulate the hydrology of watersheds. Thus, hydrological models are considered efficient tools of great importance for researching the complex hydrological processes that affect surface and subsurface hydrology of watershed. With the understanding of these processes, it is possible to evaluate the LULCC's impacts, agricultural activities, water resources management, among others [19].

2.3.1 Soil and Water Assessment Tool (SWAT)

For the trend simulations the SWAT model was chosen. This option was because the model has great acceptance in the academy, is widely used in urban regions and watersheds, and has several publications available. SWAT is a mathematical model created in 1996 and is being continuously developed since then by the Agricultural Research Service and Texas A&M University. The main function of the model is to analyze the impacts to the practice of agriculture in different types of soils and the patterns of the use of it on the surface and underground water flow, sediment production, and water quality in long periods. The SWAT model has been widely used worldwide to predict the nutrient flow discharge and loading

from watersheds of various sizes, for the development of maximum daily total load, simulating hydrology, sediments, nutrients, and pollutant load for basin scale studies dealing with the quantity and quality of water. Simulation scenarios can be useful for assessing the ecological status of the environment, considering climatic factors, soil, and water use. In general, the SWAT application to assess diffuse pollution has presented scientifically interesting results [24].

SWAT requires specific information on water, soil properties, topography, vegetation, and soil management practices in the watershed. Physically the process is associated with water movement, sediment movement, plant growth, nutrient cycling, which are directly modeled by SWAT, using this input data. The SWAT is a continuous model in time and usually works in daily time interval. One of its advantages is the possibility of making simulations for short or long time series. It considers the watershed divided into sub-basins based on relief, soils, LULC and thereby preserves the spatially distributed parameters of the entire basin and the homogeneous characteristics within the basin. The input data for each sub-basin can be grouped or organized according to the following categories: climatic, hydrologic response units (HRUs), ponds/wetlands, groundwater, main watercourse, and sub-basin drainage. To generate the HRUs in each sub-basin, a sensitivity level is adopted, eliminating the LULC's classes with an area smaller than the established value. SWAT controls the creation of HRUs based on the distribution of the different soil types and on the selected soil uses [13].

2.4 Model Calibration and Validation

SWAT calibration can be done automatically and/or manually. Manual calibration is performed by trial and error, while automatic can be performed by the SWAT-CUP[1] software that provides calibration, validation, and analysis of results' uncertainties generated by SWAT simulations [1]. The SWAT simulated data were initially calibrated in the SWAT-CUP, but they were not fully satisfactory and were therefore supplemented by manual calibration. After the complete calibration phase, the model was validated. In the validation a time series other than calibration was used, showing that the model can reproduce the series. After the simulation, calibration, and validation procedure, the results in the three stages were submitted to statistical analyses as described by Moriasi et al. [23]: Nash and Sutcliffe coefficient (NSE), normalized standard error (RSR), correlation coefficient (R^2), and percent bias (PBIAS) in addition to the visual analysis of the graphs generated by the time series.

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[1]https://swat.tamu.edu/software/swat-cup/.

Fig. 2 Methodology framework used in this research

2.5 Research Methodology

The potential hydrological impacts of a watershed in response to LULCC were analyzed for the past (1985), present (2015), and future (2030) pluviometric scarcity and excess scenarios. The methodological framework used in the present research is illustrated in Fig. 2.

2.5.1 Data Preparation

The data used in the setup of SWAT hydrological model are described in Table 1. The input parameters are necessary to represent the watersheds' characteristics

Table 1 Data used in the SWAT model

Data	Source	Spatial/temporal resolution	Number/period	Description
Elevation (DEM)	ASTER GDEM version 2	30 m	–	USGS earth-explorer[a]
Soil map	[9]	1:250.000	2003	GeoPortal EMBRAPA[b]
LULC map	[22]	1:150.000	1985; 2015; 2030	–
Meteorological data	Climate forecast system reanalysis (CFSR)	–	6 stations/ 1990; 2005	Global weather data for SWAT[c]

[a]https://earthexplorer.usgs.gov
[b]http://mapoteca.cnps.embrapa.br
[c]https://globalweather.tamu.edu/

with quality and, consequently, to generate satisfactory results in the hydrological modeling. Secondary data from previous studies and primary data provided by Lagos de São Jão Intermunicipal Consortium (CILSJ) and the Fluminense Federal University (UFF) were used in the present research. The parameters adopted were divided into topographic data, LULC maps, soil map, and meteorological data.

2.5.2 Historical, Current, and Future (LULC)

The LULC maps used for the years 1985, 2015, and 2030 were obtained through the study of [22] carried out in the Araruama Lagoon Watershed as shown in Fig. 3a, b, and c. The distribution and summary of the LULCC statistics are illustrated and described in Fig. 3d and Table 2. Observing the changes from 1985 to 2015 the classes that showed the greatest gains in their areas were: medium density urban area, bare soil and disabled salines, and high-density urban area with an increase of 117.1%, 95.5%, and 44.2%, respectively. On the other hand, the classes that presented the highest losses in this period were: salines, low density urban area, and sand and dunes with decrease of 81.2%, 45.2%, and 20.0% in their respective areas. In Fig. 3 it is possible to verify that water is the class of greater area in the analyzed 45 years. The LULC simulated map for the future (2030) was modeled considering the past patterns of 1985 and 2015 in addition to the legal constraints imposed by the environmental conservation units currently in effect in the Araruama Lagoon Watershed: Environmental Protection Area (EPA) Serra de Sapiatiba, EPA Massambaba, EPA Pau Brasil, and Costa do Sol State Park (SP) (Fig. 3).
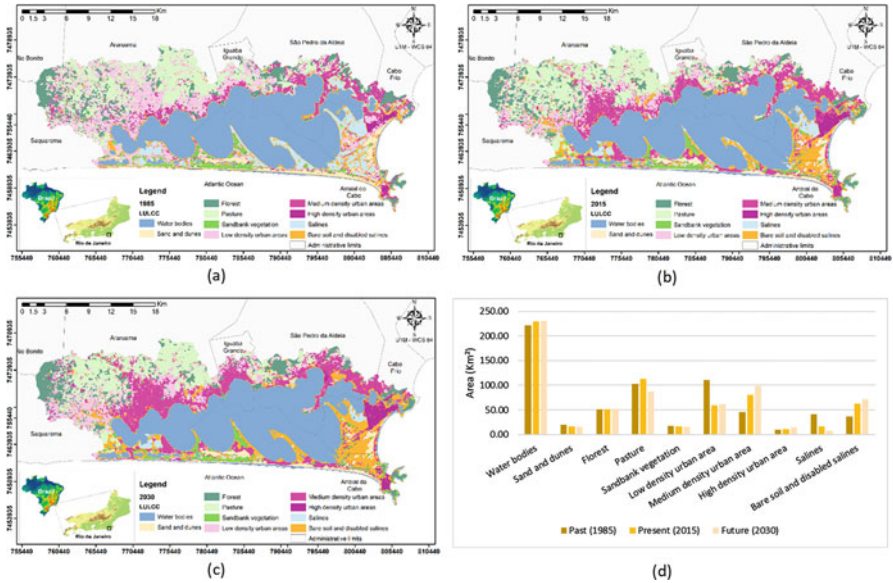
Fig. 3 LULCC for 1985 (**a**), 2015 (**b**), and 2030 (**c**) and distribution of areas in km^2 by classes LULCC (**d**) in Araruama Lagoon Watershed (adapted from [22])

2.6 Setting Scenarios

In this research, six different scenarios were considered (Table 3) to evaluate the impacts on the flow of the main tributaries of each subwatershed to the past, present, and future LULC in years with excess and scarcity of precipitation. The choice of representative years of excess (2005) and scarcity (1990) was determined by the analysis of the meteorological time series (Fig. 4).

3 Results and Discussion

The results concerning the influence, anthropic, and environmental in the subwatersheds flows were simulated by SWAT for the past (1985), present (2015), and future (2030). The subwatersheds considered in the simulation were: Moças' River, Mataruna River, Salgado River, and Ubá River, illustrated in Fig. 1. The physical and hydrological characteristics of each subwatershed, according to the hydrological model, are described in Table 4 for scenarios of scarcity and excess of precipitation.

Table 2 Statistics summary area concerning LULCC Araruama Lagoon Watershed for the periods of 1985, 2015, and 2030 (adapted from [22])

LULCC Araruama Lagoon Watershed	1985 Area (km²)	%	2015 Area (km²)	%	2030 Area (km²)	%	Changes from 1985 to 2030 Area (km²)	%	Changes from 2015 to 2030 Area (km²)	%
Water bodies	221.68	33.7	229.75	34.9	230.54	35.2	8.86	4.0	0.79	0.3
Sand and dunes	19.45	3.0	16.86	2.6	15.57	2.4	−3.88	−20.0	−1.29	−7.7
Forest	51.58	7.8	51.53	7.8	52.60	8.0	1.02	2.0	1.07	2.1
Pasture	102.58	15.6	113.21	17.2	87.32	13.3	−15.26	−14.9	−25.89	−22.9
Sandbank vegetation	17.85	2.7	16.56	2.5	15.53	2.4	−2.32	−13.0	−1.03	−6.2
Low density urban area	111.00	16.9	58.87	9.0	60.87	9.3	−50.13	−45.2	2.00	3.4
Medium density urban area	45.41	6.9	80.90	12.3	98.59	15.0	53.18	117.1	17.69	21.9
High-density urban area	10.25	1.6	10.80	1.6	14.78	2.3	4.53	44.2	3.98	36.9
Salines	40.98	6.2	16.81	2.6	7.69	1.2	−33.29	−81.2	−9.12	−54.3
Bare soil and disabled salines	36.67	5.6	62.20	9.5	71.68	10.9	35.01	95.5	9.48	15.2

Table 3 Environmental scenarios considered in hydrological modeling

Environmental scenario	Description
1. Precipitation scarcity in past	LULC 1985s and hydrological simulation considering precipitation scarcity 1990s
2. Precipitation scarcity in present	LULC 2015s and hydrological simulation considering precipitation scarcity 1990s
3. Precipitation scarcity in future	LULC 2030s and hydrological simulation considering precipitation scarcity 1990s
4. Precipitation excess in past	LULC 1985s and hydrological simulation considering precipitation excess 2005s
5. Precipitation excess in present	LULC 2015s and hydrological simulation considering precipitation excess 2005s
6. Precipitation excess in future	LULC 2030s and hydrological simulation considering precipitation excess 2005s
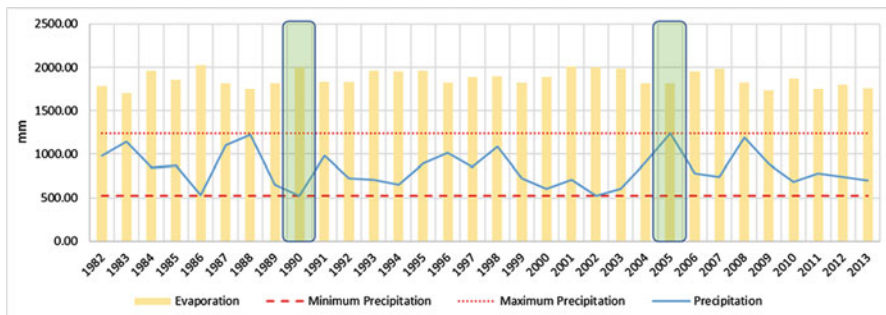
Fig. 4 Annual accumulated values of precipitation, evaporation, minimum and maximum precipitation for the Araruama Lagoon watershed, RJ, from 1982 to 2013. The years chosen to represent the pluviometric scarcity (1990) and the pluviometric excess (2005)

3.1 Model Calibration and Validation

For SWAT model calibration was necessary that the initial calibration was performed in a region adjacent to the area of application of Araruama Lagoon Watershed, which was the Silva Jardim Watershed. The region in question was chosen because it is the region closest to the application area with time series data available in [4]. The model was calibrated for the flows from 1983 to 1997 and validated from 1998 to 2010. After calibration and validation, the statistical analyses showed that the magnitude of the data (NSE) calibrated and validated in relation to the observed data presented a result classified as "good," as well as the normalized standard error (RSR). Percent bias (PBIAS), the simulated data were classified as "very good" (Table 5). Finally, the correlation coefficient, R^2, presented an uncalibrated value of 0.45, calibrated of 0.81, and validated of 0.91. The validated value approached 1, indicating that the data approached the trend line, and consequently with little dispersion.

Table 4 Physical and hydrological characteristics of the subwatersheds considered in the hydrological model

Characteristics/subwatershed	Moças' River			Mataruna River			Salgado River			Una River		
Area (km²)	89.55			40.41			17.67			7.49		
Perimeter (km)	65.85			54.96			27.78			16.59		
Minimum relief (m)	4			5			4			5		
Maximum relief (m)	575			128			94			73		
Major land-use and land-cover (LULC)	Pasture			Pasture			Pasture			Pasture		
Hydrological parameters												
Scenario of precipitation scarcity												
	Past	Present	Future	Past	Present	Future	Past	Present	Future	Past	Present	Future
Minimum annual flow (m³/s)	0.63	0.61	0.57	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum annual flow (m³/s)	6.38	6.10	5.78	0.74	1.25	1.63	0.30	0.27	0.63	0.16	0.14	0.34
Accumulated annual precipitation (mm)	522.70											
Accumulated annual evaporation (mm)	2001.57											
Scenario of precipitation excess												
	Past	Present	Future	Past	Present	Future	Past	Present	Future	Past	Present	Future
Minimum annual flow (m³/s)	0.71	0.70	0.65	0.01	0.01	0.01	0.00	0.01	0.01	0.00	0.00	0.00
Maximum annual flow (m³/s)	129.20	131.70	129.90	45.94	46.41	46.52	19.43	19.88	20.02	9.72	9.20	9.97
Accumulated annual precipitation (mm)	1241.70											
Accumulated annual Evaporation (mm)	1818.14											

Table 5 Reference and classification according to criteria established by Moriasi et al. [23] of the statistics used to analyze flows data after model calibration and validation

Category	NSE				RSR				PBIAS (%)			
	Reference	(a)	(b)	(c)	Reference	(a)	(b)	(c)	Reference	(a)	(b)	(c)
Very good	$0.75 \leq NSE \leq 1.00$	0.06	0.55	0.65	$0.0 \leq RSR \leq 0.5$	0.97	0.67	0.59	$PBIAS \leq \pm 25$	35	6	−1
Good	$0.65 \leq NSE \leq 0.75$				$0.5 \leq RSR \leq 0.6$				$\pm 25 \leq PBIAS \leq \pm 40$			
Satisfactory	$0.50 \leq NSE \leq 0.65$				$0.6 \leq RSR \leq 0.7$				$\pm 40 \leq PBIAS \leq \pm 70$			
Unsatisfactory	$NSE \leq 0.50$				$RSR \geq 0.7$				$PBIAS \geq \pm 70$			

(a) Uncalibrated; (b) Calibrated; e (c) Validated
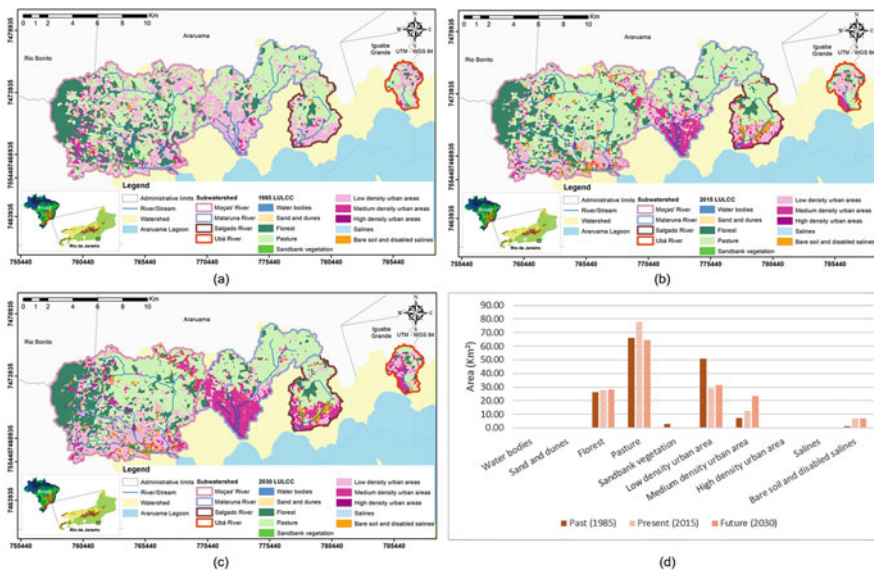
Fig. 5 LULCC for past (1985) (**a**), present (2015) (**b**), and future (2030) (**c**) and distribution of areas in km^2 by classes LULCC (**d**) in the simulated subwatersheds (adapted from [22])

3.2 LULCC

Figure 5a, b and c shows in detail the subwatersheds' LULC maps considered in hydrological modeling for the past, present, and future represented by the years 1985, 2015, and 2030, respectively. In Fig. 5d it is possible to observe the total distribution of subwatersheds areas (km^2) per LULCC's class in the 45 years analyzed. As described by Teixeira [32] and confirmed in the mapping carried out in this research, during the development of the lake's region, in the more interior areas, where the subwatersheds are located, pasture was the dominant constituent of LULCC's class in this region. Another important point to highlight is the increase in the population density represented by the decrease of low density urban areas class and the consequent and gradual increase of medium density urban areas class. This behavior is verified by Nunes [26], who emphasizes that since the 1990s the oil activity has played a significant role in the regional economy. This resulted not only in the injection of direct resources, but also indirect and secondary, increasing the population density in the region.

As shown in Fig. 3, the classifications and projections considered for the past (1985), present (2015), and future (2030) were obtained by Lima [22]. Figure 6 shows in detail each subwatershed considered in the modeling and their respective LULCC over the analyzed years. The Moças' River subwatershed presents the greater part of its area belonging to the administrative limits of Saquarema; Maturuna and Salgado entirely in the administrative limits of Araruama; and Ubá in
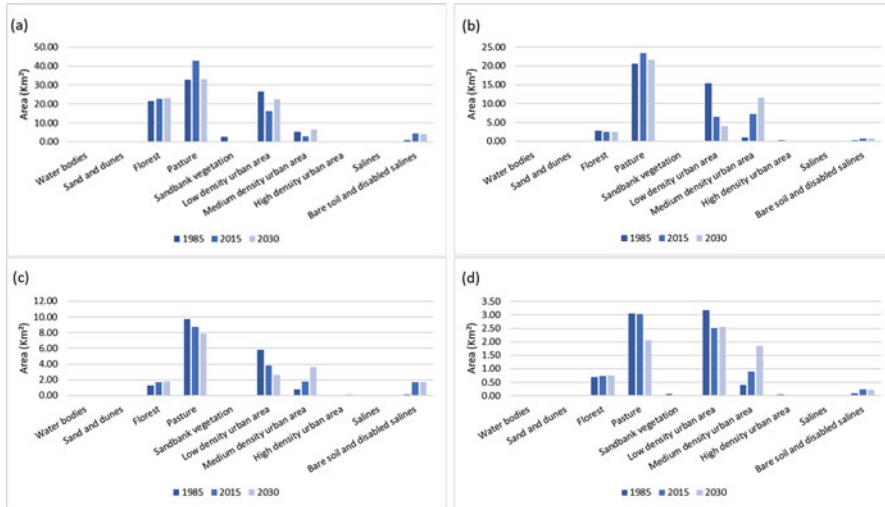
Fig. 6 Distribution of areas in km^2 by classes LULCC (d) in the simulated subwatersheds: Moças' River (**a**), Mataruna River (**b**), Salgado River (**c**), e Ubá River (**d**) for the periods of past (1985), present (2015), and future (2030)

Iguaba Grande (Fig. 1). As observed in Fig. 5d, the patterns of each subwatershed tend to have the following classes as dominants in the analyzed 45 years: pasture, low and medium density urban areas, and forest. This trend was also described by previous bibliographical references [7, 11]. Bidegain and Bizerril [7] in their study identified that the most significant classes are pasture, urban areas (population density), and saline. It should be noted that in the present study the modeling areas do not contain salines that are very significant in Araruama Lagoon watershed scale, as shown in Fig. 3 due to their regional economic importance, mainly before and during the 1990s.

Another LULC class that deserves attention is the forest. From 1900, scientists began to identify degradation of said class. The spaces of forest began to give way to sugarcane, coffee, orange groves, and finally livestock. When comparing maps of the past (1985), present (2015), and future (2030) it is possible to observe that even mathematically the class did not have significant changes, their presence was observed in different places. A plausible justification for this fact is the reforestation with *Eucalyptus* spp that cf. described by de Athayde Bohrer et al. [11] is present in the region along the RJ-106 highway, São Pedro da Aldeia and in smaller non-mappable areas.

Urban areas, both in the diagnosis (past and present) and prognosis period (future), were a class of significant changes in the four modeled subwatersheds. As found by [11], the largest urban concentrations are spatially distributed near the municipal headquarters in the surroundings of Araruama Lagoon, along the highways RJ-106, RJ-102, and RJ-140 and finally in the coastal zones. The rapid
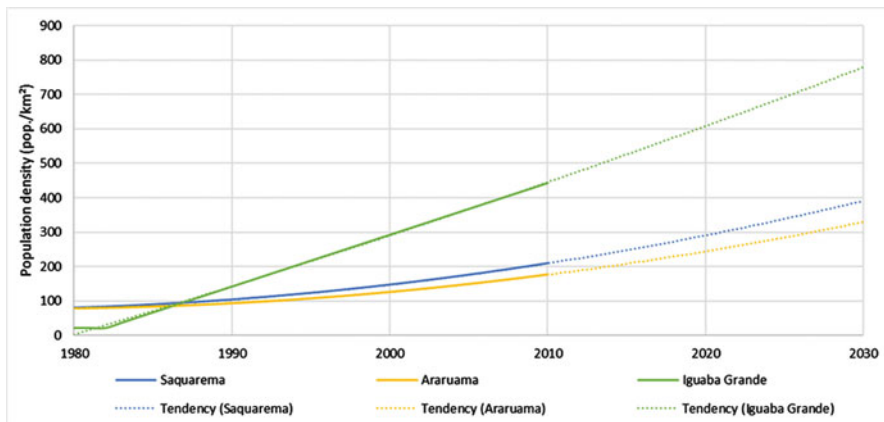
Fig. 7 Diagnosis (1980–2010) and population density (pop./km^2) prognosis (2011–2030) by administrative limits, Saquarema, Araruama, and Iguaba Grande—RJ (Source: CENSO 1980, 1991, 2000, and 2010)
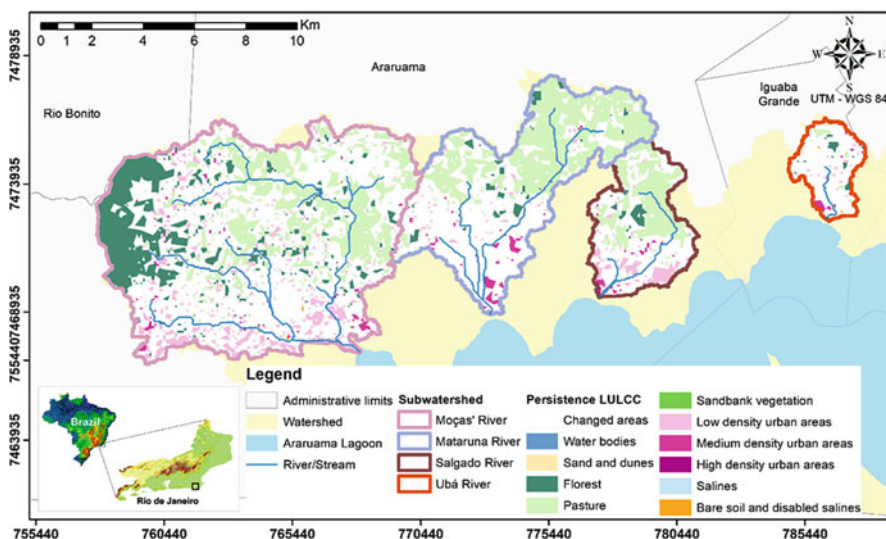
Fig. 8 LULCC's persistence map between the years of 1985 and 2030 to subwatersheds modeled

urban expansion is clearly seen in the evolution of the LULC mapping and in the population data provided by IBGE, as well as in the projections for the municipalities of Saquarema, Araruama, and Iguaba Grande in 2030 (Fig. 7).

During the 45 years analyzed, 59.0% of the total area of the subwatersheds underwent alteration in its LULC according to Fig. 8. The pasture and forest were the classes that persisted most during the years analyzed with 25% and 9% of their

areas, respectively. The changes helped to characterize and diagnose the LULC's transformations from 1985 to 2015 and to propose the future scenario for the year of 2030, considering that the conditions of infrastructural development and spatial restrictions remained the same for the current ones.

3.3 Impacts of Climate and LULCC on Streamflow

Quantifying the effect of LULCC on the hydrological behavior of a watershed is still a problem today. These changes can directly affect the hydrological processes of the region of interest through changes in evapotranspiration, rainfall interception, streamflow generation, water recharge, and soil moisture dynamics [35]. An alternative methodology that has been widely used is the temporal trend analysis based on the relation between the streamflow and precipitation for large watersheds. One of the great advantages of this method is that it can be applied in watersheds that have undergone LULCC without the necessity of a control watershed [8]. Another widely applied methodology for this purpose is the use of hydrological models, thus estimating the effects of changes local on different temporal scales. However, it should be noted that there are significant uncertainties associated with this method [27].

As described by Sanchez et al. [29] hydrological disasters classified by the Brazilian Classification and Codification of Disasters (Cobrade) in Rio de Janeiro state presented 497 records between the years of 1991 and 2012. Of the state registries cited, 13 were attested, in the Araruama Lagoon watershed, most frequently in the months of November to February of the analyzed period. The excessive population increase in the region of interest promoted a consequent increase in the waterproofing of the earth, which caused a greater volume of surface drainage; thus, municipalities with greater population density are more susceptible to flooding. It should be noted that due to the inexpressiveness of the municipality of Rio Bonito for the drainage of the hydrographic basin of interest, the data referring to it, with respect to hydrological disasters, were disregarded.

In the present research the hydrological responses to different conditions and changes of LULC in the past, present, and future were studied for maximum streamflows in the four hydrographic subwatersheds modeled in scenarios of pluviometric excess and scarcity. The results of the hydrological modeling, through the exposure of precipitation data, mean flows distributed in the months of the year in the scenarios of pluviometric scarcity and excess for each subwatershed are shown in Fig. 9. As described in item 3.2, the subwatersheds modeled presented significant changes in LULC during the analyzed 45 years and these alterations had effects on the maximum surface runoff flows of each subwatershed.

The impacts of the LULCC in the Moças River subwatershed showed that for the scenario of past precipitation scarcity to the present, it presented a mean decrease in its flow of 4% and for the present to the future of 5%. For the pluviometric excess scenario from 1985 to 2015, the reduction was cushioned by 2% and
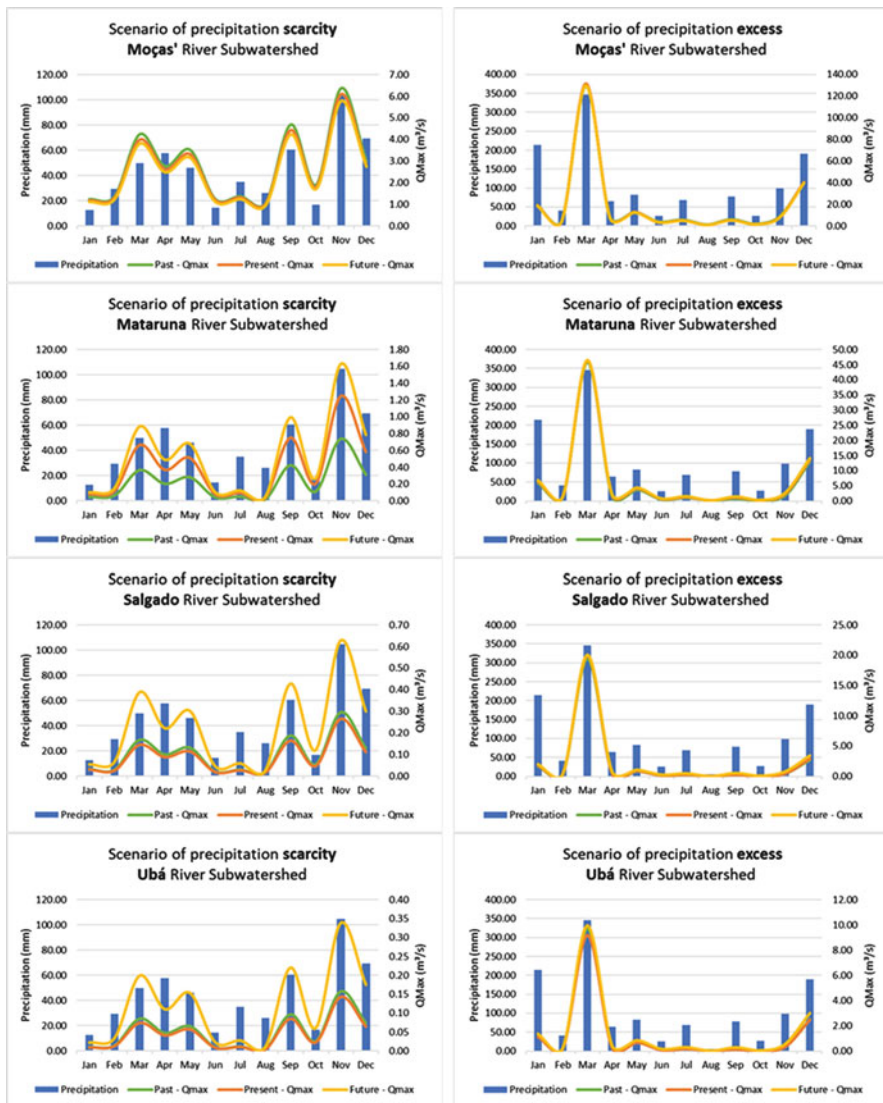
Fig. 9 Simulated streamflow to the scenario of scarcity and excess precipitation to LULCC of the past, present, and future for the Moças, Mataruna, Salgado e Ubá River subwatersheds
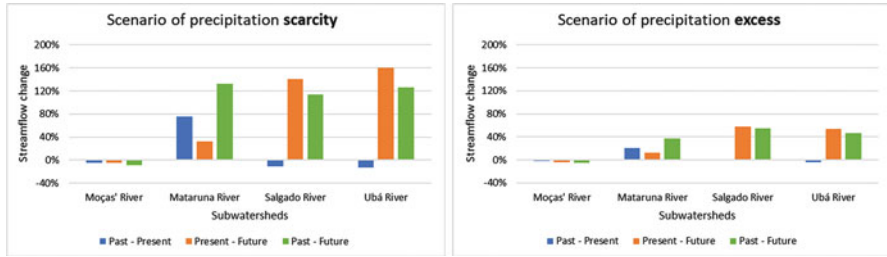
Fig. 10 Percentage variation of the past to present and future streamflow in the scenarios of precipitation scarcity and excess

from 2015 to 2030 by 4%. For Mataruna River subwatershed, the flow changes were more significant both during the period of scarcity and during the period of excessive precipitation. In the first scenario from the past to the present there was an increase of 75% and from the present to the future 32%. In the second scenario the percentages were 21% and 12%, respectively. The Salgado River subwatershed for the first 30 years analyzed presented an average annual reduction in its flow of 11%, in the prognosis the flow had an increase of 141% for the year of pluviometric scarcity. The Ubá River subwatershed presented the same hydrological behavior as the Salgado with reduction from the past to the present and increase of flow from the present to the future with percentage values of 13% and 160%, respectively (Fig. 10).

Figure 10 shows that, in general, the hydrological behavior of the subwatersheds is similar, emphasizing that for the pluviometric scarcity scenario, the percentage changes in flow are more significant. The reduction in the flows of subwatersheds, in some situations, mainly in Moças River subwatershed, was similarly found by Shrestha et al. [30] in Thailand. One possible way to reduce the flow rate is to increase evapotranspiration. On the other hand, the significant increase in flow rates, mainly from the present to the future, can be explained by the population density indicated by both the CENSO projections and the LULC prognosis. The conversion of non-urbanized areas into urban areas tends to increase the maximum flow which can cause flooding in areas near the margin of the rivers analyzed. As found in previous studies, e.g. [35], LULCC can exert influences on the flow of a system, resulting in an increase or decrease in its value depending on the nature of the change.

As found by Noori et al. [25] even if there is the same degree of urbanization in different areas of the watershed, its contribution to the streamflow depends on its location within the watershed. It should be noted that, in addition, other characteristics that need to be considered are topography and soil type which play an important role in the floods of a region. In this way, mapping and understanding the effects of urbanization on hydrological processes is essential for urban planning.

4   Conclusions

Sustainable planning and management of water resources can be more consistently accomplished when the capacity to predict LULC impacts is developed by reflecting the pressures of population densities and their local changes. This establishes a scientific challenge to understand the processes involved in these changes, as well as to formulate relationships and conceptualizations at different scales, making the predicted model of hydrological responses of a watershed to LULCC and climate more and more reliable. Thus, the present research fulfilled its objective of mapping and predicting the integrated impacts of climate and LULCC in the streamflow of a watershed of interest for scenarios of precipitation excess and scarcity.

The subwatersheds analyzed showed significant changes in their LULC over the simulated 45 years. As shown, 59.0% of the total area of the model domain suffered some type of change, which directly impacted the simulated results of the maximum streamflows of all subwatersheds. An LULCC that deserves to be highlighted is the gradual increase in medium population density area for the modeled regions, justifying some of the changes found in the modeled flows. It should be emphasized that the entire watershed also presented the same trend of population density increase. As the region has already registered hydrological disasters, knowledge of this hydrological tendency is important for urban planning and water resource management in order to mitigate such disasters.

It is important to point out, however, that during the analysis of the simulated data, some limitations of the research were identified, even though they did not compromise the research, these limitations show that there are gaps in the existence and availability of an environmental and socioeconomic basis, which would make more feasible and accurate the calibration and validation of hydrological models and LULCC models that will more actively assist in decision making.

From the above, some recommendations can be suggested, such as:

- Continuous monitoring of hydrometeorological, geological, and geotechnical conditions that allow to anticipate the occurrences of natural disasters, especially, hydrological. In this way, managers and decision makers will be able to mitigate the human and material damages resulting from such disasters [29].
- Another point to be addressed is the relationship between the hydrological disaster and the sustainability of multi-scalar urban drainage. The understanding of the complexity of the relationships between natural ecosystems, urban, and society is fundamental so that the control of floods in urban areas is reconceptualized technically and managerially. Thus, sustainable urban drainage can contribute to the control of runoff through structural and non-structural methodologies that reduce the exposure of the population vulnerable to local hydrological disasters [36].

The results of the present research can be used by several sectors and agents, e.g., LULC planners, decision makers, public administrators, among others with the purpose of promoting actions that allow the natural hydrological disaster mitigation

and/or control, considering environmental and social aspects. The identification and mapping of the main drivers of LULC and climatological changes contributes methodologically to quantify the hydrological effects in a watershed as response to these changes, considering the seasonality and the recurrence of these events. Thus, the present study is a contribution to the production of the knowledge needed to manage natural hydrological disasters in a watershed, providing subsidies so that communities can become resilient and sustainable.

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