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Where is the Lake that Was Here? A Case Study on the Portinho Lake in Piauí, Brazil¹

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ABSTRACT

The Portinho Lake is a large water body formed by a barrier on the Portinho River consisted of dunes that move from the coastal plain, in a southwest direction, towards the interior of the state of Piauí, Brazil. Historically, this lake is a great attraction for visitors. However, the intensification of water and land use in the Portinho River basin, and reductions of precipitation indexes in recent years resulted in a large decrease in the river flow that practically extinguished this lake in 2015. The reduction of this lake began to be a subject of discussion in several social sectors, evidencing the need for social and environmental planning for this basin and thus contributing to the awareness of the local population on the sustainable land and water use. This research intended to expand studies on the characterization of the Portinho River basin, including its current use and occupation and effects on the dynamics of the Portinho Lake from an integrated perspective of society and nature. The studies were based on bibliographical, cartographic, and documentary and field surveys, using geoprocessing techniques to characterize the basin area and identify socio-environmental problems that affect the Portinho Lake. This lake has hydrological problems due to the natural dynamics of the area, especially due to its water level variation, clogging, and water flow difficulties caused by moving dunes that deposit sand on its water surface. The decrease in the precipitation indexes of the basin and the most recent water use upstream of the lake are the factors of greater impact on the basin, which affect directly the dynamics of the Portinho Lake and cause losses on local activities.

Keywords: Coastal lakes. Coastal hydrography. Environmental impact. Drought.

Introduction

In the last decades, the multiple uses of water by humans have contributed to the degradation and pollution of water sources. The continuous withdrawal of water for diverse purposes have reduced its availability and generating problems of water scarcity in many regions and countries.

Water use increased considerably in the mid-1960s, especially for agriculture—irrigation of crops, poultry and swine production, animal care, and other agricultural activities (Tundisi, 2003). In addition to agricultural activities and domestic use, water is used in recreation and

tourism activities. Places where freshwater is more accessible and less costly for recreation tend to have considerable pressure on local rivers, lakes, ponds, and dams. Therefore, the water crisis tends to worsen in the coming years due to increases in the water use, mainly because of the lack of planning.

The human intervention on natural areas for occupation and economic and social interests intensified, seeking the survival of the human species, but generally using natural resources without concern for its conservation (Moraes, 2007; Paula, 2013). These actions modify natural systems, changing abruptly their characteristics

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and cause negative impacts that are often irreversible.

The coast of the state of Piauí is the smallest in the country, with approximately 66 km, but presents several natural attractions such as beaches, dunes, rivers, lakes, and mangroves, and is rich fauna and flora, especially in the Delta of Parnaíba. This region has an important set of cultural assets, such as historical architecture, handicrafts, and typical gastronomy that contribute to intensify its use and occupation (Martins Filho, 2013).

The freshwater resources in the coast of Piauí consisted of a group of springs formed by river basins with ponds and lakes that cover extensive areas, however, they are little studied. The lakes of the coastal region cover an area of 2.42% (28.7 km²), with emphasis on the river lakes of Portinho and Sobradinho (Cavalcanti, 2000). These lakes are freshwater reserves, and have social functions—artisanal fishing, tourism, recreation, and farming—that affect their environmental quality (Galvão, 2015).

The area drained by the Portinho River basin has a great geoecological value, integrating a set of landscapes where the Portinho Lake stands out. This lake is formed by a barrier on the Portinho River consisted of dunes that move from the coastal plain. The natural attributes of its basin make it a target for constant occupation by diverse producers.

Therefore, the area of the Portinho River basin is a natural environment with several social and environmental changes that are directly linked to the development of access routes, whose

surroundings are the main used areas for occupation. The lack of environmental planning for spatial organization and use of these areas has contributed to attract people and generate inadequate occupation and use. This created situations of hydro-environmental vulnerability and silting or transformation of channels and lakes. Portinho Lake integrates the water system of this basin and has been changing and characterized as an imbalanced lake, mainly because of the reduction on its water volume. The area of this lake is approximate 5 km², extending for 9 km in the north direction in the coastal plain of Piauí (Mendes Júnior, 2011).

Considering the environmental problems that surround the Portinho basin, and the significant climatic variations in the last decades, this work intends to expand studies on its characterization, including its current use and occupation and effects on the dynamics of the Portinho Lake from an integrated perspective of society and nature.

Material and Methods

The Portinho River basin and Portinho Lake (Figure 1) are in parts of two geographical regions of the north of the state of Piauí—Pre-Coastal Tablelands, and Coastal Plain (Lima, 1987). Once the spatial limits and objectives were defined, a bibliographical survey was carried out with collection of statistical data, and analysis of socioeconomic indicators, and geo-cartographic data (thematic mapping). In addition, a visit on this region, intending to understand the complexity of the basin, was carried out.



Figure 1. Portinho Lake at two different times. Photos taken by Francisco Soares Santos-Filho (left) and Tarcys Kléblio da Silva Mesquita (right).

Meteorological data were acquired from the nearest meteorological station, in the municipality of Parnaíba, and information from Bastos, 2015; INMET, 2016 (National Institute of Meteorology); and SUDENE, 1990 (Superintendence of Northeast Development) was used. Graphs and tables of the historical series of meteorological data of 1949-1959 were elaborated because this period presented precipitation indexes similar or inferior to those of 2006-2016.

The Portinho River basin delineation and altimetric mapping was carried out using geocartographic data—topographic charts (SA. 24-Y-A-IV Parnaíba, and SA. 24-Y-C-I Cocal) and interferometric images of the Shuttle Radar Topography Mission (SRTM)—obtained from the Brazilian Geomorphometric Database (TOPODATA) of the National Institute of Space Research (INPE). This material contained the contour bank, and altimetric data of the basin, with drainage area at scale of 1:100,000.

The thematic maps, illustrations and data systematization was processed using the ArcGIS 10.3.1 and Microsoft Office programs. Images of the satellites SRTM (INPE, 2015) and LANDSAT TM (DGI-INPE, 2016) orbit/point 219/63, photographs, and aerial images were used for the preparation of maps, and guide the fieldwork. An aerial image of the satellite LANDSAT 8 TM sensor of 2016 was used to develop the current land use map; this image was reworked in the ArcGIS 10.3.1 program and vectored with field confirmations.

Images of the entire area of the studied river basin and its UTM (Universal Transverse Mercator), and Degree/Minute/Second Coordinates were acquired using the Google Earth 7.1.5 program, thus facilitating the image treatment, and georeferencing work.

The fieldworks were important for the analysis because of the observation of the natural aspects, drainage-relief relationship, presence or absence of erosive processes, occurrence and density of plant species, and photographic record of the river basin. The uses of the water and surrounding areas of the valley of this river, and the opinion of local inhabitants and visitors of the Portinho Lake on its recent changes were also assessed.

Results and Discussion

The Portinho River basin is in the lower Parnaíba River region, a territory classified as Coastal Plain (CODEVASF/PLANAP, 2006) that covers an area of approximately 359.66 km², and the municipalities of Buriti dos Lopes (12.6 km²), Bom Princípio do Piauí (135.77 km²), Luís Correia (37.42 km²) and Parnaíba (173.87 km²).

The area of the Portinho River basin has an important geoecological value, integrating a set of landscapes. Its main components are the Portinho River and the Riacho Brandão, its tributary. This tributary is not the most extensive, but is the greater contributor to the water flow and volume of the Portinho River compared to the other streams upstream of the Portinho Lake (Figure 2):

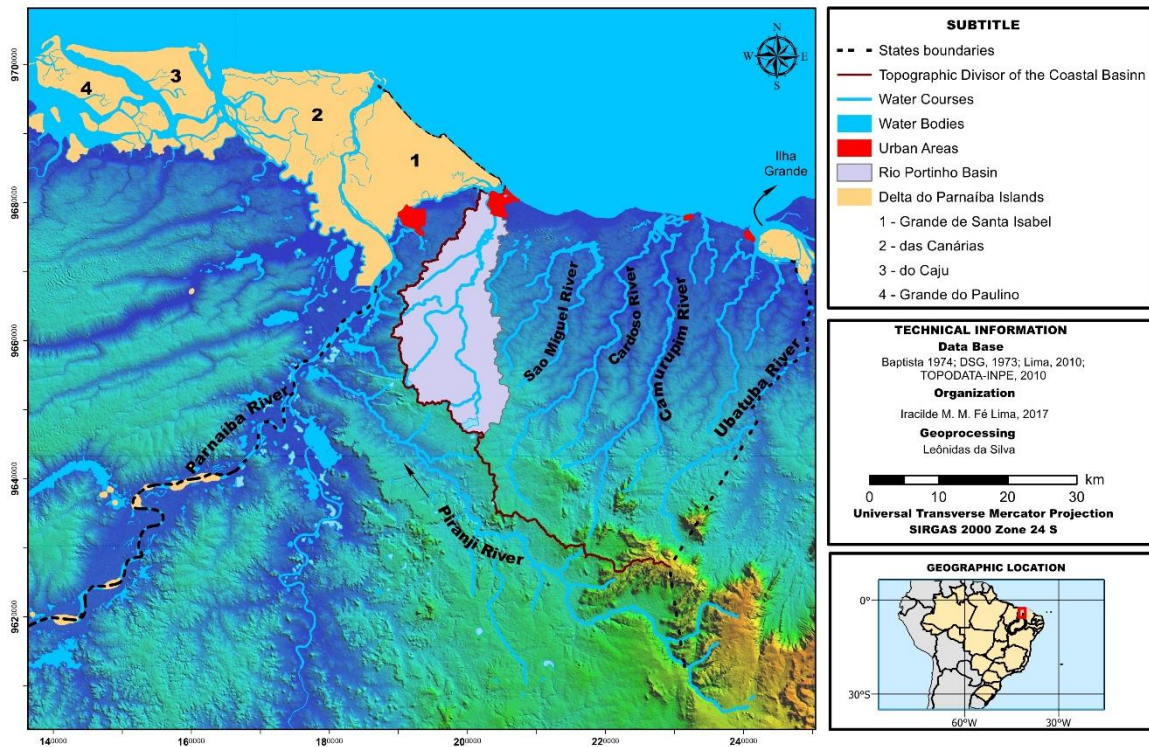


Figure 2. Location of the Portinho River basin.

This area is currently used for tourism, leisure, fishing, dairy farming and industries, family farming, irrigated rice crops, rice processing industry, and ceramic industries (CODEVASF/PLANAP, 2006). This region has an important set of cultural assets that contribute to intensify its use and occupation, with an expressive population increase in the last decades (Martins Filho, 2013).

According to the CEPRO Foundation (1996) and the Köppen classification, the climate area is in a transitioning area between tropical humid, with summer rains (Aw) and tropical humid, with summer rains extending until autumn (Aw').

Bastos et al. (2000) developed a climate classification for the region using the methodology of Varejão-Silva and Barros (2001), considering the moisture index proposed by Thornthwaite (1948) and Thornthwaite and Mather (1955). According to this classification, the predominant climate in the region is dry sub-humid (C1), with a

rainy season concentrated (more than 90%) in the first half of the year, with erratic precipitation in time and space. This region has an annual average precipitation of approximately 1200 mm (Bastos; Rodrigues and Andrade JR, 2000).

The coastal plain of Piauí has relatively high precipitation rates compared to the state average. This precipitation is erratic, presenting a rainy season from December to April or May, with heavy precipitation, and maximum of 298.4 mm in March, and a dry season from June to November, with sparse precipitation reaching a minimum of 1.1 mm in September (Cavalcanti, 1996). However, these rates have declined considerably over the last decade, even during the rainy season.

Based on the climatic data (Table 1), the temperature, sunshine, and evapotranspiration increased in part of the river basin, and the precipitation reduced significantly from 2006 to 2016, and from 1949 to 1959 (Table 2). Despite the lack of precipitation data for the areas of the main tributaries of the Portinho River, the effects of the drought can be seen in the Grande Lake in Bom Princípio do Piauí PI, and Canto do Morro Lake in

Buriti dos Lopes PI. These meteorological data do not characterize an abrupt climatic change, but are likely to affect the dynamics of the basin, as seen in two different periods (Table 1 and Table 2). This indicates an important effect of the most recent

climatic conditions on the reduction of the feeding of this basin and, consequently, the Portinho Lake, which completely dried in December in 2010 to 2016, as seen in the photographs of this lake and its surrounding dunes (Figure 1).

Table 1. Annual averages of climatic parameters from 2006 to 2016 in Parnaíba, Piauí, Brazil.

Climatic Parameter/Year	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Average air temperature (°C)	28	28.3	27.8	27.4	28.7	27.6	28.4	28.4	28.1	28.6	-
Maximum air temperature (°C)	32.8	33.3	32.5	31.8	33.7	32.2	33.5	33.3	33.1	33.5	-
Minimum air temperature (°C)	23.3	23.3	23.2	23	23.6	22.9	23.3	23.3	23.3	23.3	-
Sunshine (hours/day)	7.8	7.8	7.3	6.9	7.9	7.5	8.2	8.3	7.9	8.1	-
Evapotranspiration (mm/day)	5.3	4.9	4.6	4.4	5.2	4.9	5.5	5.3	4.9	5.5	-
Precipitation (mm)	1,151	1,077	1,378	1,646	629.1	1,107.2	624.6	853.4	978.9	696.5	805.6

According to the Tables 1 and 2, the rainfall indexes reduced throughout the period of 1949 to 1959, when the lake presented a water deficit, according to residents of the region (João Raimundo Bezerra Amaral, Personal Communication, October 2016). This denotes a

strongly relationship between the problems that afflicting the Portinho River region and the precipitation reduction, as seen in previous periods, which characterizes it as a cyclical phenomenon (Table 02).

Table 2. Annual average precipitation from 1949 to 1959 in Parnaíba, Piauí, Brazil.

Climatic Parameter/Year	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959
Precipitation (mm)	727.5	701	296	612	639	633.6	1.588.90	506.2	0	0	963.8

Regarding the Portinho River's course, its upper course was defined as the section of approximately 12 km in the municipality of Bom Princípio do Piauí PI, starting in the Grande Lake, at 80 meters altitude in the Serra Grande geological formation, up to the railroad in the Escuro Lake region. This section presents crystalline water springs in its first half, and bed covered with sandy sediments with crystalline rock outcrops in the following stretch. Interestingly, the beds of the upper course of the Portinho River and its tributaries were dry in the month of October in this area.

The medium course of the Portinho River starts at the crossing point of the railway in the

Escuro Lake, making a course of approximately 18 km up to the Olho D'agua town. This area of the basin is formed mainly by the Barreiras geological group, and contains Coastal Tablelands, with more sandy beds, and drainage cut by vicinal roads without proper culverts for water flows.

The lower course of the Portinho River was defined as the stretch that start at the Portinho Lake that partly drains the Barreiras group, and partly cut the dunes or is covered by them. The mouth of its tributary of greater flow, the Riacho Brandão, is in this stretch. From the Portinho Lake and Portinho town, the river is a water stream that reach the mouth of the Igaraçu River, in the Amarração bay, which is affected by the sea level during high tides.

The vegetation of the region presents herbaceous communities that cover dunes in stabilization process, areas of Pleistocene dunes, tree and shrub formations (flooded and non-flooded frutices), and open and closed fields with varying density of herbaceous species (Santos-Filho et al. 2010; Santos-Filho et al. 2013).

The vegetation distribution in this basin is linked to climatic factors, physiographic characteristics of the terrain, and anthropogenic activities. The vegetation cover of this basin undergoes major changes due to the seasonality of the climate of the region—two well-defined dry (winter) and rainy (summer) seasons. Moreover, these changes are due to the erratic precipitation in space and time in this region, which generates rapid responses of the vegetation to the environmental changes. The presence of various types of soil also contributes to the distribution of this vegetation.

According to Santos-Filho et al. (2013), the surroundings of the Portinho Lake can be described partly

[...] as a non-floodable frutices and partly as a field. This area presents nearby mangroves, near the Portinho River, and is close to the lake formed by a barrier on this river, caused by the dynamics of the dunes.

Frutices are pioneer arbustive formations consisted predominantly of shrub plants with heights of less than 1 to more than 2.5 meters.

The predominating vegetation types in the municipalities of Parnaíba, and Luís Correia are restinga and caatinga; and in Buriti dos Lopes and Bom Princípio do Piauí, campo-cerrado and caatinga (Table 3).

Table 3. Characteristics of the plant cover, and soils of the Portinho River basin.

Municipality	Predominant Soils	Predominant Vegetation Cover
Parnaíba	Dystrophic quartz sands, eutrophic alluvial soils, and hydromorphic laterites combined with dystrophic red yellow Latosols (Oxisols).	Mangrove, restinga, and shrubby Caatinga.
Luís Correia	Marine quartz sands, dystrophic quartz sands, and eutrophic alluvial soils.	Restinga, dune vegetation, and arboreal-shrubby Caatinga.
Buriti dos Lopes	Dystrophic quartz sands, lithic soils, hydromorphic laterite, and dystrophic red-yellow Latosols (Oxisols).	Campo-cerrado, shrub-arboreal Caatinga, and mixed secondary forest.
Bom Princípio do Piauí	Dystrophic quartz sands, lithic soils, hydromorphic laterite, and dystrophic red-yellow Latosols (Oxisols).	Campo-cerrado, and shrub-arboreal caatinga.

The natural and cultural attributes combined with the socioeconomic activities of this coastal region, which contains the mid-low and lower Portinho River, have making it one of the great attractions for occupation of diverse producers.

The Portinho River basin, as well as many other coastal basins in Brazil, has undergone several interventions for human activities, which transform its geocological into social elements. The use of water resources for the implementation of these activities, such as mining, livestock, crop irrigations, and daily activities of riparian populations (clothe washing and recreation) are usually inadequate. Although it brings economic growth and some financial return, these activities have contributed to the modification of the environmental quality of the area. These changes are affecting negatively the natural environment, with erosion in the river banks, silting, dune mobilization, impermeabilization of the soil, and degradation of river and lake banks.

Regarding land use, factors that lead to changes and the expectation of environmental justice due to the different interests in the natural resources of this basin stand out within the sustainable development discussion. Galvão (2015) studied the soil use in this area and found that recent activities such as water dam constructions for fish farming, combined with the reduction of rainfall in the last decades, contributed strongly to the reduction of the Portinho Lake water volume, and this is also occurring in the Riacho Brandão sub-basin.

The marks of human action on this basin are seen through the deforestation of the vegetation cover, inadequate management of soils and water resources, predatory hunting, burning practices, mining, and garbage dumping (Figure 3).



Garbage found in the Portinho River bed. October 2016.
Photo taken by Tarcys Kléblio da Silva Mesquita.



Mining in an area near the Portinho Lake. October 2016.
Photo taken by Tarcys Kléblio da Silva Mesquita.

Figure 3. Photographs of inadequate land use on the banks of the Portinho River and Lake.

Based on the visual texture of the satellite image for the river basin area, it is a relatively conserved physical-natural environment, although presenting changes that may be directly linked to the recent land and water uses. A large irrigated area in the basin region, at south Parnaíba and north Bom Princípio do Piauí, was identified as the irrigated perimeter of the Coastal Tablelands. The water supply in this irrigated area is from the Parnaíba River and this land use affects the natural dynamics of the Portinho River basin. Agricultural areas are found along the entire basin, especially by the rivers, but in smaller proportions when compared to the Tablelands (Figure 4).

Agriculture and livestock are the main activities identified throughout the basin area, which include the use of the vegetation in the river banks as pastures for animals. One of the oldest and still used methods in livestock is the burning of vegetation for planting pastures. Burns become frequent, especially from September to November, intending to clean the land for planting, but sometimes the fire gets out of control and reaches large dimensions. Low humidity combined with high temperature and wind are determining factors for out-of-control burns.

The rural area of the basin is very populated, especially in its left bank, which encompasses the municipalities of Parnaíba and Bom Princípio do Piauí. This region is characterized by changes in the natural environment, mostly directly linked to the development of access routes, whose surroundings are the main used areas for occupation and often constructed without any study or environmental planning, and end up affecting the drainage of the water courses that they cross.

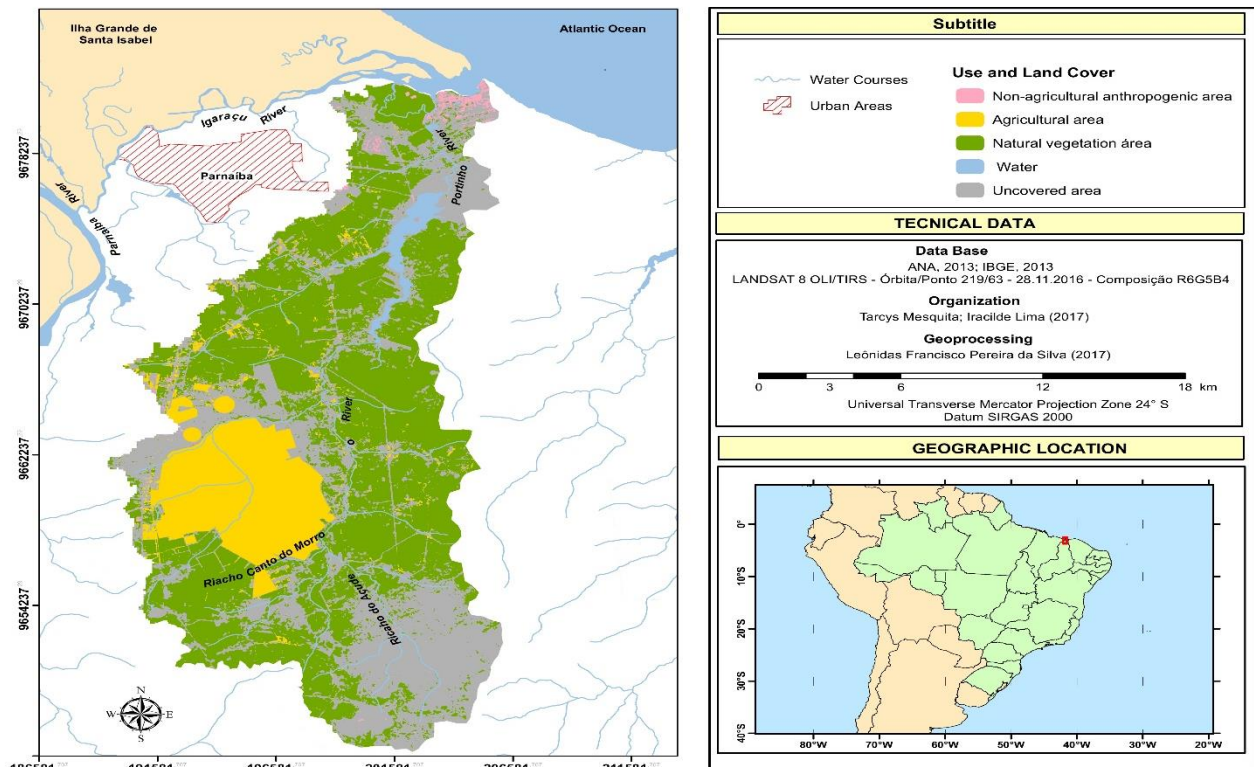


Figure 4: Map of the current land use and cover²

Regarding the barriers on the river, according to the field observations, the river was dry from its springs, which are located far from the barriers. This situation affects the current situation of the Portinho Lake, but are not alone responsible for its droughts, since the springs that are upstream of the barriers are completely dry. This confirms the hypothesis that the rainfall reduction had strong effects on the basin water shortage, but it does not

mean that these barriers have no effect on it (Galvão, 2015).

Therefore, the impacts on the basin and, consequently, in the Portinho Lake are due to a series of factors, especially to those linked to the decrease of rainfall, increase of temperature, and water evaporation, and the human action—irregular constructions of houses and roads, and private dams for irrigation and fish farming purposes.

² Uncovered areas refer to areas in which the vegetation is sparse or null, as found in Bom Princípio do Piauí; it includes dune areas, as found in the Luís Correia region, and areas with human intervention, as found near the tablelands (agricultural areas).

These land uses can affect the environmental quality of the basin and compromise its water quality; several parts of the basin are already without its natural vegetation due to agricultural uses. The absence of vegetation cover, combined with the soil typology of the basin, generate a great erosion due to the high-water flow speed, and less capacity of soil water storage. The basin area has low rainfall during most of the year, causing the formation of dunes formed by coastal sand carried by the dry wind.

Considering the current water and land uses, especially for agricultural activities and extensive livestock farming, the Portinho River basin is undergoing a significant anthropogenic intervention.

The rainfall reduction (Figure 5) is the main factor in the current situation of the Portinho River basin and Portinho Lake; the constant reductions in rainfall rates in the last decades—in addition to the current water and land uses—were key for the hydrological problems of the basin, since that this basin is supplied mainly by rainfall.

These data show the water deficit that occurs every year between June and December; and considering the months of May and January, the drought period increased from 7 to 9 months throughout the years, especially in 2010, when the water deficit prolonged throughout the whole year.

These water balances denote a high-water deficit for Parnaíba, and the hydrological problems for the Portinho region, which are intrinsically connected to the reduction of precipitation indexes that were intensified in recent years due to the current water and land uses in the basin area.

Conclusion

The results found in this study can be considered a warning of the current trend of uncontrolled increase in water use and land occupation in the municipalities located in the region of the Portinho River basin, Piauí, Brazil. The aspects found indicate serious hydro-

environmental problems in this river basin in recent years, especially regarding the high-water reduction of the Portinho Lake.

These considerations agree with findings of recent studies on the Piauí coast. They indicate that, historically, this lake has represented a great attraction to visitors for the practice of leisure and recreation, mainly due to its natural beauty. Moreover, this lake is the base for the economics of traditional populations of the area. However, the reduction of rainfall rates, advancement of moving dunes towards the lake, and inadequate use of the water of this river have resulted in a large decrease in the Portinho River flow, causing practically permanent extinction of the Portinho Lake from 2010 to 2016.

The analysis of the available data on the activities developed in this area, fieldwork observation on the Portinho River basin, photographs, and maps generated in the present study assisted in the identification of the current characteristics and problems in this environment. These data indicate that the negative hydro-environmental impacts generated by the current water and land uses on this river basin are more intense than those generated by traditional ones.

Considering the current imbalance of the river-lake system in the Portinho River basin, future researches must prioritize more precise definitions of the environmental potentialities and vulnerabilities of the area, and develop technologies to meet the needs of the population while applying sustainable development practices. Environmental education must be involved in all the essential actions to be developed in the region of the Portinho River basin.

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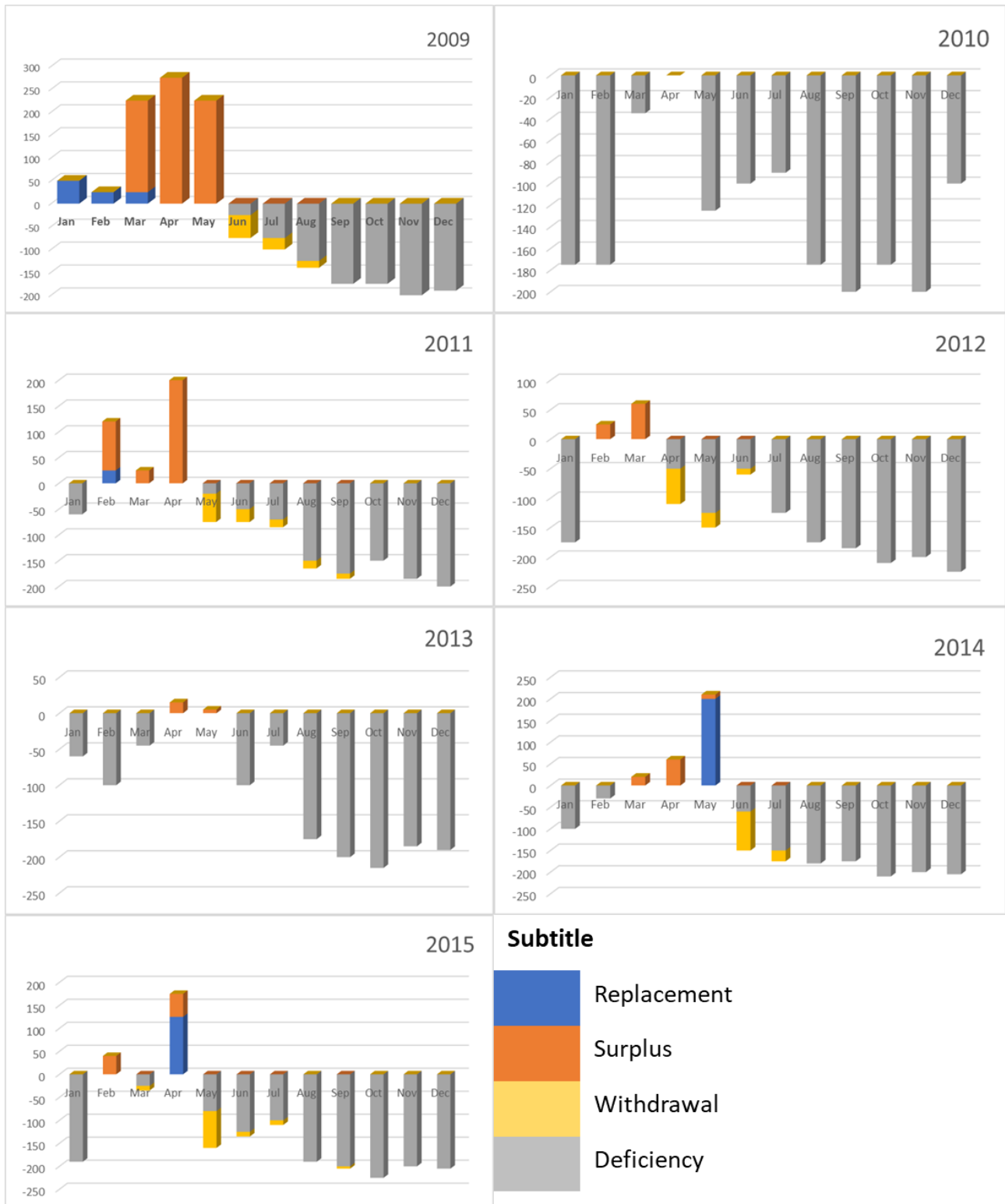


Figure 5. Climatological water balance of the years 2009 to 2015. Parnaíba, Piauí, Brazil

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