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THE USE OF CARTOGRAPHY TO THE APPLICATION OF THE DPSIR MODEL TO THE DIAGNOSIS OF THE HYDROGRAPHIC BASIN OF THE GUARIBAS RIVER IN NORTHEASTERN BRAZIL: GUIDELINES FOR LOCAL ENVIRONMENTAL MANAGEMENT

O Uso de Cartografia para a Aplicação do Modelo DPSIR Destinado ao Diagnóstico da Bacia Hidrográfica do Rio Guaribas no Nordeste Brasil: Diretrizes Para a Gestão Ambiental Local

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ABSTRACT

The present study analyzed the application of the Driving Forces-Pressure-State-Impact-Response (DPSIR) model as a decision-making tool for the development of effective public policy, based on the production of maps and the formulation of proposals that aim to improve the quality of life of the population of the Guaribas basin, in northeastern Brazil. The model emphasizes the analysis of the eco-systemic and anthropogenic relationships that constitute the natu-ral systems present within the study area. The appropriation of space within the Guaribas basin is the result of the ongoing urbani-zation process, which creates major inequalities in the use of coastal space. Overall, the DPSIR model proved highly effective for the integrated analysis of the socio-environmental problems affect-ing the Guaribas basin.

Keywords: Hydrographic Basin, Guaribas River, DPSIR Model, Environmental Planning, Geographic Information Systems.

RESUMO

O presente estudo analisou a aplicação do modelo forças motrizes-Pressão-Estado-Impacto-Resposta (DPSIR) como uma ferramenta de tomada de decisões para o desenvolvimento de políticas públicas eficazes, com base na produção de mapas e na formulação de propostas que visam melhorar a qualidade de vida da população da bacia do Guaribas, no nordeste do Brasil. O modelo enfatiza a análise das relações ecossistêmicas e antropogênicas que constituem os sistemas naturais presentes na área de estudo. A apropriação do espaço dentro da bacia do rio Guaribas é o resultado do processo de urbanização em curso, o que cria grandes desigualdades na utilização do espaço costeiro. No geral, o modelo DPSIR provou ser altamente eficaz para a análise integrada dos problemas socioambientais que afetam a bacia do Guaribas.

Palavras Chave: Bacia Hidrográfica, Rio Guaribas, Modelo DPSIR, Planejamento Ambiental, Sistemas de Informação Geográfica.

1. INTRODUCTION

When considered as a component of environmental analysis, hydrographic basins can be considered as territorial units, within which each type of space has a specific function related to its environmental characteristics and the patterns of land use and occupation, essential to the development of environmental planning and management. A number of authors (NASCIMENTO, 2003; BO-TELHO, 2006; RODRIGUES; SILVA; LEAL, 2011; TUNDISI, 2003; SOUZA; FERNANDES, 2000) have concluded that the available, classic models may often be inadequate for the planning of anthropogenic activities and the exploitation of natural resources, principally because they dissociate socio-economic questions from intrinsic environmental features.

The European Environment Agency (EAA) has developed the DPSIR (Driving Forces, Pressure, State, Impact, Response) model for the production of environmental reports and theoretical frame-works for the description of environmental problems through the standardization of the different sectors of human activities and environmental variables , (GIUPPONI, 2002). This model is used in many regions of the world to measure and evaluate the environ-mental impacts resulting from human activities, as well as providing diagnoses, environmental prognoses, and guidelines for environmental planning and the development of public policies appropriate to local conditions.

2. METHODOLOGICAL PROCEDURES

The application of new methods to the study of environmental questions, in particular for the planning of the more adequate exploitation of natural resources, should emphasize the understanding of the interactions and inter-relationships of the different elements that existent in natural systems (BERTALANFFY, 1997; BERTRAND, 1972; CHRISTOFOLETTI, 1980; GERASIMOV, 1980; GRIGORIEV, 1968; SOTCHAVA, 1974; RODRIGUEZ,; SILVA; CAVALCANTI, 2007; SOUSA et al., 2009; TRICART, 1977; ROSS, 2006). In this context, the DPSIR model provides a means of measuring environmental impacts resulting from human activities, as well as establishing a working basis for the diagnosis and prediction of environmental problems, and the development of guidelines for environmental planning (CABANILLAS, 2007).

In the early 1990s, the Organization for Economic Cooperation and Development proposed the PSR (Pressure - State - Response) model as a working tool. This model establishes the relationships among the pressures that society exerts on the environment, its resulting state or condition, and the response that society must pro-duce in order to alleviate or prevent the negative consequences of these pressures (CASADO, 2007). This model did not consider questions of sustainability, however, and did not provide information on ecological functions or ecosystem structure (CABANILLAS, 2007).

The conversion of the concept of pressure into one of "driving force" was an important step, given that pressure has negative connotations, whereas driving force may generate both positive and negative outcomes (JIDELBERTO, 2011). It was necessary to insert the impact parameter between the state and response indicators, in or-der to measure modifications of the state and promote the measures necessary to control the impacts.

In this context, the European Environment Agency proposed an analytic model that aimed to describe the environmental problems arising from the relationship between society and nature (CABANILLAS, 2007). This model, denominated DPSIR, considers that human activities or driving forces (D), in particular industries and transport systems, exert pressures (P) on the environment, such as the emission of pollutants, which degrade the state (S) of the environment, in relation to both ecosystems and public health. The impact (I) resulting from this process elicits a response (R) from the society through political measures, such as norms, laws, and the production of information, which may be directed at any sector of the system (KRAEMER, 2006). The relationships among the five basic categories of the DPSIR model are shown in Figure 1.

The methodological procedures of the

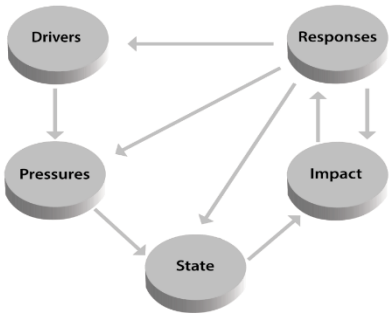

Fig. 1 - The components of the DPSIR model. Source: Giupponi (2002).

present study were divided into two distinct phases. The first phase consisted of a literature search, processing of the primary data, and the analysis of aerial photographs of the coast of São Gonçalo do Amarante, which were obtained from the Brazilian Mineral Resources Research Company (CPRM) on a 1:50,000 scale, and 1:35,000 scale aerophotocharts from 2007 and 2012 made available by the Ceará State Planning and Strategic Economy Institute (IPECE).

In the second phase, field excursions were conducted for the collection of data on the physical features of the ecosystems of the estuary and adjacent areas, the identification of the principal environ-mental units, and the characterization of the modifications caused by land use and occupation. These data included photographic records and geographic coordinates taken using a Garmin Etrex GPS. This phase was concluded by the development of cartographic products in a Geographic Information System (GIS) environment.

3. LOCATION OF THE STUDY AREA

Most (95%) of the Guaribas hydrographic basin is located within the northeastern extreme of the municipality of São Gonçalo do Amarante, on the coast of the Brazilian state of Ceará (Figure 2), be-tween 3º36'40.75" S, 38º55'26.11" W and 3º31'32.37" S, 38º48'26.59" W. The rest (5%) of the basin is located in the north-ern extreme of the neighboring municipality of Caucaia. The basin lies 50 km due northwest of the state capital, Fortaleza, and can be reached by the coastal CE-085 state highway, and the CE-422 highway, which links Fortaleza to the PSIC.

The basin covers a total area of 6.010 ha, and encompasses three conservation units: (i) the Pecém State Environmental Protection Area (Pecém EPA), which was created on June 5th, 1998 by Ceará state decree number 24,957, covers an area of 122 ha; (ii) Pecém State Ecological Station, created by Ceará state decree number 30,895 of April 20th, 2012, with an area of 973 ha, and (iii) the Botanical Garden, established by municipal decree number 799/03 of March 8th, 2003, which demarcated an area of 19 ha.

The Guaribas River is 1.159 ha km in length, from its headwaters in the inter-dune zone of the Batateiras smallholding to its mouth in the urban area of Pecém beach in the town of Pecém. The principal tributaries of the Guaribas are the Caraúbas, Prata, and Gregório streams, which flow into the right margin of the river.

4. APPLICATIONS OF THE DPSIR MODEL AS A DIAGNOSTIC TOOL FOR THE GUARIBAS BASIN

The DPSIR model is used to describe the relationships between the origins and the consequences of environmental problems. However, to understand this dynamic, it is necessary to establish the nature of the links among its different elements. For example, the relationship between the Driving Forces and the Pressures from economic activities is a function of the ecoefficiency (ANDRADE; MARINHO; KIPENTOK, 2001) of the local technology and the systems in use, that is, the driving forces will originate less pressure when the ecoefficiency of the area is higher. Similarly, the relation-ship between the Impact on public health or natural systems and the state or conditions of these systems will depend on their capacities and limits.

In the present study, the Driving Force component of the DPSIR refers specifically to the process of urbanization, which produces a set of pressures: (i) the development of urban nuclei, (ii) demographic evolution, and (iii) real estate speculation (social, cultural, and economic transformations).

The State component is represented by the basic sanitation conditions of the urban areas. The Impact indices were (i) inadequate disposal of solid waste, (ii) occupation of dune fields, and (iii) the deforestation of extensive areas of the coastal plateau, fixed dunes, and mangroves. The Response component of the present study refers

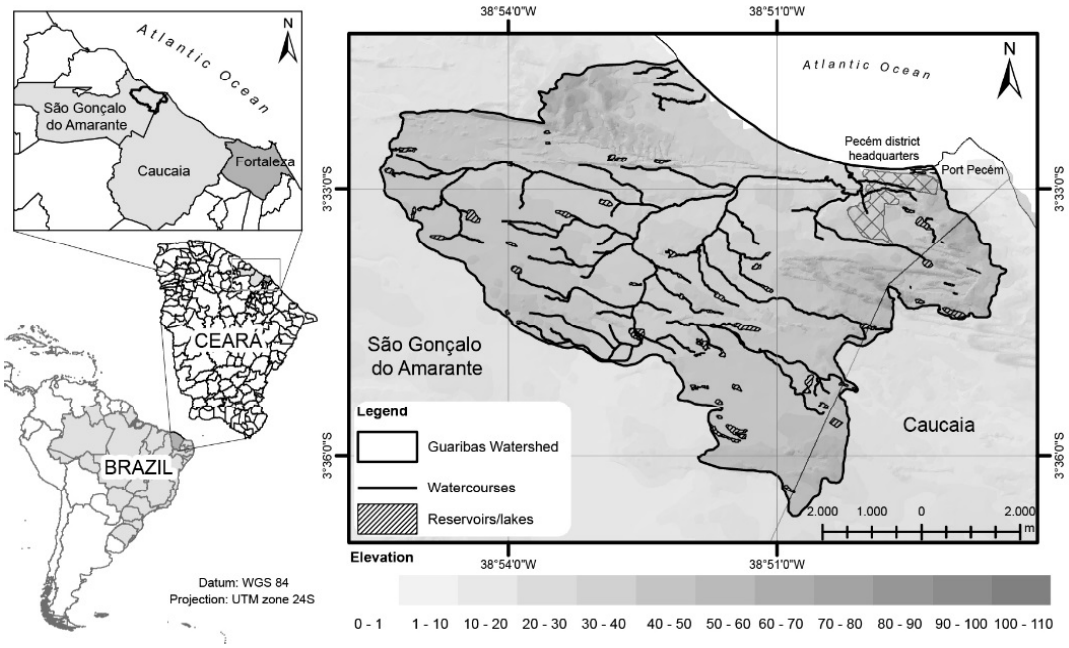

Fig. 2 - Location of the hydrographic basin of the Guaribas River in north-eastern Brazil.

to the improvement of urban infrastructure and the indices of formal education and income in the population. The starting point of the analyses were the indices of Driving Forces, given that they represent the beginning of the process of the conversion of the natural landscape of the Guaribas basin into artificial environments. (Table 1).

Table 1: Elements of the DPSIR model applied to the analysis of the hydro-graphic basin of the Guaribas River

Driving Force (D)	***DPSIR elements***
Urbanization 	**(P) Pressures:** Evolution of the population and urban areas of the Guaribas basin; **(S) State:** Basic sanitation conditions of the municipal districts located within the Guaribas basin; **(I) Impacts:** Emission of untreated domestic effluents, inadequate disposal of solid waste, occupation of dune field, deforestation and burn-off; **(R) Responses:** Public services, urban infrastructure, and indices of education and income.

The expansion of urban nuclei in the Guaribas basin is based on two assumptions: (i) the occupation of the basin originated in the main urban center of Pecém, located within the lower reaches of the river, and (ii) the process is based primarily on the occupation and use of the land in Pecém district and the adjacent areas. In 1958, urban development within the Guaribas basin occupied a total area of only 98 hectares (Figure 3). In 1988 (Figure 4), this area had risen to 1058 hectares, an increase of 1079.59% (960 hectares) over a thirty-year period.

This growth in urban development appears to have resulted from a set of factors, including (i) an increase in tourism, attracted by the natural beauty of the area, (ii) real estate speculation, (iii) the installation of new commercial establishments to meet the growing demands for consumer products, (iv) the construction of the local public market (in the 1970s), (v) the installation of a generator and the illumination of the town's two main streets during the night, and (vi) the installation of a public electricity network and the construction of a highway (in the 1980s) linking the town to the state capital, Fortaleza (AZEVEDO, 1998). By 2007 (Figure 5), the urban areas occupied a total of 1258 hectares, increasing 10 ha (0.78%) to 1268 hectares by 2012 (Figure 6), resulting from the influx of a specialized workforce from other Brazilian states seeking employment at the companies associated with the PSIC.

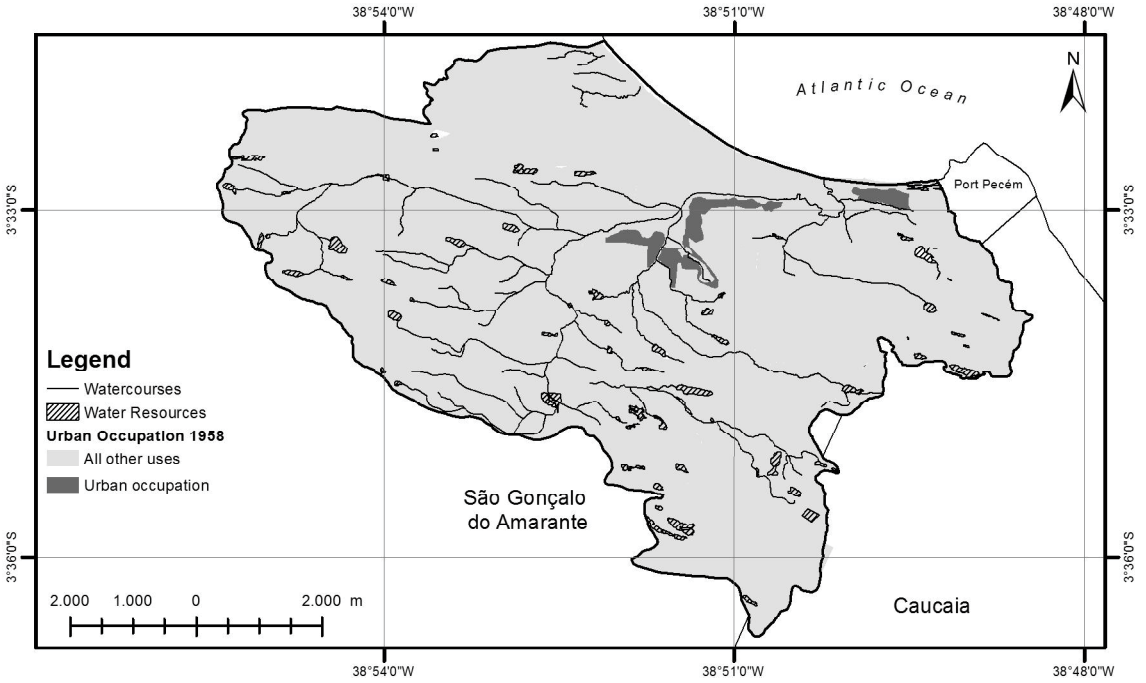

Fig. 3 - Distribution of urban areas in the Guaribas basin in 1958.

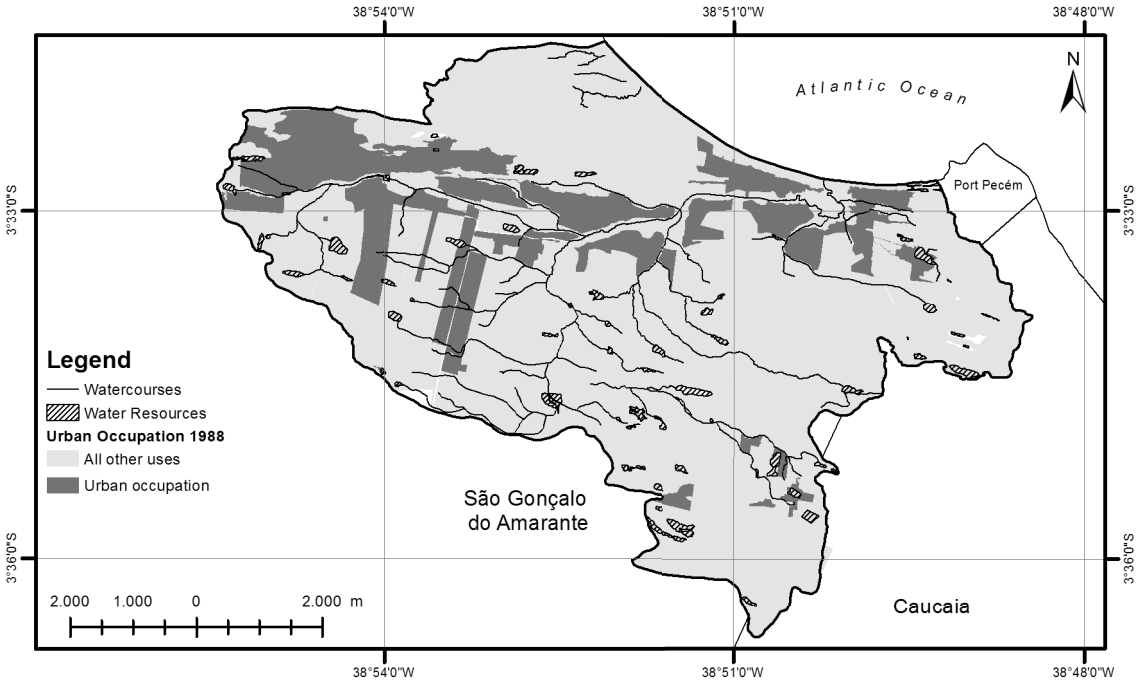

Fig. 4 - Distribution of urban areas in the Guaribas basin in 1988.

Local real estate speculation has grown out of the increasing interest in the expansion of urban development in the district of Pecém, related primarily to the presence of the PSIC, which has attracted a diversity of companies and property developers. Observations on site confirm the ongoing growth in the number of residences, housing both the local population and people from other regions, in particular Fortaleza and São Gonçalo do Amarante. This development has occupied the beachfront, mobile dune fields, and even the mangrove ecosystem.

In the 1960s, the natural resources of Pecém were favorable to the development of tourism, which encouraged property speculation. This resulted in a growth in local commerce, and the establishment of new working relationships, given that some families that had previously depended on fishing abandoned this activity to become live-in housekeepers in holiday homes (MONTEIRO, 2001).

The local population was gradually pushed

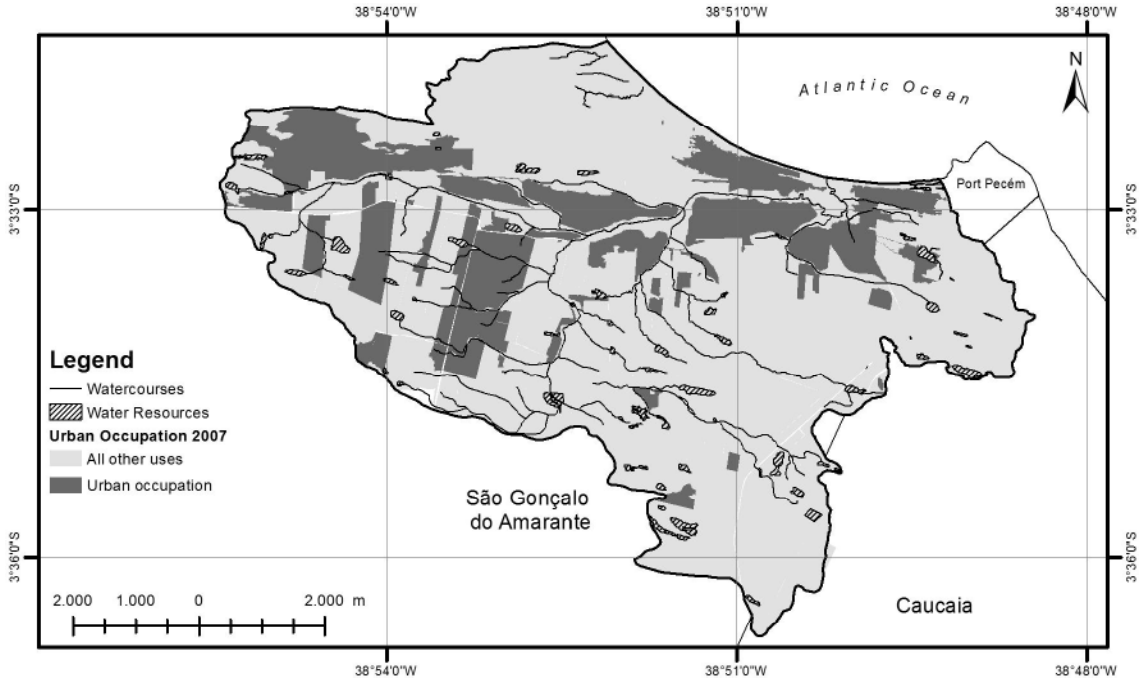

Fig. 5 - Distribution of urban areas in the Guaribas basin in 2007.

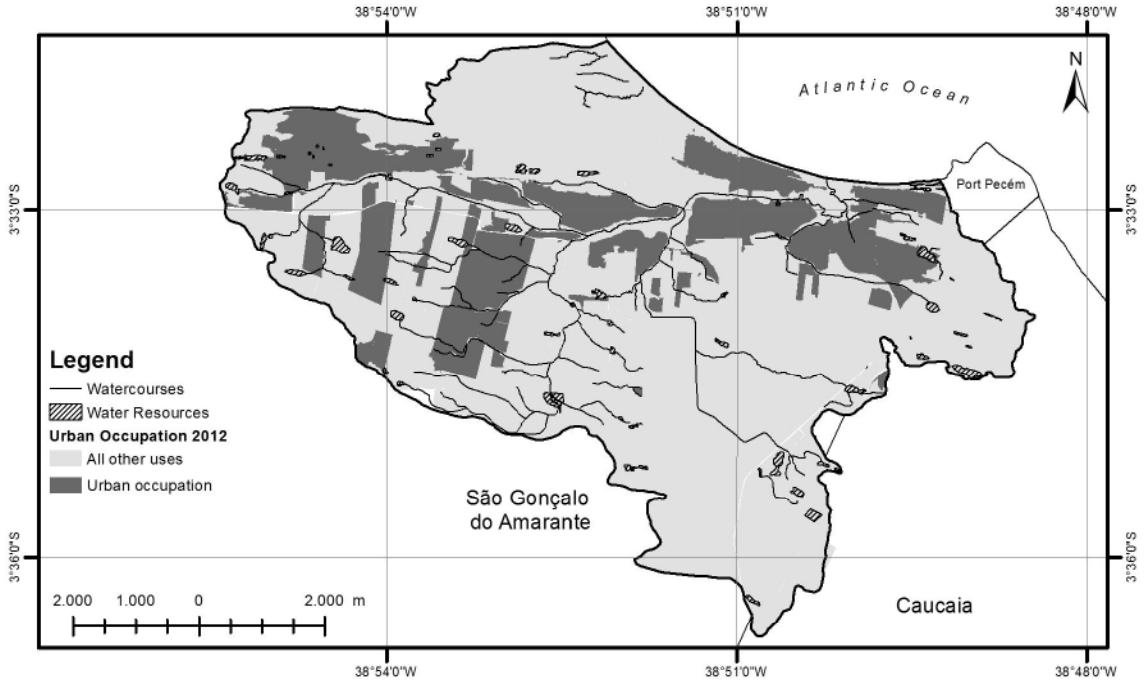

Fig. 6 - Distribution of urban areas in the Guaribas basin in 2012.

out of its traditional territory. The old thatch huts were replaced by brick houses for both local residents and holiday homes. Part of the dune system was occupied and the mangrove was landfilled for the construction of new housing. Domestic waste began to be discharged into the man-grove, resulting in a reduction in the productivity of local fisheries (fish and mangrove crab) due to pollution (ALBUQUERQUE, 2007).

In the 1980s, the principal housing complex in Pecém was the Pecém Vacation Colony, constructed on land belonging to the Prata family. The Barra do Pecém housing estate, located on the dunes, was then established. Property was developed in other parts of Pecém, including the Park Sul housing estate located between the old town center and the Teachers' Vacation Colony (GOMES, 1999).

There was an improvement in the income of some local shopkeepers, especially those in the food trade, although this was not necessarily the case for the owners of building supply stores and other types of products, given that the companies involved in the construction of

the PSIC consumed few, if any local goods and services. This was due to the relatively poor quality of the services, and the high prices of local goods, determined in part by the freighting costs (ARAÚJO, 2002).

Both Gomes (1999) and Araújo (2002) also noted subtle changes in local customs. For example, whereas much of the local population would traditionally spend their evenings meeting socially in the street, this habit was abandoned due to the marked increase in the volume of traffic related to the construction of the port, especially trucking, which left the streets covered in dust.

It is important to note here that the communities of the Guaribas basin are unanimous in their condemnation of the accelerated process of unplanned and unregulated urban development which has affected the whole region. This has included the appearance of shanty towns, the unauthorized occupation of protected areas, an increase in social problems, such as the sexual exploitation of minors, teen pregnancies, prostitution, drugs, and a lack of adequate policing.

With regard to the lack or inadequacy of the sanitation system available in the Guaribas basin, the discharge of untreated domes-tic effluents into the river and its tributaries is a universal problem, especially in the middle and lower sectors of the basin. Among other consequences, the local mangrove ecosystem has been modified extensively by the input of untreated domestic effluents.

The problems related to the lack of a public sanitation system in-crease along the course of the river, with the accumulation of urban development and riverside residences, especially along the lower course of the river. The absence of a basic sanitation system and the unregulated occupation of the margins of the river are the most common problems affecting the quality of its water. Few riverside homes have any form of basic sanitation or the means for the treatment of their effluents.

The discharge of untreated domestic waste directly into the river is a direct result of the region's lack of a public sanitation system, which has a serious impact on water quality. These effluents com-bine with the river water to create a source of pollution.

According to data from the federal government's Family Health Program, the urban areas of the Guaribas basin (the districts of Siupé, Catuana, Pecém, and Taíba) all suffer from a lack of a public sanitation system. This is emphasized by the use of wells as the primary water supply in the majority of households (Siúpe - 79%, Taíba - 99%, Pecém - 62%, and Catuana - 58%), and the predominance of septic tanks for the treatment of waste (Siupé - 80%, Taíba - 98%, Pecém - 63%, and Catuana - 72%).

The hydrological resources of the Guaribas basin have been thrown out of equilibrium by the negative environmental impacts caused by illicit practices, which reflects the lack of any effective environmental policy in the region, derived from basic concepts of sustainability, such as the capacity of support of the environment. The implementation of policies that will guarantee the security of the local hydrological resources is a major challenge, especially in the areas where economically-deprived populations depend on political decisions that often have no clear connection with their local reality. Fundamentally, these problems are the result of the current model of economic development, which ignores the specific carrying capacity of each environment.

The explosive growth of the populations of the Guaribas basin over the past two decades has resulted in a marked increase in the production of effluents, which have become a major source of pollution of the local water supply. Domestic effluents contain high concentrations of nutrients, which cause a number of types of impact, in particular, a reduction in the levels of dissolved oxygen in the water (LANDIM NETO, 2013).

In the middle and upper sectors of the basin, open-air rubbish tips can be found in a number of communities, representing a potential source of contamination of the soil and groundwater. Even so, most of the region has no effective trash collection system.

The occupation of dune fields, which are classified legally as Areas of Permanent Protection (APPs), associated with the lack of public sanitation and the problem of the disposal of solid waste, makes these ecosystems vulnerable to a range of potential risks and impacts, including (i) degradation of the APP, (ii)

destabilization of the dune fields, resulting in the disturbance of the sedimentological equilibrium between the dunes and the marine ecosystem, (iii) pollution of the water of lakes, estuaries, and adjacent coastal areas by the unregulated discharge of untreated effluents, solid waste, and other materials, (iv) contamination of the groundwater due to the lack of adequate sanitation, and (v) siltation of lakes, rivers, estuaries, and sandbanks.

The mobile dune field has been occupied primarily by holiday homes, mostly owned by residents of Fortaleza. This process interrupts the aeolian transport of sediments that maintains the characteristics of the beach. Meireles et al. (2005) concluded that the occupation of the dunes, beach, and margins of the estuary, which are all subject to wind, wave, and tidal forces, has resulted in the progressive erosion of the sediments of the beach.

The vegetation of a river basin is fundamentally important to its environmental integrity, in particular with regard to its role as an interceptor of precipitation, which is retained in the soil and partly re-turned to the atmosphere through evaporation (AB'SABER, 2002). This process is vital to the hydrological balance of a river basin, through the underground storage of precipitation. Deforestation is one of the principal causes of soil degradation, given that the removal of the vegetation cover leaves the soil exposed to the full force of the rainfall, which increases its vulnerability to erosive processes and the loss of biomass and, as a consequence, its biodiversity (BERTONI, 1999).

Agricultural plots in the study area are typically cleared by burn-off, which increases the fertility of the soil during the subsequent year or two (PRIMAVESI, 2002). Following this period, however, the benefits disappear, and the soil may become poorer in nutrients than it was prior to burning. This practice is typical of the small subsistence plots of maize, beans, and cassava. The environmental impacts present in the Guaribas basin are shown in Table 2 and Figure 7.

An additional consequence of population growth is an increase in the demand for public services, such as education, healthcare, sanitation, transport, policing, and leisure activities. One of the primary worries of the residents that live in the communities adjacent to the PSIC is the lack of employment opportunities for the local workforce in the companies installed (or to be installed) in this complex (ARAÚJO, 2002). In part, this reflects the demands of these companies for specific qualifications or schooling levels. Data on school attendance in the study area (provided by the São Gonçalo do Amarante municipal secretary for education) are shown in Table 3.

Table 2: Environmental impacts present in the hydrographic basin of the Guaribas River

01-Burn out	09.B-Sewage
02-Refuse	09.C-Invasion of dunes
03-Eutrophication	10-Refuse
04-Invasion of dunes	11-Invasion of dunes
05-Invasion of dunes	12-Sewage
06-Sewage	13-Deposition of oil on the beach
07-Occupation beach strip	14-Sewage
08.A-Sewage	15-Invasion of dunes
08.B-Mangrove invasion	16 Sewage
09.A-Sewage	17-Issuance of sewer to mangrove

The proportion of school-age children attending primary school in the municipality of São Gonçalo decreased between 2007 and 2011, from 93.7% to 92.2%. Even lower rates were recorded for secondary schooling, which also declined between years. In São Gonçalo do Amarante, 73.8% of children attended secondary school in 2007, and 70.2% in 2011.

In São Gonçalo do Amarante between 2007 and 2011, more than 80% of formal employment involved workers with only a primary education (graduated or not). While the participation of secondary school graduates increased over this period, the number of employees with only a primary education remained high. The number of college-educated employees also increased between years, although they still represented less than 20% of the workforce employed by local industries and shipping companies. The number of employees with graduate degrees is practically zero, a situation which remained unchanged between years.

An additional preoccupation of local communities is the failure of the public health service to cope with the increasing demand caused by the explosive growth in the local population, most of which involves migrants

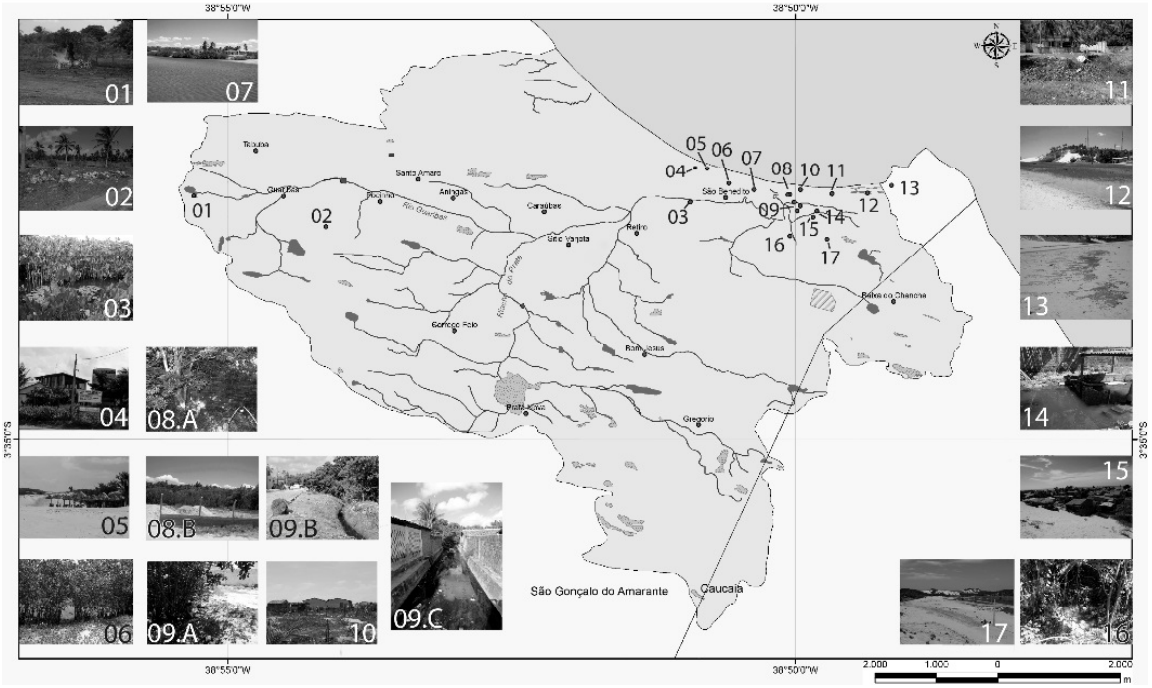

Fig. 7 - Environmental impacts present in the hydrographic basin of the Guaribas River.

Table 3: School attendance in the districts of Caucaia and São Gonçalo do Amarante in 2012 Source: Education secretaries of the municipalities of São Gonçalo do Amarante and Caucaia

Municipality	*District*	*Number of schools*	*Number of pupils*		
			Kindergarten	Primary school	Secondary school
São Gonçalo do Amarante	Pecém	5	667	2.079	870
	Taíba	3	236	764	-
	Siupé	2	146	454	-
Caucaia	Catuana	13	497	1548	-

from other Brazilian states. The availability of resources for the needs of the most vulnerable sectors of the population, such as senior citizens and people with disabilities, is already clearly insufficient. According to the Ceará state Public Health Administration for the 2nd Region, the public healthcare system in São Gonçalo do Amarante consists of one municipal hospital, two ambulance crews, 16 family health teams, and one outpatient clinic, still under construction. A total of 424 healthcare workers are employed in the municipality by the Brazilian National Health System (LANDIM NETO, 2013).

5. CONCLUSIONS

The development of the DPSIR model for the Guaribas basin was based on the quantification and qualitative assessment of socio-environmental and economic indices. Environmental indices pro-vide a powerful diagnostic tool that may serve a number of different purposes, in particular, by contributing to an increase in public awareness with regard to environmental problems and the need to support political decision-making.

The current reality of the Guaribas basin emphasizes the ongoing deterioration of its natural environments, which is occurring in a chaotic manner, due to the lack of any systematic public planning or effective regulation of land use. This has resulted in alterations of the different components of the landscape and the natural dynamics of the predominant processes governing the local natural systems, as well as threatening the availability of natural resources. Unplanned demographic expansion has resulted in considerable impacts on the local environment, such as the destruction of dunes for the construction of buildings, the installation of infrastructure along the beachfront, the discharge of effluents into bodies of water, and the illegal

occupation of natural environments (floodplains, dunes, beaches, etc.).

The Guaribas basin clearly requires an integrated management program and the introduction of effective public policies that focus on the well-being of the local population. It will be especially important to conduct integrated, multidisciplinary studies in order to better comprehend the social and environmental needs of the region, as well as the cooperation of local administrators in order to guarantee the effective implementation of the measures recommended by the scientists, with the full participation of the communities involved in the process.

The present study has reinforced the value of the DPSIR model for the integrated analysis of environmental problems in the context of their underlying causes. The model also provides insights into the responses required from public administrators, the community, and economic sectors.

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