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METHODOLOGICAL APPROACH TO DETERMINE THE CAPACITY FOR ENVIRONMENTAL RESILIENCE IN WATERSHEDS

ABORDAGEM METODOLÓGICA PARA DETERMINAÇÃO DA CAPACIDADE DE RESILIÊNCIA AMBIENTAL EM BACIAS HIDROGRÁFICAS

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ABSTRACT

The determination of resilience capacity constitutes an important tool for environmental conservation and preservation. The aim of the present study was to evaluate the environmental resilience capacity of the lower course of the basin of the Poti River (LCPR) in the state of Piauí in northeastern Brazil. For such, analyses were performed of the natural and socioeconomic aspects of the area. A geographic information system was used for interpreting the lower Poti River and identifying the main existing environmental risks. The images were edited using *SPRING 5.2* and *ARCMAP 10.3*. Environmental resilience capacity was determined by calculating an environmental resilience index (ERI) based on two additional indexes: the natural resilience index (NRI) and the municipal social vulnerability index (MSVI). Environmental resilience capacity was low in the urban areas of the river due to the greater pressure on the environment as a result of demographic density and the exploitation of natural resources. In contrast, rural areas (86 percent of LCRP) showed a moderate-to-high degree of environmental resilience, due to the occurrence of large areas predominantly covered with natural vegetation. The municipal social vulnerability index reflects the various public strategies adopted by administrators. Another finding was that the method developed for evaluating environmental resilience based on the analysis of natural resilience and social vulnerability is important to the planning and management of river basins in terms of the sustainable development of its uses in different geographic areas.

KEYWORDS: Vulnerability; Resilience; Hydrographic basin; Sustainability

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RESUMO

A determinação da capacidade de resiliência constitui uma importante ferramenta para a conservação e preservação ambiental. O objetivo do presente estudo foi avaliar a capacidade de resiliência ambiental do baixo curso da bacia do rio Poti (BCRP) no estado do Piauí, no nordeste do Brasil. Para tanto, foram realizadas análises dos aspectos naturais e socioeconômicos da área. Um sistema de informações geográficas foi utilizado para interpretar o baixo Poti e identificar os principais riscos ambientais existentes. As imagens foram editadas usando SPRING 5.2 e ARCMAP 10.3. A capacidade de resiliência ambiental foi determinada pelo cálculo de um índice de resiliência ambiental (IRA) baseado em dois índices adicionais: o índice de resiliência natural (IRN) e o índice municipal de vulnerabilidade social (IMVS). A capacidade de resiliência ambiental foi baixa nas áreas urbanas do rio devido à maior pressão sobre o meio ambiente em função da densidade demográfica e da exploração dos recursos naturais. Por outro lado, as áreas rurais (86% da BCRP) apresentaram um grau de resiliência ambiental de moderado a alto, devido a ocorrência de grandes áreas predominantemente cobertas por vegetação natural. O índice municipal de vulnerabilidade social reflete as diversas estratégias públicas adotadas pelos gestores. Outra constatação foi que o método desenvolvido para avaliação da resiliência ambiental com base na análise da resiliência natural e vulnerabilidade social é importante para o planejamento e gestão de bacias hidrográficas no que diz respeito ao desenvolvimento sustentável, de seus usos em diferentes áreas geográficas.

PALAVRAS-CHAVE: vulnerabilidade; resiliência; bacia hidrográfica; Sustentabilidade

INTRODUCTION

The appropriation of nature by humans due to the pressure of economic production and the exploitation of natural resources without any consideration of physical and natural limits can cause serious harm to the environment, often hindering its capacity to maintain its original characteristics, functions and services. It is therefore important to use the natural resources of river basins correctly, paying due attention to the preservation of the physical-natural characteristics of the environment, in order to minimize the impacts of human activity and enable environmental regeneration.

Given their systemic functioning, river basins are the site of interaction between biotic and abiotic factors on the one hand, and socioeconomic/cultural dynamics on the other. Because of the demands placed on the natural resources for the sake of socioeconomic development, they are subject to powerful pressures that often push geosystems and ecosystems beyond their resilience capacity.

Resilience is the capacity a system has to absorb disturbances and reorganize itself to return to full functioning. This includes the capacity not only to return to a pre-existing state of equilibrium, but also to progress in terms of adapting to further disturbances. Thus resilience has to do with the capacity of a system to maintain its integrity over time, especially in relation to external pressures (Holling, 1973; Klein et al., 2003; Adger et al., 2005; Folke, 2006; Chapin et al., 2004; Cutter et al., 2008; Müller et al., 2010a, 2010b; Burkhard et al., 2011; Evans, 2011; Ponce-Campos et al., 2013; Oliveira e Aquino, 2020).

On the environmental perspective, studies on resilience are increasing in both Brazil and in the world. Nevertheless, their emphasis is on social factors. It is therefore important to apply this concept to the environmental aspect, in function of the emergency of a sustainable use and management of natural resources with a view to the conservation of ecosystems and, consequently, society.

Many studies have addressed river basins over the years, their main goal being to identify the dynamics of rivers in the framework of the development of landforms. However, given their systemic nature and their importance for landscape studies, river basins have also been analyzed in terms of geosystemic and land planning units. Based on this premise, in the present study it was aimed to propose a methodology for constructing an Environmental Resilience Index (ERI) for studying the capacity of environmental resilience in a hydrographic basin. In this case, it was used the lower course of the Poti River (state of Piauí, Northeastern Brazil), through an integrated analysis of natural and socioeconomic aspects of this area. Existing environmental impacts have been identified, based on the modes of managing natural resources, and used as the main variables. This way, a perspective of use of these results can occur, since their usefulness in subsiding planning of actions aimed at sustainable land use, while paying due consideration to socio-environmental aspects.

METHODS

The LCPR is located in the central northern portion of the state of Piauí, Brazil (Fig. 1). The study area for analyzing environmental resilience was the drainage of the river in the stretch where it is perennial. This area has approximately 4600 km^2, amounting to 11.3 percent of the total area of the river basin.

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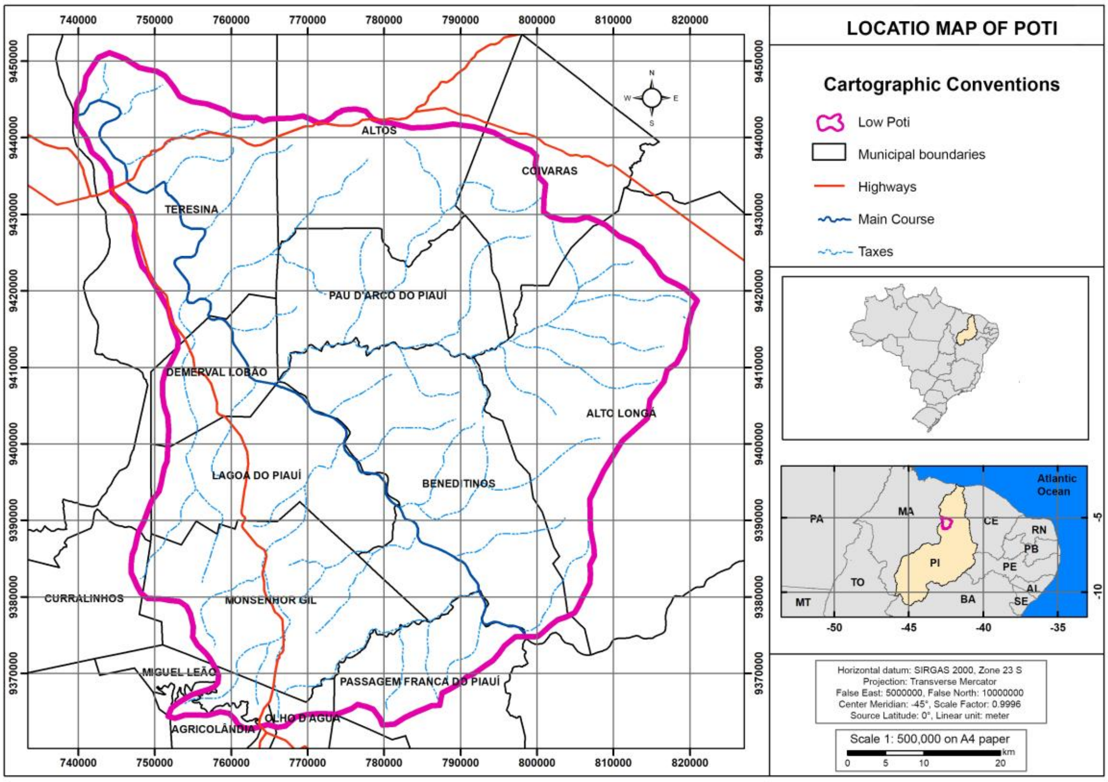
Figure 1: Location and drainage of the lower course of the hydrographic basin of the Poti River, Piauí (Brazil)



Source: Authors, 2021

The LCPR is situated in the transition zone between the humid Amazon climate to the west and a semi-arid climate to the east. The average annual maximum temperatures range from 34 to 36°C and the average annual minimum temperatures range from 20 to 22°C (Lima & Augustin, 2014).

The flow of the Poti River is of the semi-intermittent type, to become perennial only in its lower course, beginning at the city of Beneditinos. This occurs downstream from the confluence of two important tributaries, the Sambito and Berlengas Rivers, whose waters add to the springs that feed the Poti River from this point onward.

The present study uses descriptive and recognition methods, based on qualitative and quantitative approaches. Since the aim of integrated analysis is to understand the dynamics of the whole based on an examination of its parts, the criteria proposed by Tricart (1977) were used for characterizing the environment under study and analyzing the relationships of its constitutive components. The theoretical tools used throughout the study have been adapted to the environmental characteristics of the lower course of the Poti River.

To establish an environmental resilience index (ERI), from the correlation of social and environmental aspects, a systematic temporal analysis was performed of natural features between 1985 and 2015 for analyzing the behavior and alterations of natural resources, admitting from a systemic analysis, that they are integrated by several components which maintain mutual relationship, and are subject to continuous fluxes of matter and energy. For this purpose, a natural resilience index (NRI) was at first created taking into account the means of the attributes of average declivity, pedology, soil temperature and the normalized difference vegetation index (NDVI). This step is fundamental for comprehension the natural dynamics of the environment and its resilience capacity, through articulation of these attributes in the analyzed period (Equation 1). This was done through the application of fuzzy logic and made it possible to identify the natural resilience of the LCPR based on the analysis of satellite images from 1985 to 2015. Soil temperature and NDVI are relevant for observing the impacts on the environment, caused by human activities in this time period.

$$NRI = (Dm*i_1+Ped*i_2 +TempS*i_3 +NDVI*i_4) \qquad \text{(Equation 1)}$$

in which NRI = natural resilience index; i_n= relative importance of the variable; Dm = mean declivity; Ped= pedology; TempS = soil temperature; NDVI = normalized difference, soil-adjusted vegetation index.

The weighting of variables was based on Saaty's AHP technique (Ramos et al., 2014), which resorts to pairwise comparisons. A weight matrix was then created for each variable and the consistency ratio (CR) was calculated. This is the ratio between a coherence index and a random coherence index, the result of which indicates whether the ratio estimated by the matrix is consistent or random. Saaty (1991; apud Ramos et al., 2014) notes that, in order to be considered acceptable, good consistency measures should be equal to or less than 0.10 (Table 1).

Table 1: Relative importance (AHP) of the environmental variables used to evaluate natural resilience in the lower Poti River

Environmental variable	Relative importance (AHP)	
Soil temperature	0.05	
Declivity	0.11	
Pedology	0.24	
NDVI	0.60	CR:0.036

Source: Authors (2021), based on Saaty (1991; *apud* Ramos, Cunha & Cunha, 2014)

Mapping algebra was used in a geographic information system (GIS) with data from the years 1985 and 2015. This allowed for the calculation of the NRI of the lower Poti River, making it possible to identify areas that underwent positive or negative changes.

Given the importance of mapping social vulnerability in land management and organization policies, the next step was to create a municipal social vulnerability index (MSVI). It followed the method developed by Cunha et al. (2011), which combines populations at risk with the support capacity of the land system. This index was created based on principal component analysis (PCA) of a set of demographic, environmental, social and cultural variables of the households of the group of census sectors that make up the area of the lower course of the Poti River. It uses census data from 2010, which are the latest existing official data from government authorities.

Based on studies conducted by Cutter (2003; 2011) and Cunha et al. (2011), the MSVI was determined through PCA, using the SPSS statistical analysis software. PCA was useful for eliminating redundant variables and grouping the remaining variables into number of factors (Cunha et al., 2011). This method operates in the following manner: (Step I) Normalization of variables using z-scores, the mean of which is zero and the standard deviation, 1; (Step II) Application of factor analysis in SPSS (version 17); (Step III) Analysis of data correlation matrix to eliminate redundant variables (multicollinearity analysis); (Step IV) Further factor analysis to reach parameters deemed necessary for results to be considered valid (variance rate higher than 60 percent, with Kaiser-Meyer-Olkin value and communality levels higher than 0.5). (Step V) Interpretation and scaling of obtained factors and how they influence social vulnerability; as the values do not always have the determined orientation, it is necessary to scale partial indexes so that a higher end result of the equation denotes greater social vulnerability. Thus, if the factor scores of variables that contribute to diminish vulnerability have a positive orientation, the score must be multiplied by -1. (Step VI) Combination of factor scores of each land unit into a single value in terms of criticality or support capacity; (Step VII) Exportation of data from SPSS to ArcGIS 10.2 in order to arrive at a spatial representation of the results; the merging of the table exported from SPSS and the table in ArcGIS used one code for each census sector (*Instituto Brasileiro de Geografia e Estatística* – IBGE [Brazilian Institute of Geography and Statistics], 2011); (Step VIII) Classification of end results of the MSVI evaluation equation based on the criteria proposed by Cutter et al. (2008).

The region of the lower course of the Poti River consists of 11 municipalities with 1252 census sectors (2010 census) that served as the basis for the collection of the sample data. They include urban and rural areas, areas of different uses, built-up areas, populated areas, open and unpopulated areas. A set of 79 variables were organized into seven groups (education, residences, gender, resident, ethnicity, income and age), with 35 remaining after the collinearity diagnostic test was conducted. As a result, there emerged 10 explanatory factors for detailed study.

The classification of latent factors identified for the social vulnerability of LPR had demonstrated that the factors 1, 2, 4, 6, 8 and 10 showed a negative contribution. It means they are the variables that increase the vulnerability for the census sectors who they represent, while the other factors showed a positive contribution.

In this study the dimensions of social vulnerability were calculated through the use of the weighted sum technique (CUNHA et al., 2011), since in this procedure the different aspects of the obtained latent factors are considered, as well as their particularities. This way, the calculation of each one of the dimensions for each analysis unit of the study area was determined through the Equation 2. The contributions, when positives, equal1; when negatives, equal -1.

$$D = (Cf1 * F1x1 * Vf1) + ... (Cfn * Fnxn * Vfn) \quad \text{(Equation 2)}$$

in which D = vulnerability dimension; Cf = contribution of factor[10]; F = factor value for each unit of analysis; V = percentage of variance accounted for by each factor.

The scores of the various factors for each census sector were exported to ArcGIS 10.2, which allowed us to determine the final MSVI for each census sector and to map it according to an empirical classification of the results as very low, low, moderate, high and very high.

The third step was to determine the ERI by numerically combining the NRI and MSVI results (Table 2), following the method described by Cunha et al. (2011) and Mendes et al. (2011).

Table 2: Numerical comparison of NRI and MSVI

MSVI/NRI	1	2	3	4	5
1	1	2	3	4	5
2	2	4	6	8	10
3	3	6	9	12	15
4	4	8	12	16	20
5	5	10	15	20	25

- VERY LOW
- LOW
- MODERATE
- HIGH
- VERY HIGH

Source: Cunha *et al.* (2011) and Mendes *et al.* (2011)

After cross-checking the data, a map was generated with the five groups ranging from very high to very low, using equidistant intervals to evaluate the resilience capacity of the environment while considering the existing socio-environmental vulnerabilities (Table 3). For the purpose of interpreting environmental resilience, classifications of high and very high based on observations in the area were considered progressive, whereas classifications of low and very low were considered regressive.

Table 3: Parameters for classification of environmental resilience index

Classification of environmental resilience	Interpretation	Observation of environment
Very high ↓ High	Progressive	When there are conditions for the environment to regenerate itself easily in the occurrence of human pressure and for society to recover from the consequences of environmental degradation over the time period under analysis (positive feedback)
Moderate	Moderate	When morphogenetic and pedogenetic processes are unaltered over the time period under analysis, resulting in lower levels of aggression against the environment and by the environment against society
Low ↓ Very low	Regressive	When there are little or no conditions for the environment to regenerate itself due to the pressures exerted upon it or for society to recover from the consequences of environmental degradation over the time period under analysis (negative feedback)

Source: Authors, 2021

After superposing the data, a map with five classes from high to very low was generated, using equidistant intervals for evaluating the capacity of resilience of the environment, against existing socioenvironmental vulnerabilities. For the interpretation of environmental resilience the classification high to very high was considered as progressive; the low to very low was considered regressive, according to the observations in the area.

GIS was used for interpreting the area as well as identifying the conditions of the natural resources and existing risks stemming from the forms of use in various scenarios (1985 and 2015). The images were georeferenced with SIRGAS 2000 coordinates and edited with the use of SPRING 5.2 (free software) and ArcMap 10.3 (60-day free trial version).

On-site verification was performed to examine and define the areas of the experimental surveys and to map and characterize the landforms, vegetation and types of land use.

RESULTS AND DISCUSSION

Spatiotemporal scales play an important role in the analysis of environmental resilience due to the fact that ecosystem processes operate in a spatiotemporal hierarchy and disturbances are determined by spatiotemporal factors. Muller et al. (2016) mention that long

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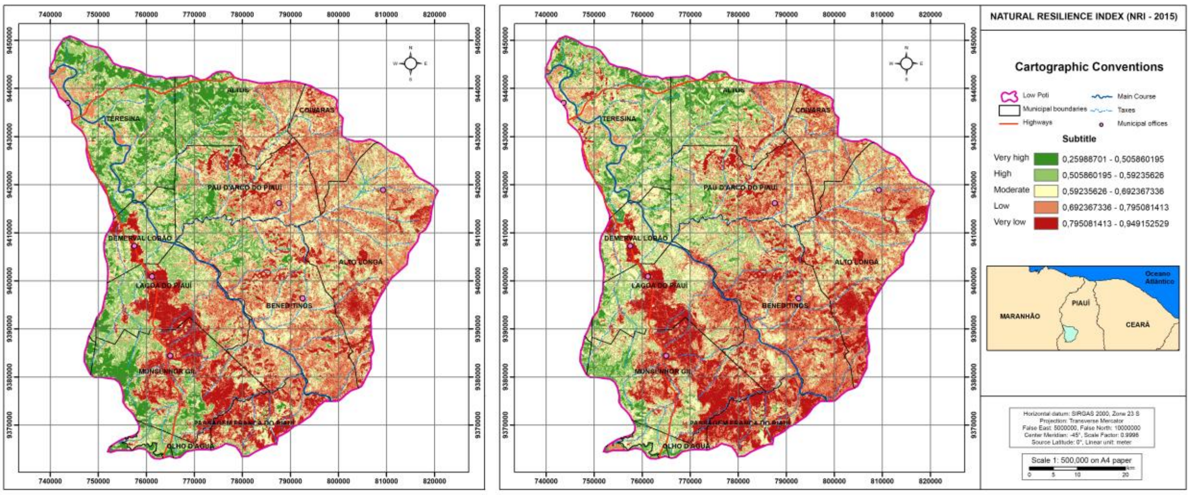
term process can produce cumulative harm and degradation, increasing the vulnerability of the ecosystem, what can cause the reduction of resilience capacity.

The LPR shows vegetation transitions between caatinga, cerrado and babassu forest, what reflects its climate and pedological conditions of the area. The NRI of the lower course of the Poti River created for 1985 and 2015 (Fig. 3) showed that the low and very low classes increased to approximately 21 thousand hectares, which amounts to 5.6 percent of the area. The increase occurred mainly in such urban areas as the city of Teresina, which expanded during that period. It also occurred in areas of exposed soil between the municipalities of Lagoa do Piauí and Passagem Franca do Piauí, which have a predominance of Lithic Neossols and gently undulating relief, as well as between the municipalities of Beneditinos and Coivaras, which are characterized by undulating to gently undulating relief and a marked presence of Petric Plinthosols and *caatinga*/*cerrado* [semiarid/savanna] vegetation, the main activity carried out in the region being family farming.

Figure 3: NRI of the lower course of the Poti River (State of Piauí, Brazil) in 1985 and 2015.



Source: Authors, 2021

Figure 3 also shows that the areas with very low NRI were mainly associated with Lithic Neossols, which are characterized by young, undeveloped soils. However, some areas have limitations in terms of agricultural use due to their low effective depth, small water storage capacity and high susceptibility to erosion (Melo et al., 2001; Santos & Aquino, 2015). Therefore, its main indication is for environmental preservation, focusing the characteristics of soil, vegetation and climate, previously described.

It is possible to observe that the NRI had reduced approximately 33 thousand hectares (8.7 percent) for the class high to very high, that is associated to the area with the greatest plant cover of *cerrado* (savanna) and babassu (*Attalea speciosa* Mart.), stretching from the municipality of Monsenhor Gil to the municipality of Altos, in the southwestern and northern portions of the river basin.

The moderate class increased by eight thousand hectares. This had to do with the reduction in primary vegetation, which can lead to diminished natural resilience if no preventive and restoring actions are taken with regard to the soil and vegetation.

Except for the city of Teresina, the socioeconomic activity of the area under study is predominantly linked to the subsistence agriculture practiced by small farmers, most of whom employ rudimentary cultivation methods that compromise the environment. These farmers often perform planned burning of the vegetation, without any regard for conservation.

As mention above, a MSVI was created to evaluate social vulnerability for the lower course of the Poti River. It consisted of a set of 79 variables organized into seven groups (education, residences, gender, resident, ethnicity, income and age), with 35 remaining after the collinearity diagnostic test was conducted. Based on 35 explicative variables, six factors who explained 60.2% of the variance were retained, with major significance for the discriminated groups in the MSVI, among all census sectors of the LPR. Table 4 displays the factors accounting for more than 5 percent of the variance.

Table 4: Factors retained and significance explained for evaluation of MSVI in the lower course of the Poti river basin

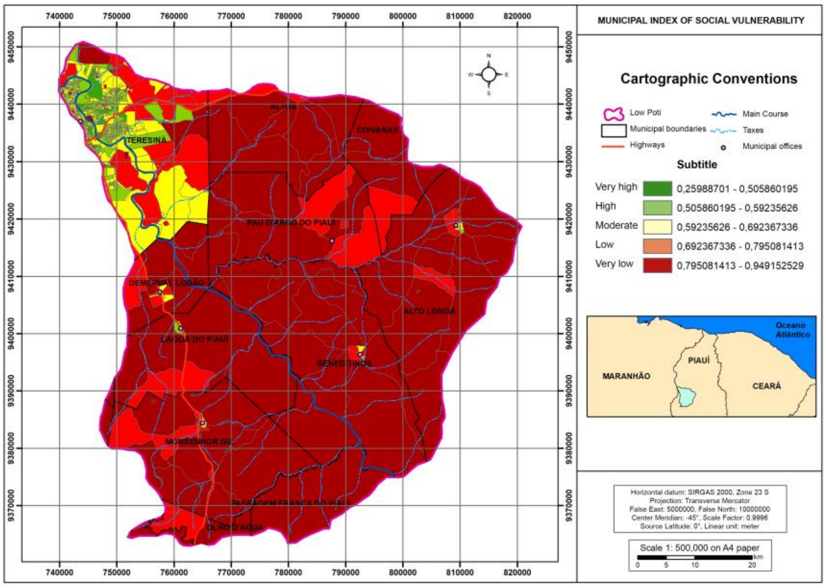
Factor	Designation	Explained variance (%)	Dominant variable	Correlation (dominant variable/factor) (%)
1	Infrastructure	22.04	Residence with trash collection	0.888
2	Income	13.64	Head of household earning 5 to 10 times Brazil's monthly minimum wage	0.828
3	Age	6.87	Individuals 65 years of age or older	0.814
4	Gender	6.58	Head of household – man	0.867
5	Residence	5.88	Residence/area	0.980
6	Residents	5.18	Resident/home	-0.864

Source: Authors, 2021

Table 4 shows that the first factor, who regard to infrastructure of the area, accounts for 22.04 percent of the variance and mostly reflects trash collection at domiciles. The second factor accounts for 14 percent of the variance and is related to the income of the household head – which in turn reflects social and economic inequality in the study region, where the majority of households heads survive on less than Brazil's monthly minimum wage. The third factor accounts for 6.87 percent of the variance and is mainly related to the percentage of seniors (people aged 65 years or older). Senior citizens are mostly concentrated in rural areas, in contrast to economically active people, who tend to live in urban areas. The fourth factor accounts for 6.58 percent of the variance and is linked to gender, with the main variable in this case being men in the position of household head. The fifth factor relates to the number of domiciles per area and accounts for 5.88 percent of the variance. The sixth factor accounts for 5.18 percent and is mostly related to the number of residents per domicile.

These factors highlight the reality about the municipalities who make part of LPR, as displayed in Figure 4, whose urban areas as the city of Teresina and the municipal capitals have a very low to moderate MSVI, as a result of the population's higher economic power, better infrastructure and greater number of job opportunities. These data stand in contrast to those of the rural areas of the river basin, where greater social vulnerability is found and an older population predominates, related to agricultural activities and lower purchasing power.

Figure 4: MSVI map of the lower course of the Poti River (State of Piauí, Brazil)



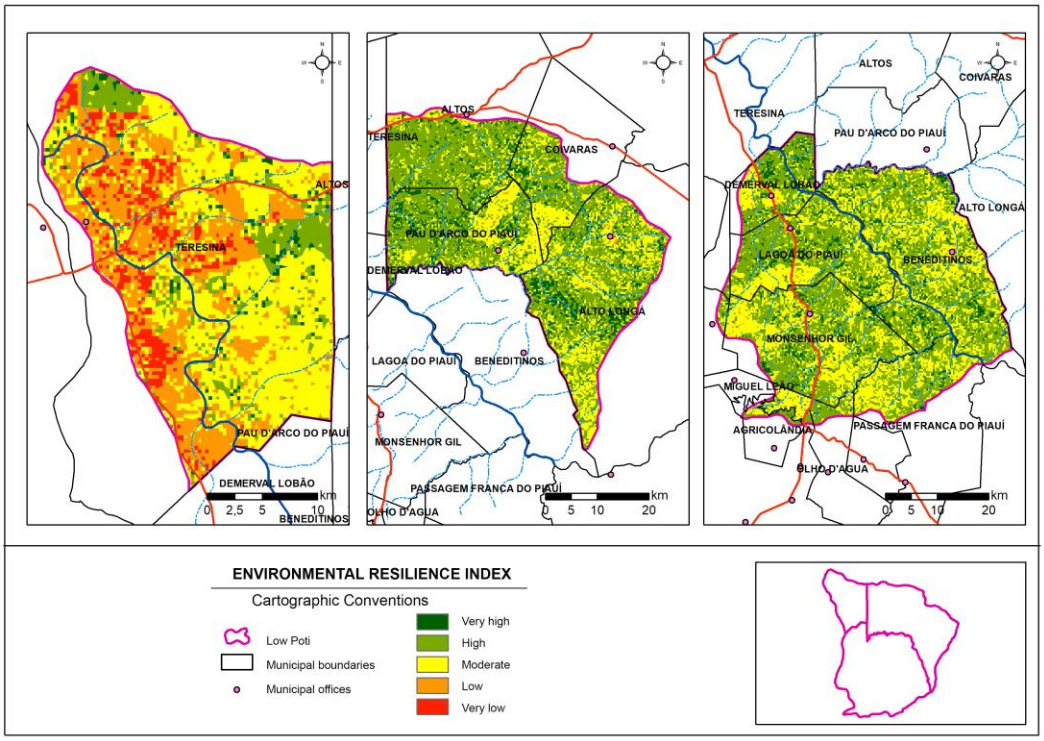
Source: Authors, 2021

The analysis of social vulnerability in the study area (Figure 4) based on the 2010 census (IBGE, 2010), allows to observe that in the rural area of LPR the MSVI classification to be high- (13 percent) to very high (79 percent), due to lowest population index, reduced home infrastructure in terms of water supply services and sanitation, lower economic capacity on the part of residents, low levels of schooling and higher demographic ageing, given that the majority of the economically active and younger population are to be found in the urban areas.

According to the 2010 census (IBGE, 2010), approximately 9.49 percent of the population inhabit in the rural part of the lower course of Poti River, whereas 90.51 percent inhabit urban areas. Moreover, many families live in urban areas and only travel to rural areas on weekends or during planting season. This situation must do with the fact that the municipalities are located near the state capital.

The importance of environmental resilience, which encompasses the resilience capacity of both social and natural systems, has led a growing number of researchers to address this correlation (Fiksel, 2003, 2006; Cumming, 2011; Mu et al., 2011; Francis & Bekera, 2014). For the purposes of the present study, the NRI results (a comparison of the years 1985 and 2015) were cross-checked with the MSVI of the lower Poti River basin, from which there resulted the environmental resilience index (ERI). For the sake of clarity, a tripartite spatial subdivision has been established. The first subdivision (Figure 5-A) corresponds to the more urbanized area of the lower course of the Poti River, epitomized by the state capital – Teresina. The second subdivision (Figure 5-B) corresponds to the northern and northeastern portion of the lower course of Poti River and includes the municipalities of Alto Longá, Pau D'Arco do Piauí, Altos and Coivaras, which have a higher NRI due to the fact that these areas are better preserved. The third subdivision (Figure 5-C) corresponds to the southern and southwestern portions of the lower Poti River and encompasses the municipalities of Beneditinos, Monsenhor Gil, Lagoa do Piauí and Demerval Lobão, which have a somewhat lower NRI.

Figure 4: Map of environmental resilience index of lower course of Poti River, state of Piauí, Brazil.



Source: Authors, 2021

Regarding the first subdivision, the ERI in the city of Teresina is moderate (45 percent) in the rural areas, low (32 percent) in areas with better sanitation infrastructure and a population with greater purchasing power, and very low (9 percent) in the city's peripheral areas. This way, a regressive tendency of the environmental resilience capacity is showed, demonstrating low viability of the environment for recomposing itself, in detriment of the pressures caused by inordinate growth. This has to do with the urban structure, as for the most part it shows greater demographic density and poor sanitation, compromising the quality of the environment and, consequently, its wholesomeness for the population in areas with poor infrastructure.

In the second subdivision, which corresponds to the northern and northeastern portions of the lower course of the Poti River and comprises the municipalities of Alto Longá, Pau D'arco do Piauí, Altos and Coivaras, the ERI is classified as moderate- (31 percent) to high (56 percent) and very high (13 percent) (between Altos and Pau D'arco do Piauí), due to its higher vegetation index. A similar situation is to be found in the third subdivision (southern and southeastern portions of the lower course of the Poti River), which comprises the municipalities of Demerval Lobão, Beneditinos and Monsenhor Gil and whose ERI ranges from moderate (39 percent) to high (52 percent). Correspond, in this way, in both subdivisions, to a capacity of progressive environmental recovering, when the condition of recomposing by the environment is achieved, from implemented pressures by human being or another agent. However, there exists a tendency toward a moderate ERI, due not only to public mismanagement in the region as regards conservation and the sustainable management of natural resources, notably the predominant *cerrado* (savanna) vegetation, but also to the high MSVI in both subdivisions.

In their analysis of the natural resources in the municipality of Demerval Lobão, which is in the study area of the present research work, Costa et al. (2015) found that in some areas there were changes caused by human activities, particularly deforestation, which is carried out in accordance with private interests. The result is an increase in soil erosion and the silting-up of creeks and of the Poti River itself, making the environment more vulnerable to human action, as well as the reduction of the environmental resilience. A similar situation occurs in other municipalities of the lower course of the Poti River.

Studying the resilience capacity of soils in Canada, Francis et al. (2016) concluded that a resilient system is not necessarily an immutable system, but rather has the capacity to absorb disturbances while maintaining its essential functions. Since the region covered by our study is in the northern part of the country and constitutes a transition zone comprising rainforest, *cerrado* (savanna) and *caatinga* (semi-arid forest) vegetation due to the conditions of the climate and relief, the negative anthropogenic impacts tend to cause this system to lose its structural functionality over time, thereby compromising its resilience.

The lower course of the Poti River is characterized by predominantly rural areas, in which agricultural activities are the local population's main source of income and livelihood. Table 5 displays areas planted with perennial and non-perennial crops between 1985 and 2015.

Table 5: Cultivated area per municipality in lower course of Poti River, state of Piauí, Brazil

Municipality	Area of permanent crops in 1985 (ha)	Area of permanent crops in 2015 (ha)	Area of temporary crops in 1985 (ha)	Area of temporary crops in 2015 (ha)
Altos	788	659	10,549	2774
Teresina	1324	676	9997	16,041
Demerval Lobão	265	101	2498	1220
Beneditinos	205	240	3815	2071
Lagoa do Piauí	-	83	-	809
Pau D'Arco do Piauí	-	165	-	1138
Miguel Leão	144	33	2868	1054
Monsenhor Gil	341	290	6355	3499
Passagem Franca	-	255	-	1222
Coivaras	-	855	-	496
Alto Longá	204	412	10,705	2805
TOTAL	3271	3769	46,787	33,074

Source: IBGE, 2016

Table 5 shows that the area of non-perennial crops is larger than that of perennial crops. However, a 29.31 percent reduction in the area of non-perennial crops occurred in the lower course of the Poti River between 1985 and 2015, with the municipalities of Teresina and Monsenhor Gil as the most prominent in this respect. This has to do with the rural exodus in the period and with soil depletion caused by mismanagement, which compromises its recovery. However, due to the creation of new municipalities, such as Lagoa do Piauí, Pau D'Arco do Piauí, Passagem Franca and Coivaras, which have a predominantly rural population, the total area of perennial crops increased by 15.2 percent in the lower course of the Poti River.

On-site observations showed that agricultural activities are performed by small-scale farmers who employ rudimentary, inefficient methods, for family consumption and trade in the municipal markets.

The non-perennial crops include corn, watermelon, beans, rice, sugarcane and cassava. In contrast, mango and banana are perennial crops (IBGE, 2016). It should be pointed out that crops such as beans and cassava lose more soil and water, due to erosion, than rice, which in turn loses more than corn and sugarcane. Therefore, parceling the land for the latter crops would be a way to reduce soil loss by erosion, with the width of each tract to be determined by the slope of the terrain, type of soil and crop.

According to Vital (2007) and Delamare et al. (2017), non-perennial crops contain a number of contradictions: despite their economic value, they can have negative impacts on the physical environment, such as soil erosion, the contamination of water bodies by pesticides, and a reduction in biodiversity due to the planting of monocultures. Laliberté & Legendre (2010) argue that the intensification of the extraction of natural resources and of land use caused by anthropogenic pressure increases the vulnerability of ecosystems.

In a study conducted in Sweden, Vogel et al. (2012) found that the resilience of pastures and their resistance to drought conditions in summer are highly dependent on the intensity of soil management and partially dependent on species richness. The authors found that vegetation removal for pastures reduces their resistance to drought, but increases the resistance of species. Vogel et al. (2012) mention that resilience was positively related to the resistance of species, thanks to the adequate management of the area under analysis. The authors also found that a low cutting frequency provided greater resistance of the pastures to drought.

Regarding the management conditions in the lower course of the Poti River, we can see that high and very high ERIs mean greater capacity of the environment to recover from human intervention and greater recovery capacity on the part of populations in the occurrence of environmental disturbances. In contrast, low and very low ERIs indicate that this capacity is compromised both for people and the environment. Moderate ERIs indicate a possibility of recovery. Therefore, it is suggested that feedback mechanisms be put in place to operate between social pressure, environmental degradation and the inhabitants' quality of life.

CONCLUSIONS

The analyses and observations of the information presented in this study enable an integrated understanding of the relationships among physical, biological and anthropogenic systems. The NRI and MSVI proved to be effective for assessments and for determining preventive measures aimed at the sustainable management of the environment in the geographic area of a river basin. These indices are therefore important factors to consider in the evaluation of the resilience capacity of an environment and its management.

Thus, the methodological proposal applied from the IRA showed to be one of the way for evaluating the capacity of environmental resilience, when confronted with different forms of land use and occupation. This index is an important alternative for achieving sustainability in river basins or other geographical contexts, becoming possible its application in environmental management, for demonstrating the capacity of the environment to recover, from different natural and anthropogenic impacts over time

Sustainable management of the soil aimed at maintaining its resilience capacity should be conducted in such a way that the input demands do not exceed its natural regeneration capacity, as is the case with the use of rudimentary agricultural methods. Another necessary action for achieving environmental resilience is the control of erosion with practices that replace nutrients, limit the burning of organic matter, diminish percolation and control the causes of soil impoverishment.

Concerning the practices of the use and management of natural resources in the lower course of the Poti River, environmental resilience is achievable provided there is a management plan for the preventive control of those resources. This requires adequate management of the soil, vegetation, surface water and groundwater, ensuring both the conservation of species and the quality of water and ecosystem services, in order to provide the environment with the capacity to regenerate itself without compromising its functioning. A healthy environment sustains life and improves the standards of environmental and social quality.

This way, the temporal analysis of the NRI of the lower course of the Poti River, from the analyzed variables, proved to be one of the possible tool for environmental management, since it gives a diagnosis of the basin, and subside actions who favor the resilience of the environment. This index was also capable of to point out that the use of sustainable techniques of management of both soil and vegetation can allow the recovering of the environment in short to medium term. However, monitoring measures by professionals are needed so that adequate recovery of the natural resources and environmental resilience can be achieved.

This way, the developed methodological proposal for evaluating the capacity of resilience of the environment from environmental and socioeconomical aspects, fulfilled the goals set by the authors, allowing its application in the management of river basins in different environments, as well as in other geographical scales.

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