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IMPACTS OF LAND USE DYNAMICS ON ECOSYSTEM SERVICES IN WATERSHEDS THAT BENEFITING FROM THE TRANSFER OF WATER FROM THE SÃO FRANCISCO RIVER

IMPACTOS DA DINÂMICA DO USO DA TERRA SOBRE OS SERVIÇOS ECOSSISTÊMICOS EM BACIAS HIDROGRÁFICAS BENEFICIADAS PELA TRANSPOSIÇÃO DO RIO SÃO FRANCISCO

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ABSTRACT
Changes in land use, whether natural or anthropogenic, have an impact on the provision of ecosystem services, therefore they must be monitored. The aim of this study was the valuation of ecosystem services in watersheds that receive water from the transposition of the São Francisco River which are being strongly impacted by the transposition project. Images referring to land use were acquired for the years 2011, 2017 and 2021. Were acquired and manually adjusted for the following land-use categories: Forest Formation, Dense Caatinga, Open Caatinga, Grassland/Pasture, Cultivated Area, Exposed Soil, Body of Water, and Urban Centre. The value of the ecosystem services was determined from the area data of each target as a function of the global coefficient of the ecosystem service adjusted for our conditions; the sensitivity coefficient was then determined to assess the robustness of the method used. Despite the method being robust for most of the targets under study, it is not suitable for areas of exposed soil, as it presents no value for the coefficient. The valuation of ecosystem services points to the importance of conserving natural resources, mainly by highlighting their value to the well-being of society; as such, the values described here should be understood as a minimum measure of the ability of the ecosystems under study to provide services. Watersheds that receive the transposed waters should be better protected, especially in view of the increasing exploitation of areas of natural vegetation. The value of ecosystem services should be considered when formulating public policies that impact on natural resources.
Keywords:
Natural resources, Land cover, Socio-environmental impact, Valuation of ecosystem services.

RESUMO
Mudanças no uso do solo, sejam elas naturais ou antrópicas, impactam na prestação de serviços ecossistêmicos, portanto devem ser monitoradas. O objetivo deste estudo foi a valoração dos serviços ecossistêmicos em bacias hidrográficas que recebem água da transposição do Rio São Francisco e que estão sendo fortemente impactadas pelo projeto de transposição. Imagens referentes ao uso do solo foram adquiridas para os anos de 2011, 2017 e 2021. Foram adquiridas e ajustadas manualmente para as seguintes categorias de uso do solo: Formação Florestal, Caatinga Densa, Caatinga Aberta, Campo/Pastagem, Área Cultivada, Solo Exposto, Corpo D'Água e Centro Urbano. O valor dos serviços ecossistêmicos foi determinado a partir dos dados de área de cada alvo em função do coeficiente global do serviço ecossistêmico ajustado para nossas condições; o coeficiente de sensibilidade foi então determinado para avaliar a robustez do método utilizado. Apesar do método ser robusto para a maioria dos alvos em estudo, ele não é adequado para áreas de solo exposto, pois não apresenta valor para o coeficiente. A valoração dos serviços ecossistêmicos aponta para a importância da conservação dos recursos naturais, principalmente ao destacar seu valor para o bem-estar da sociedade; como tal, os valores aqui descritos devem ser entendidos como uma medida mínima da capacidade dos ecossistemas em estudo de fornecer serviços. As bacias hidrográficas que recebem as águas transpostas devem ser mais bem protegidas, especialmente em vista da crescente exploração de áreas de vegetação natural. O valor dos serviços ecossistêmicos deve ser considerado na formulação de políticas públicas que impactem os recursos naturais.
Palavras-chave:
Recursos naturais, Cobertura do solo, Impacto socioambiental, Valoração dos serviços ecossistêmicos.

INTRODUCTION

Based on the idea of ending the problems of water scarcity in the northern Northeast, the São Francisco River Integration Project (PISF) arrives in Ceará surrounded by political and legal impasses and questions regarding its environmental impacts. The largest water infrastructure project in the country aims to guarantee water security for around 12 million people in the states of Ceará, Paraíba, Pernambuco and Rio Grande do Norte, Ministries of Regional Development – MDR (2020). Several researches across the globe aim to evaluate the impacts of water transfer works between river basins, in the most diverse aspects, given the magnitude of the impacts that large-scale works cause to the environment.

Various surveys around the world aim to assess the impact of works for transposing water between river basins in their most diverse aspects, given the magnitude of the impact that large works have on the environment.

Guo et al. (2020) studied the water diversion project from the south to the north of China. The authors emphasised that the increase in hydrological connectivity may have favoured biological invasion, and promoted the biotic homogenisation of reservoirs. Liu et al. (2020), studying the same water transfer project, demonstrated that water availability increased in in the regions that received the waters, however, the transfer of water poses adverse risks to the ecosystem and the environment.

According to the National Water Agency (ANA) the outflow from the project will not harm the São Francisco River, even during periods of water recession. This is because the transposed flow makes up part of the volume that would naturally reach the sea. Despite the justification of offering water security and the ability to develop the regions that benefit, Ferreira (2019) points out that the transposition has generated great expectation, justified not only by scenarios of drought, but also public controversy, especially the impact on ecosystems and communities. For Henkes (2014), justifying transposition by economic development without considering the environmental and social aspects translates into an impact on society, especially in the semi-arid region.

According to the Ceará Water Resources Management Company (COGERH), by February 2023, a total of 235,760,244 m³ had been transferred via the emergency section of the Ceará Water Belt (CAC) to the Castanhão Reservoir. Nunes and Medeiros (2020) and Silva and Sousa (2019) pointed out that between 2011 and 2017, poor water management prioritised service to the capital and metropolitan region, while other regions suffered serious restrictions on their supply.

For Cortez et al. (2017) serving diffuse communities in the State of Ceará remains difficult and costly and that the multi-annual 2010-2017 drought showed the need for a proactive vision, with action in risk management. Thus, geotechnologies associated with water management can help managers make decisions Barbosa et al. (2021) point out that geoprocessing helps in prediction and decision-making about natural resources, being fundamental for mapping areas with imminent damage to ecosystems.

Due to its complexity, carrying out a systemic analysis of the dynamics of natural resources over time requires the use of techniques and methodologies that aim to translate the way that nature behaves in the face of natural phenomena and anthropogenic action. It is in this context that the concept of ecosystem services emerges, which consists in grouping as many services as possible afforded by nature for the well-being and maintenance of life on the planet.

Among the various definitions of ecosystem services, Daily (1997) defined them as being the conditions and processes from which natural ecosystems and the species that comprise them sustain and allow human life.

According to Rosa, Souza and Sánchez (2020), the concept of ecosystem services has been gaining ground in decision-making processes, and in the management of projects that have the potential to cause significant environmental degradation. Rosa et al. (2020) points out that the first and fundamental step to assess the impact of a project on ecosystem services is to identify the ecosystems.

Costanza et al. (2014) emphasise that expressing the value of ecosystem services in monetary units does not mean that they should be treated as commodities; expressing services in monetary units is an estimate of their benefits to a society that includes the public in general.

Researchers such as Kreuter et al. (2001), Hu et al. (2008), and Cunha et al. (2014), using the model proposed by Costanza et al. (1997), and based on global values, estimated the value of an ecosystem service on a reduced scale, at the level of a municipality and a watershed. Using this model with regional clusters proves to be useful in assessing changes in land use (Costanza et al., 2014).

Barcelos et al. (2018) worked with the methodology proposed by Costanza et al. (1997) to calculate the value of ecosystem services in the Serra dos Martírios State Park in Pará and obtained a monetary value of R$ 101,008,218.10 yr^{-1}. The authors point out that this value should be understood as the minimum value for the use and existence of the park.

In this context, it is highlighted that valuing the ecosystem services of a given region on the globe is bringing to light the benefits that nature provides for human well-being, and can serve as a basis for decision-making by environmental managers that can limit or expand the exploitation of natural resources.

Due to the impacts associated with the transposition of water between hydrographic regions, the objective was to quantify ecosystem services by mapping land uses between the years 2011, 2017 and 2021 in the Salgado and Alto and Médio Jaguaribe river basins, benefiting from the waters from the transposition of the São Francisco River and from this perspective verify the impacts linked to the reception of the waters.

MATERIAL AND METHODS

Characterisation of the study area

The study was carried out in the Alto Jaguaribe, Médio Jaguaribe and Salgado Basin river basins in Ceará (Fig. 1). Comprising an area of 48,956.60 km², occupying the southern portion of the state. This region is being marked by intense water infrastructure works, such as the works on the Ceará Water Belt - CAC and the São Francisco River Integration Project - PISF, which will carry the transposed waters to the state's main reservoirs, the Orós dam (when completed to CAC works) in the Alto Jaguaribe basin and Castanhão in the middle Jaguaribe (through the emergency section and Salgado Branch).

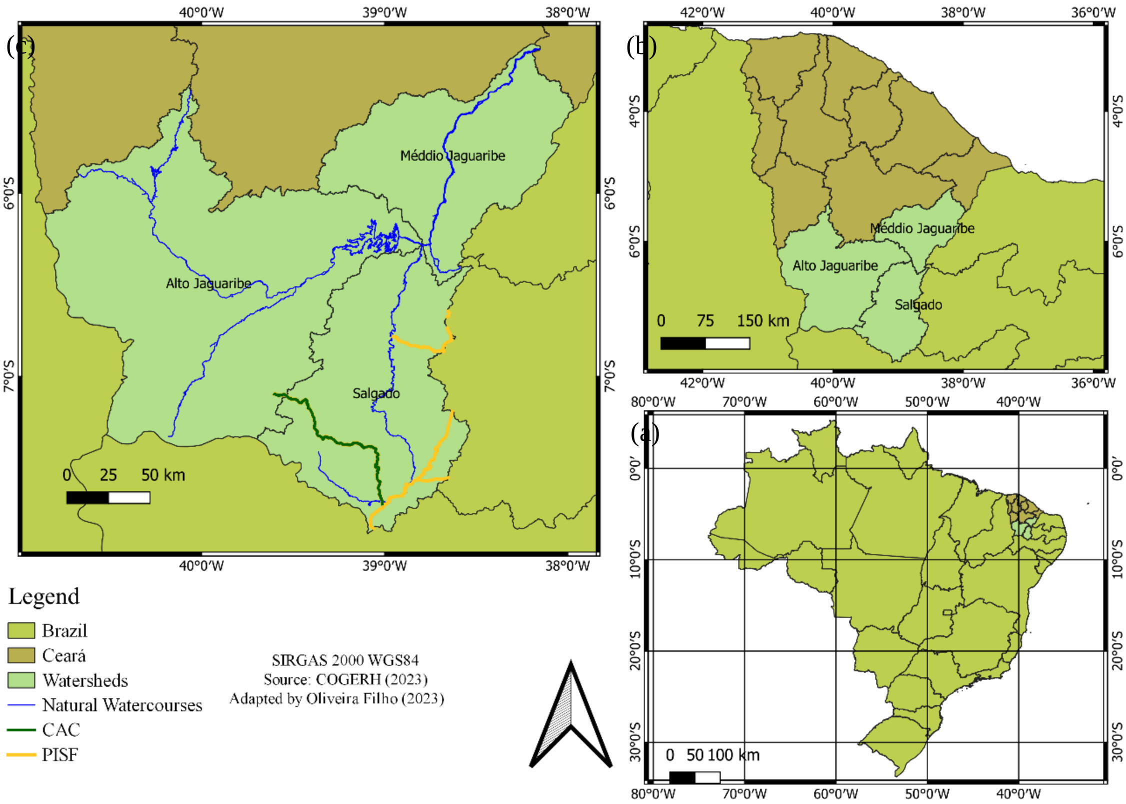

Figure 1 Location of the study area of the present work: Watersheds of the Upper Jaguaribe, Middle Jaguaribe and Salgado Basin, Northeast of Brazil

Data acquisition and processing

To create land use maps, images made available on the MapBiomas Collection 7.0 (2023) platform were used for the state of Ceará in the following years: 2011, 2017 and 2021, which allowed us to carry out a spatial and temporal analysis of land cover. for area of interest. After acquiring the soil cover images, a cut was made for the area of interest (Upper and Middle Jaguaribe River Basins and Salgado Basin), then the images were reclassified using the table reclassification tool available on the free software QGis®.

Eight categories of land use were grouped, namely: Forest Formation (high vegetation cover, e.g. the Araripe plateau), Dense Caatinga (vegetation typical of larger and higher-density Caatinga), Open Caatinga (typical spontaneous vegetation of smaller size and low-density land cover), Grassland/Pasture (areas of pasture, either covered predominantly with natural grasses or under non-irrigated management), Cultivated Area (cultivation of perennial crops, long cycles, managed with use of irrigation), Exposed Soil (areas with a predominance of exposed soil most of the year, whether natural or anthropogenic), Body of water (rivers, lakes, dams, weirs and reservoirs), and Urban centre (combination of buildings, predominance of areas occupied by paving and civil construction) then, area data was extracted by grouped class to compare the representativeness of the areas, variation over time and valuation of ecosystem services.

Valuation of Ecosystem Services

The value of the ecosystem services (VES) was estimated using the method proposed by Costanza et al. (1997), updated in Costanza et al. (2014). We used the global coefficients proposed by the authors who estimated the overall VES for 17 ecosystem services in 16 global biomes.

The values of ecosystem services for the eight land use classes identified in the study area were obtained by similarity between the 16 biomes identified in the model by Costanza et al. (1997) with the cover classes identified in the area. In this way, the most representative biome was used as a proxy for land use classes. Thus, the respective coefficients proposed by Costanza et al. were assigned. (1997) and Costanza et al. (2014) to land use categories (Table 1).

Table 1 Global coefficients for the individual mean values of ecosystem services (USD 2023 ha^{-1} yr^{-1}) by class of land use and occupation

	Ecosystem Services	Land-Use Categories							
		Forest Formation	Dense Caatinga	Open Caatinga	Grass/ Pasture	Cultivated Area	Exposed Soil	Body of Water	Urban Centre
1	Gas regulation	5.91	17.74	17.74	13.30	-	-	-	-
2	Climate regulation	1,050.86	3,021.02	3,021.02	59.12	607.46	-	-	1,337.59
3	Disturbance regulation	28.08	97.55	97.55	-	-	-	-	-
4	Water regulation	4.43	11.82	11.82	4.43	-	-	11,105.66	23.65
5	Water supply	211.35	39.91	39.91	88.68	591.20	-	2,672.22	-
6	Erosion control	147.80	498.02	498.08	65.03	158.15	-	-	-
7	Soil formation	20.69	20.69	20.69	2.96	786.29	-	-	-
8	Nutrient cycling	97.55	4.43	4.43	-	-	-	-	-
9	Waste treatment	177.36	177.36	177.36	110.85	586.76	-	1,356.80	-
10	Pollination	13.30	44.34	44.34	51.73	32.52	-	-	
11	Biological control	249.78	16.26	16.26	45.82	48.77	-	-	-
12	Habitat / refuge	914.88	57.64	57.64	1,794.29	-	-	-	-
13	Food production	399.06	295.60	295.60	1,761.77	3,433.38	-	156.67	-
14	Raw materials	224.66	124.15	124.15	79.81	323.68	-	-	-
15	Genetic resources	662.14	2,242.12	2,242.12	1,794.29	1,540.07	-	-	-
16	Recreation	1,408.53	1,281.42	1,281.42	38.43	121.20	-	3,201.34	8,483,40
17	Cultural services	1.48	2.96	2.96	246.83	-	-	-	-
	Total	5,617,86	7,953.03	7,953.09	6,157.34	8,229.48	-	18,492.69	9,844.64

[a] Adapted from Costanza et al. (1997) and Costanza et al. (2014). Values adjusted based on the CPI from December 2007 to January 2023.

[b] '-' No information available.

The total value of ecosystem services for 2011, 2017 and 2021 was obtained with the equation proposed by Kreuter et al. (2001):

$$VES_{total}= \Sigma(A_k * CV_k) \quad (1)$$

where: VES_{total} is the total value of ecosystem services (USD); A_k is the total area of each land-use category k (ha); CV_k is the coefficient value of the ecosystem services for land-use category k (USD $ha^{-1}.yr^{-1}$).

After estimating the total value of the ecosystem services by class of use and occupation, the impact of changes in use and occupation on the 17 ecosystem functions was estimated individually for the area under study. The individual contributions of the ecosystem functions were calculated as described by Hu et al. (2008):

$$VES_f= \Sigma(Ak * CV_{fk}) \quad (2)$$

where: VES_f is the estimated value of ecosystem service f (USD); Ak is the area of land-use category k (ha); CV_{fk} is the coefficient value for ecosystem service f in category k (USD $ha^{-1}.yr^{-1}$).

The percentage variation was also calculated in order to verify changes in the area (ha) of each category of land use and occupation and in the values of the ecosystem services for the period under study (USD). Finally, a sensitivity analysis was carried out to check the dependence of our estimates of changes in the values of the ecosystem services on the applied coefficients. Thus, an adjustment of ±50% was applied to the mean values of the ecosystem services proposed by Costanza et al. (1997) and Costanza et al. (2014) for the classes of land use and occupation under study. From this analysis, it was possible to verify the robustness of the estimated values for the ecosystem services.

The sensitivity coefficient (SC) was calculated for each class and year under study based on the standard economic concept of elasticity suggested by Mansfield (1985), Stigler (1987) indicated by Kreuter et al. (2001), Hu et al. (2008), and Ferreira et al. (2019):

$$SC = \frac{(VES_j - VES_i)/VES_i}{(CV_{jk} - CV_{ik})/CV_{ik}} \quad (3)$$

where: SC is the sensitivity coefficient; VES is the estimated value of the ecosystem services; CV is the coefficient value extracted from Costanza et al. (1997) and Costanza et al. (2014); *i* and j are initial and adjusted values, respectively; k represents the class of land use and occupation. All the data were processed using the Microsoft Excel® software.

When SC > 1, the coefficient is considered elastic, whereas if the ratio is less than one, the estimated value is inelastic. The greater the proportional variation in the value of the service in relation to the change it effects in coefficient value, the more critical is the use of the coefficient in determining the value of the ecosystem service.

RESULTS AND DISCUSSION

According to Rosa, Sousa and Sanchez (2020), even though the land-cover map does not demonstrate the provision of ecosystem services, these help the process of identifying the services and spatialising the analysis. Fig. 2 presents the temporal spatialization of land use and Table 2 provides area data for the different classes studied.

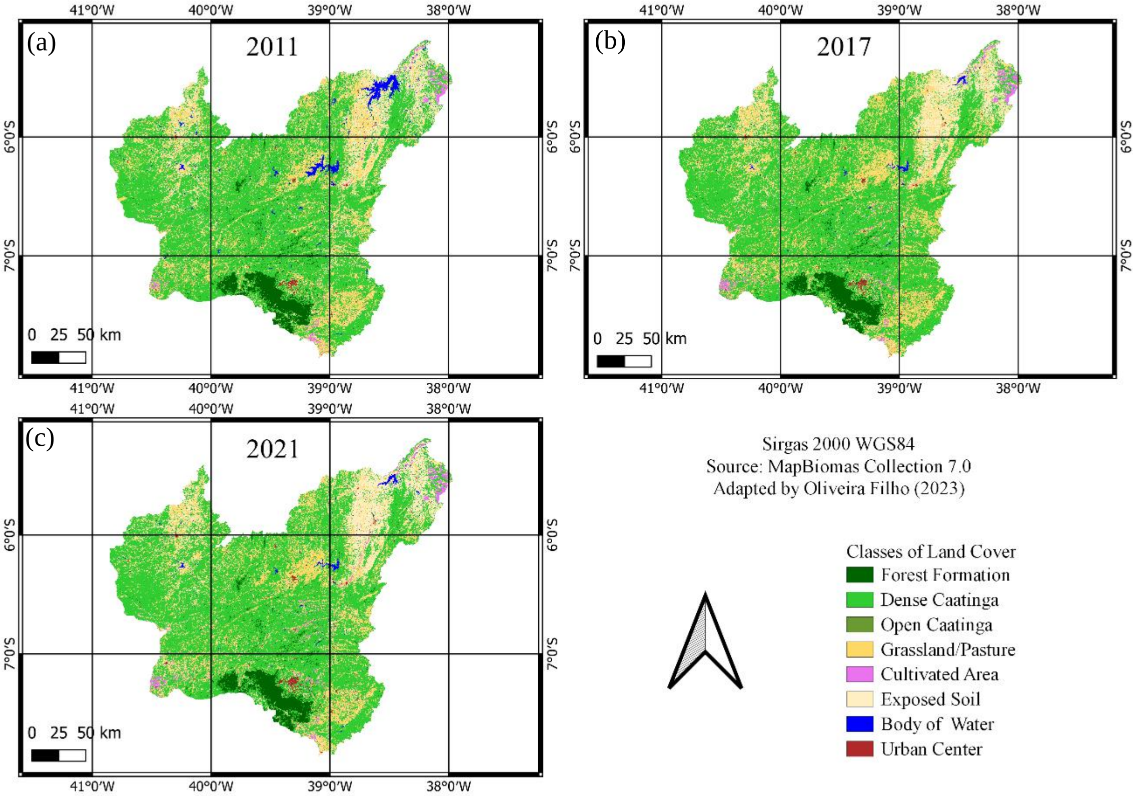

Figure 2 Maps of land use for the watersheds under study: Upper Jaguaribe, Middle Jaguaribe and the Salgado Basin for **a** 2011, **b** 2017 and **c** 2021

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Table 2 Areas of the classes of land use and occupation in the watersheds of the Upper Jaguaribe, Middle Jaguaribe and Salgado Basin in Ceará

Class	Land Cover (ha)			Percentage area (%)		
	2011	2017	2021	2011	2017	2021
Forest Formation	215,441.28	220,167.45	220,903.02	4.40	4.50	4.51
Dense Caatinga	2,964,905.73	2,970,620.10	2,962,584.99	60.56	60.68	60.51
Open Caatinga	86,872.14	94,132.71	93,151.35	1.77	1.92	1.90
Grassland/Pasture	758,904.12	889,632.27	698,584.77	15.50	18.17	14.27
Cultivated Area	49,093.38	78,298.02	82,239.75	1.00	1.60	1.68
Exposed Soil	717,741.36	604,904.85	783,488.16	14.66	12.36	16.00
Body of Water	86,854.95	19,500.39	31,984.56	1.77	0.40	0.65
Urban Centre	15,846.84	18,404.01	22,723.20	0.32	0.38	0.46
Total	4,895,659.80	4,895,659.80	4,895,659.80	100.00	100.00	100.00

The changes in soil cover observed within the study period were more significant for the class of water bodies, mainly in the period from 2011 to 2017 with a reduction of 1.77% in the occupied area, to 0.40%, given this scenario, the transfer of water to Ceará is justified as a measure to minimize the effects of the drought. In 2021, water was transported to the castanhão dam, as well as the dams in the extreme south of the state were filled by the transposed waters, reflecting an increase in the area occupied by water, as seen in the table above for the year 2021. In the same period there was increase in the area occupied by the Cultivated Area classes, from 1.00% to 1.60% and the Grass/Pasture class with an increase from 15.50% to 18.17% (Table 2). These variations in soil cover must be related to the dry period experienced between these years in the state.

In 2011 the 'Exposed Soil' class covered an area equal to 14.66% of the area under study, in 2017 this decreased to 12.36%; in 2021 the exposed area grew and occupied 16.00% of the study area. It can be seen that with the reduction in the area occupied by exposed soil (2011 to 2017), the cultivated areas and areas of grassland/pasture grew, while with the reduction in the area of grassland/pasture from 2017 to 2021, the area of exposed soil increased in the same period. From this perspective, it is possible to infer that cultivated areas occupy, at certain times, areas of exposed soil, this is probably due to the seasonality of rainfall, an intrinsic characteristic of the Brazilian semi-arid region..

Special attention should be given to the 'Exposed Soil' class, where the processes of expansion alert to the risk of degradation and desertification. It should also be noted that the greatest occurrence of anthropogenic areas in the Castanhão basin where the so-called desertification nucleus of the middle Jaguaribe is called.

Cunha et al. (2014) observed that in the Jacuípe basin in Bahia, the authors found a 27% reduction in natural vegetation while the Grass/Pasture area grew in the same proportion over a period of 12 years (2000-2012). Still according to the authors, the expansion of land use can be explained by socio-environmental, cultural and economic issues. Different from what is observed in the present work, in which forest formations remained with little variation, even in a period with extreme events such as drought and expansion of the Cultivated Area and areas with Grasses/Pastures as observed in table 2. This behavior observed This is mainly due to the fact that the forest formation area is protected by law, as a permanent conservation unit, which is the Chapada do Araripe National Forest/CE.

As can be seen in Table 2, the 'Dense Caatinga' class has the greatest area in the region under study, followed by Grassland/Pasture and Exposed Soil. Based on this observation, a careful look should be given to this region of the state, because, while most of the area is occupied by natural vegetation, the exploited areas add up to more than 30%. Therefore, measures that encourage preservation of the natural resources, such as environmental compensation, should be encouraged.

Barbosa et al. (2021), performing a spatial and temporal analysis of surface waters in Ceará from 2012 to 2017, concluded that the prolonged drought reduced the amount of surface water available. This is illustrated in the above figure, which shows a reduction in surface water over the years of the study, with a slight recovery in 2021.

When it comes to the expansion of urban areas, extremely important issues have to be taken into account, such as the rural exodus and the socio-environmental impact from the lack of any public policies for settling people in the countryside.

Researchers like Ferreira et al. (2019), evaluating spatial and temporal changes in the availability of ecosystem services, found that during 1989, 2007 and 2014 in the watershed of the Riacho das Piabas in Paraíba, there was an increase of 115% in the built-up area. Furthermore, according to the authors, the disorderly expansion of urban centres can have an irreversible impact on the environment and quality of life of a society.

In line with the present study, Ferreira et al. (2019) found that arboreal vegetation offered the most ecosystem functions, and was, therefore, the most valuable. This means that areas of Caatinga, as well as the area of forest formation, must be maintained so that a greater supply of ecosystem services be provided for the well-being of society.

The valuation of ecosystem services proves to be a tool that makes it possible to emphasise natural resources that in many cases are neglected by managers or are not even important issues for society (BARCELOS et al., 2018), this topic gains prominence when it comes to the transposition of waters that benefit states and municipalities, and therefore specific legislation must be created regarding the use and exploitation of natural resources resulting from the increase in water supply.

In order to assess the importance of natural resources to the well-being of society, Table 3 shows the total estimated value of ecosystem services identified in the area under study for 2011, 2017 and 2021, in the different classes of land use.

Table 3 Estimated total value for ecosystem services provided in the watersheds of the Upper Jaguaribe, Middle Jaguaribe and Salgado Basin in Ceará

Class	VES$_{total}$ (USD 2023 x 10^6 yr^{-1})			Variation (USD 2023 x 10^6 yr^{-1})					
	2011	2017	2021	2011 a 2017	(%)	2017 a 2021	(%)	2011 a 2021	(%)
Forest Formation	1,210.32	1,236.87	1,241.00	26.55	2.19	4.13	0.33	30.68	2.54
Dense Caatinga	23,579.98	23,625.43	23,561.53	45.45	0.19	-63.90	-0.27	-18.46	-0.08
Open Caatinga	690.90	748.65	740.84	57.74	8.36	-7.80	-1.04	49.94	7.23
Grassland/Pasture	4,672.83	5,477.77	4,301.42	804.94	17.23	-1,176.34	-21.47	-371.41	-7.95
Cultivated Area	404.01	644.35	676.79	240.34	59.49	32.44	5.03	272.78	67.52
Exposed Soil	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Body of Water	1,606.18	360.61	591.48	-1,245.57	-77.55	230.87	64.02	-1,014.70	-63.17
Urban Centre	156.01	181.18	223.70	25.17	16.14	42.52	23.47	67.70	43.39
Total	32,320.24	32,274.86	31,336.77	-45.37	-0.14	-938.10	-2.91	-983.47	-3.04

The ‘Forest Formation ‘class showed little change in value over the period studied, 2.54% (Table 3). This behaviour underlines the need for maintaining vegetated areas for the well-being of society. It also implies that it is necessary to strengthen policies for the preservation and conservation of natural resources, given that the arrival of transposed waters tends to boost agricultural exploitation, which would lead to the exploitation of new areas.

As shown in Table 3, the class of land use that is most representative of the estimated value for ecosystem services is dense Caatinga, with a total estimated VES of around USD 23,561.53 x 10^6 in 2021. The results of Ferreira et al. (2019) corroborate those of our study, in which the category with the highest value for ecosystem functions was the ‘Forest Formation’ class. This observation underlines the importance of natural reserves for the state, and consequently for the well-being of society.

For the ‘Open Caatinga’ class, growth can be seen until 2017, with 8.36% growth during the period (Table 3). The estimated total increase in VES was from USD 690.90 in 2011 to USD 740.84 in 2021, i.e. a variation of 7.23%, showing that even with a period of adverse weather conditions such as the drought that occurred, and the expansion of agricultural areas, which may have been influenced by the greater water supply provided by the transposition, there was little change in the natural coverage.

For the coverage of Grass/Pastures, the second greatest expressiveness for the ecosystem services of the studied area, it was observed that from 2011 to 2017 there was the greatest increase in the period, its total VSE varied in this period in the order of US$ 840.94 with a reduction in its value in the period following 2017 to 2021 and in the interval studied, there was a negative variation of -7.95%, showing that the supply of services in this coverage slowed down.

For the class of Water Bodies, what can be seen is that its value was drastically reduced until 2017, representing a percentage variation of the order of -77.55%, in the following interval, there was an increase of 64.02% this increase is due both to the contributions arising from transposition and to the rains that arrived on a larger scale from 2017 and within the period 2011 to 2021 there was a reduction in the order of -63.17% in relation to the total ecosystem services estimated for the river basins studied . This behavior is due to the successive years of drought that occurred in Ceará from 2011 to 2017 (Cortez et al., 2017; Silva and Sousa, 2019; Nunes and Medeiros, 2020 and Barbosa et al., 2021) which placed the state in critical situation regarding water supply.

Together with the reduction in bodies of water, exploitation of Grassland/Pasture and Cultivated Areas increased. This was underlined when evaluating the total ecosystem services of these classes, the Cultivated Areas showing constant growth during the period under study, with an increase of 67.52% (Table 3). This result implies saying about the strength of agricultural exploration in the region, even with a period of water recession experienced, the services provided by agricultural activities proved to have the strength to grow. This growth may be due to speculation about the increase in water supply caused by water transposition.

The ‘Urban Centre’ class, despite supplying a low estimated total VES, showed constant growth in providing for the well-being of society, implying that urban areas also play a fundamental role in maintaining life, differing from Ferreira et al. (2019), who concluded that urban expansion had a negative effect on total estimated value and on the availability of ecosystem services that are important for maintaining life and the socioeconomic activities of current and future generations, especially the services provided by areas of shrub and tree vegetation. Here we consider the fundamental role of urban centres in generating wealth and social development.

Throughout the period under study (Table 3), there was little variation in the total estimated value for ecosystem services. With the arrival of the transposed water, there is an immediate tendency to increase agricultural exploitation in the region, which infers that, given the increase in agricultural activity, this part of the state deserves special attention, particularly on the part of people managing natural resources.

For the ‘Exposed Soil’ class, the methodology proved to be lacking, since in areas of climate seasonality where there are well-defined rainy periods and ‘dry’ periods of water recession, assigning a null value to the coefficient for this type of cover in the semi-arid region may not reflect reality, as it considers neither the peculiarities of the climate nor such management practices as rainfed cultivation or even off-season periods that leave the soil surface exposed.

Given these limitations, we can see the need to advance our knowledge of the provision of ecosystem services in semi-arid regions, and especially in the Caatinga. As a subsequent step to this study, we intend to develop a methodology that ensures greater effectiveness in the valuation of ecosystem services.

The estimated values for most ecosystem functions (Table 4) showed a reduction between 2011 and 2021, with water regulation and water supply showing the greatest relative reduction, of -60.62% and -26.44%, respectively. The exceptions were climate regulation, disturbance regulation, erosion control, soil formation, nutrient cycling, biological control, and the production of food and raw materials. The highest relative increase, of 24.05%, was for soil formation,

Table 4 Estimate of individual values of the ecosystem services provided by the watersheds of the Upper Jaguaribe, Middle Jaguaribe and Salgado Basin in Ceará

	Ecosystem Service	VES$_f$ (2023 USD x 10^6 yr^{-1})			Relative Percentage (%)		
		2011	2017	2021	2011 to 2017	2017 to 2021	2011 to 2021
1	**Gas regulation**	65.51	67.50	64.81	3.05	-3.99	-1,07
2	**Climate regulation**	9,541.77	9,614.82	9,585.23	0.77	-0.31	0,46
3	**Disturbance regulation**	303.75	305.15	304.29	0.46	-0.28	0,18
4	**Water regulation**	1,005.34	258.14	395.94	-74.32	53.38	-60,62
5	**Water supply**	495.75	346.14	364.68	-30.18	5.36	-26,44
6	**Erosion control**	1,608.81	1,629.09	1,612.91	1.26	-0.99	0,25
7	**Soil formation**	108.45	132.16	134.53	21.87	1.79	24,05
8	**Nutrient cycling**	34.54	35.05	35.09	1.50	0.09	1,59
9	**Waste treatment**	810.25	753.63	750.23	-6.99	-0.45	-7,41
10	**Pollination**	179.04	187.39	177.24	4.66	-5.41	-1,00
11	**Biological control**	140.60	149.41	140.88	6.26	-5.71	0,20
12	**Habitat / refuge**	1,734.70	1,974.34	1,631.70	13.81	-17.35	-5,94
13	**Food production**	2,507.26	2,833.01	2,509.55	12.99	-11.42	0,09
14	**Raw materials**	503.74	526.30	511.37	4.48	-2.84	1,52
15	**Genetic resources**	8,422.41	8,734.17	8,377.71	3.70	-4.08	-0,53
16	**Recreation**	4,661.67	4,499.58	4,558.81	-3.48	1.32	-2,21
17	**Cultural services**	196.67	228.99	181.80	16.43	-20.60	-7,56
	Total	32.320,24	32,274.86	31,336.77	-23.72	-11.51	-84.43

As shown in Table 4, the ecosystem functions, water regulation and water supply, showed the greatest reduction from 2011 to 2017. During the period under study, from 2011 to 2021, the reduction was of the order of USD -609.40 for water regulation and USD -131.07 for water supply. This loss may be due to reductions in reservoir levels resulting from long periods of drought.

For the other ecosystem functions, Table 4 shows variations with a lower relative percentage. In general, there was an estimated loss of USD -983.47 in total value.

Among the factors that may contribute to changes in the availability of ecosystem services, Barcelos et al. (2018) points out that anthropogenic pressures on natural systems can lead to problems of water and soil contamination, causing an imbalance in the ecosystems. Furthermore, according to the same authors, the lack of supervision can cause future problems in protecting natural systems.

Cunha et al. (2014) found a reduction of around 65% in the listed ecosystem services of the Jacuípe basin in Bahia, attributing this harmful effect to changes in land occupation in terms of reduced vegetation cover.

In order to verify whether the method used is efficient for estimating values of ecosystem services in the semi-arid region of Brazil, we carried out a sensitivity analysis, adjusting the ES coefficients provided by the classes of land use and land cover (Table 5).

Table 5 Estimate of total ecosystem services adjusted for ± 50% (VESa), relative percentage variation in the studied intervals, and sensitivity coefficient (SC)

Coefficient Value (CV)	VES$_a$ (USD x 10^6 yr^{-1})			Variation (%)			SC		
	2011	2017	2021	2011 to 2017	2017 to 2021	2011 to 2021	2011	2017	2021
Forest Formation +50%	32,925.40	32,893.30	31,957.27	-0.10	-2.85	-2.94	0.04	0.04	0.04
Forest Formation -50%	31,715.08	31,656.43	30,716.27	-0.18	-2.97	-3.15	0.04	0.04	0.04
Dense Caatinga +50%	44,110.23	44,087.58	43,117.53	-0.05	-2.20	-2.25	0.53	0.54	0.55
Dense Caatinga -50%	20,530.24	20,462.15	19,556.00	-0.33	-4.43	-4.75	1.15	1.15	1.20
Open Caatinga +50%	32,665.69	32,649.19	31,707.19	-0.05	-2.89	-2.93	0.02	0.02	0.02
Open Caatinga -50%	31,974.79	31,900.54	30,966.35	-0.23	-2.93	-3.15	0.02	0.02	0.02
Grassland/Pasture +50%	34,656.65	35,013.75	33,487.48	1.03	-4.36	-3.37	0.13	0.16	0.13
Grassland/Pasture -50%	29,983.82	29,535.98	29,186.06	-1.49	-1.18	-2.66	0.16	0.19	0.15
Cultivated Area +50%	32,522.24	32,597.04	31,675.16	0.23	-2.83	-2.60	0.01	0.02	0.02
Cultivated Area -50%	32,118.23	31,952.69	30,998.37	-0.52	-2.99	-3.49	0.01	0.02	0.02
Exposed Soil +50%	32,320.24	32,274.86	31,336.77	-0.14	-2.91	-3.04	-	-	-
Exposed Soil -50%	32,320.24	32,274.86	31,336.77	-0.14	-2.91	-3.04	-	-	-
Body of Water +50%	33,123.33	32,455.17	31,632.51	-2.02	-2.53	-4.50	0.05	0.01	0.02
Body of Water -50%	31,517.15	32,094.56	31,041.03	1.83	-3.28	-1.51	0.05	0.01	0.02
Urban Centre +50%	32,398.24	32,365.45	31,448.62	-0.10	-2.83	-2.93	0.00	0.01	0.01
Urban Centre -50%	32,242.23	32,184.27	31,224.92	-0.18	-2.98	-3.16	0.00	0.01	0.01

The ‘Dense Caatinga’ land use and occupation class had the highest sensitivity coefficient from 2011 to 2021, ranging from 1.15 to 1.20 when the coefficient was adjusted for -50% and from 0.53 to 0.55 when the coefficient was adjusted for +50%. With the exception of dense Caatinga adjusted for -50%, all the values identified for SC were less than one (1) (Table 5).

According to Hu et al. (2008), high or overvalued coefficients may substantially affect actual changes in the values of ecosystem services over time. For this reason, the value of SC > 1 for the dense Caatinga may be due to the high value attributed to this type of cover, as well as its greater representation in the area.

With some exceptions, the estimated values for ecosystem services in the watersheds of the Upper and Middle Jaguaribe and the Salgado Basin are inelastic, i.e. low sensitivity in relation to the global mean values suggested by Costanza et al. (1997) and Costanza et al. (2014). As such, the values obtained here are relatively robust and may be reasonably acceptable. A similar result was seen by Hu et al. (2008), studying the impact of changes in land cover on ecosystem services in southwestern China.

The availability of ecosystem services during the period under study varied little when the ± 50% adjustment was applied. The greatest variation was in the 'Dense Caatinga' class when applying the -50% adjustment from 2011 to 2021, with a variation of -4.75%, followed by the 'Body of Water' class, with a variation of -4.50% for the same period. Both from 2017 to 2021 and 2011 to 2021, the observed variations when adjusted for ± 50% were negative, indicating a reduction in the capacity to supply the services provided in the watersheds under study.

From 2011 to 2017, positive variations can be seen when the ± 50% adjustment is applied (Table 5), indicating a gain in providing ecosystem services; however, these gains, in addition to being low, decreased over time and as described above, until 2021 the variations were negative. Ferreira et al. (2019) also obtained negative variations for the same adjustment when they investigated the changes in ecosystem services in the Northeast of Brazil.

CONCLUSIONS

More than 65% of the area under study is occupied by natural vegetation, which reflects in greater value and capacity to provide ecosystem services. In addition, the area is strategic for supplying the water needs of the state, as it contains the two largest reservoirs in the state the Orós dam and the Castanhão dam, in addition to receiving the transposition water distribution dams.

The prolonged drought severely impacted the availability of water throughout the state; the period from 2011 to 2017 saw the greatest reduction in bodies of water, which reflects the need for the waters transferred from the São Francisco River to Ceará. The reduction in the area occupied by water reflects in a loss in the value of ecosystem services while increasing the water supply from the reception of transposed waters, there was a gain in values in the last year studied..

During the period under study, variations were seen in land cover and consequently in the values of the identified ecosystem services, attesting to the effectiveness of the methodology. This result was reinforced by the sensitivity coefficient applied in adjusting the coefficients used as the base value in the study.

Several issues need to be considered, such as the lack of a global mean value for areas of exposed soil, which reflects in the total value of the ecosystem services being underestimated, since in semi-arid regions, especially in areas of Caatinga, land cover tends to be seasonal due to the rainfall regime. New studies are therefore being developed to remedy this failure by creating a model that would identify the possible services provided by areas of exposed soil as well as readjusting the coefficients to local reality.

We emphasise that the values presented here are an estimate of the minimum value of the benefits provided by nature, both directly and indirectly, to the well-being of society. These values should be taken into account when designing projects that may interfere in natural resources, as is the case with water transposition projects. Therefore, as there is still no methodology for using transposed waters, it is recommended to use the value of ecosystem services as a parameter to evaluate the cost of water throughout the areas benefited by transposition.

Variations seen in the ‘Cultivated Area’, ‘Grassland/Pasture’, ‘Exposed Soil’ and ‘Urban Centre’ classes infer the need for intensive control, so that the full weight of the laws protecting natural resources be applied in view of a possible scenario of exploitation of the natural resources resulting from the increase in water supply provided by the transposition.

The management of transposed waters should ensure access to water for those communities that actually need a supply. To aim not only at increasing supply and availability, but to guarantee access to water to widespread communities ensures a life of dignity.

Finally, it is recommended that a compensation policy be drawn up for the conservation and recovery of natural resources in the area, which is understood to be strategic for water security in the state. Compensation can be one alternative for containing the expansion of anthropogenic action against ecosystems. Payment for environmental services, for example, should be present in the watersheds that supply the water, and valuation of the ecosystem services in these units can be the basis for justifying this payment.

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