CORPUS PUBLISHERS

Environmental Sciences and Ecology: Current Research (ESECR)

Volume 3 Issue 6, 2022

Article Information

Received date : August 04, 2022

Published date: August 17, 2022

***Corresponding author**

Ana Maria Severo Chaves, PhD in Geography at the Federal University of Sergipe, São Cristóvão-SE, Sergipe, Brazil

Keywords

Geoecology; Tropical Dry Forest; Modelling; Remote sensing

Research Article

Spatial Analysis of the Geoecological Adequability Index in Semi-Arid Watersheds, Northeast of Brazil

Ana Maria Severo Chaves[1*], Carlos Roberto Silva Filho[2], Jânio Carlos Fernandes Guedes[3], Diógenes Félix da Silva Costa[4] and Rosemeri Melo & Souza[5]

[1]*PhD in Geography at the Federal University of Sergipe, São Cristóvão-SE, Brazil*

[2]*Graduated in Geography from the Federal University of Rio Grande do Norte, Caicó-RN, Brazil*

[3]*PhD student in geography at the Federal University of Ceará, Fortaleza-CE, Brazil*

[4]*Sector of Environmental Studies, Câmara Cascudo Museum, Federal University of Rio Grande do Norte, Brazil*

[5]*Department of Environmental Engineering, Federal University of Sergipe, Brazil*

Abstract

This research aimed to perform a comparative analysis of Geoecological Adequability (GA) in two semi-arid watersheds in Northeastern Brazil based on a classification carried out in a GIS (Geographic Information System) environment using the algebra map tool. The GA calculation reveals the interactions between landscape components through GIS, namely soil, slope, vegetation and land cover. Weights were assigned (1, 2 or 3) to the different cartographic layers of the geoecological components measured using the algebra map tool, through the arithmetic means, to classify the semiarid basins into different adequability levels, as follows: adequate, partially adequate and inadequate to anthropic uses. These procedures verified the predominance of the "adequate" class with a territorial area above 42% in both investigated basins; the "partially adequate" level and the second most comprehensive class comprised values between 30% and 40%; and, while smaller territorial extensions, below 20%, were "inadequate". Based on these findings, it was possible to measure the most suitable areas for anthropic use in the studied basins and indicate the areas that should be conserved, with emphasis on protection and/or regeneration of the natural vegetation cover. This is important information concerning the planning and environmental management of these semi-arid landscapes in an objective and efficient way.

Introduction

Changes in land use and land cover (LULC) tend to favor and accentuate the impacts generated by anthropic activities in river basins, with negative effects on complex and vulnerable environments in semiarid climates, such as the erosion process developments, water course silting, reservoir eutrophication, superficial water scarcity and natural vegetation removal [1-5]. Studies in the semiarid and arid regions of the United States (US) indicate negative changes in the water context, either due to both natural phenomena induced by climate change (increased temperatures and tree mortality) and anthropic actions (removal of tree and understory vegetation or anthropic pollutants released into the atmosphere), which has increasingly caused greater water stress in the semiarid and arid basins of the western region of the country [1,6,7]. Another worrying fact in these regions is the fact that, after the removal of most of the natural vegetation cover for agricultural use, areas containing native vegetation are often restricted to small fragmented portions and negatively influenced by changes in the use of the surrounding land [8,9]. Specifically with regard to semi-arid regions, a widespread concern regarding environmental impacts is noted in the literature, highlighting soil and ecosystem-degradation effects, which have led to the emergence of large international projects with the purpose of evaluating degraded areas due to changes in LULC occurred [8-12].Thus, research performing comparative analyses between hydrographic basins in different arid and semi-arid regions worldwide provides an integrated understanding of different realities, phenomena and physical-environmental conditions, since these factors are subjected to different LULC pressures, causing marked changes in these environments [13-17]. However, Araújo and Piedra (2009) highlight that, in order to obtain significant results, it is important that the compared basins display certain similarities in terms of contribution areas of the same order of magnitude, land use and slope [16] also warn of the need for a relatively large amount of data, and the fact that the absence of hydrological and meteorological information is often common [7,15-17].

Many of these gaps are overcome with the use of Geographic Information Systems, which allow for the modeling of remote sensing data, highlighting LULC mapping, Normalized Difference Vegetation Index (NDVI) and integrated studies based on thematic cartographies to verify water availability and groundwater recharges [2,3,8,9,18-21]. Specifically regarding the use of NDVI, this index makes it possible to identify vegetation cover patterns, as well as spatial and temporal analyses of phytogeographic dynamics, monitoring water soil availability, land uses and drought effects [2, 19, 22-25]. Considering the global climate change scenario, there is an urgent need to conduct research in semi-arid watersheds, mainly for the purpose of planning and integrated management of water resources. With this aim, this research carried out a comparative analysis on the geoecological adequability between two hydrographic basins located in the hot and dry semi-arid region of South America (Northeastern Brazil). With the ais of data modeling in GIS, the existing interactions between the environmental components that influence the LULC configuration were assessed, estimating geoecological adequability levels. It appears that research involving the modeling of landscape geoecological interactions contributes positively to the achievement of more efficient diagnoses of the environmental conditions of these river systems, aiding decision makers to develop more effective natural resource and water management planning and management [26-30].

How to cite this article : Chaves AMS, Silva Filho CR, Guedes JCF, Costa DFS and Melo & Souza R (2022) Spatial Analysis of the Geoecological Adequability Index in Semi-Arid Watersheds, Northeast of Brazil. Environ Sci Ecol: Curr Res 3: 1070

Materials and Methods

Study area

The studied semi-arid watersheds are located in Northeastern Brazil (Figure 1), in the Agreste of the state of Pernambuco (São José creek-PE/BRSJ-PE microbasin, 146.69 Km²) and the other in the Seridó region of the state of Rio Grande do Norte (São José river microbasin-RN/BRSJ-RN (109.15 Km²). Their landscapes are located exclusively in a rural environment, elongated, displaying a fourth-order river hierarchy according to Strahler (1952), a dendritic drainage network, with similar vegetation cover and LULC. The altimetric variation between the basins is of approximately 310m, taking into account the maximum elevation, with BRSJ-PE established at 980m and 470m altimetric accounts, with an amplitude of 510m. BRSJ-RN, on the other hand, is set between 670m and 180m altitude, with an amplitude of 490m, expressing a moving model and similar when the elevation differential between the microbasins is of only 20m.

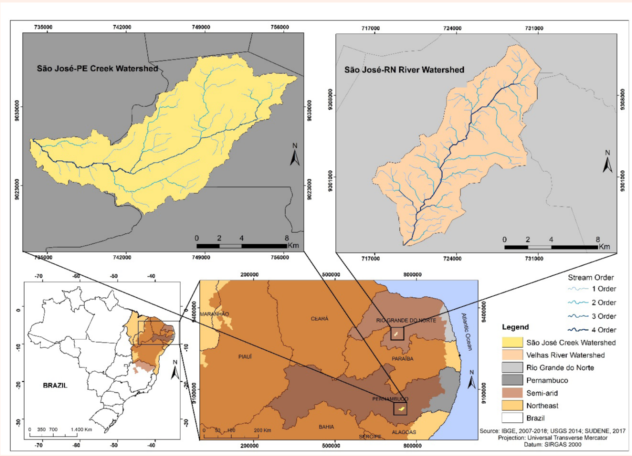

Figure 1: Geographic location map of the São José-RN and São José creek-PE microbasins. Prepared by the authors, 2020.

Regarding climatic conditions, the Riacho São José-PE basin presents rain and temperature variations from east to west, due to terrain elevation differences and its elongated shape. According to the Köppen climate classification, BRSJ-PE presents two climatic types, namely Csa (Subtropical Climate with a dry and hot Summer) to the east, at altitudes above 800 m above the Borborema plateau in the municipality of Caetés-PE, where precipitation reaches 710 mm per year, concentrated in autumn (from April to June) and in the beginning of winter (July), with an average annual temperature of 20.9°C, with a maximum of 22.7°C; and Bsh (Low Latitude Semi-Arid Climate) to the west, a representative climate of the Brazilian semi-arid region, from the Borborema plateau to the Sertaneja depression, with annual precipitation of around 700mm and average annual temperature of 24°C in the semi-arid hinterland hinterland [31]. The São José-RN River basin, on the other hand, is fully inserted in the BSh climate, with an average annual temperature around 26.5°C and an average annual precipitation of around 650 mm [31], typical values found in the semi-arid hinterland.

Technical and operational procedures

The basin delimitation was performed using the digital elevation model (DEM) from images obtained from the Shuttle Radar Topography Mission (SRTM) (sheets SC-24-X-B and SB-24-X-D), with spatial resolution of 90 m. The images were post-processed for the spatial reference system in the UTM projection, using Datum SIRGAS 2000 (zone 24S). The watershed delimitation was performed as described by, adopting the methodological procedures indicated by [32], as follows: Fill sink, flow direction, flow accumulation, conditional/with, stream to feature and watershed. The creation and editing of the geoecological cartographic base took place in the Geographic Information System (GIS) environment of the ArcGIS Pro software (license n. 1a0742dc7e7c1427aeee93dc7da217ea). Geoprocessing and remote sensing tools were used to process the basin's necessary information of soil classes [33], terrain slope (by SRTM), vegetation spatialization by the Normalized Difference Vegetation Index (NDVI) and land use and coverage (LULC). The NDVI was calculated based on [34], using the red and near infrared bands (bands 4 and 5), corrected according to the Landsat 8 Data User Manual. (https://www.usgs.gov/media/files/landsat-8-data-users-handbook). Considering canopy height, the vegetation cover was divided into four strata: arboreal (above 7.0 m), arboreal-shrubby (between 1.0 to 7.0 m), shrubby (0.50 to 3, 0 m) and herbaceous (below 0.50 m), and absence of vegetation (without vegetation cover) (Bertrand, 1966). In addition, during field activities, plant species common among basins were identified, based on a canonical list. Concerning LULC mapping, the red, near infrared and short-wave infrared bands of the Landsat 8 (4, 5 and 6, respectively) were used. TAhe composition of bands in false color (Red-Green-Blue system) was obtained, so that the different land cover modes could be identified and interpreted using the maximum likelihood classification method - Maxver [34], i.e. supervised classification, in which the researcher or analyst has prior knowledge of the studied area and can provide samples of the established classes. In choosing the classes to be mapped, the general IBGE Technical Manual for Land Use and Land Cover classification (2013) was followed, with theaid help of the key for the interpretation of Jensen's satellite image (2000), as natural vegetation areas, man-made agricultural areas and other areas.

Map algebra: calculation of geoecological adequability levels

The geoecological adequability calculation (Equation 1) was performed using the map algebra technique [35,32], applying the simple arithmetic means. To carry out this processing, the cartographic base used herein was in a raster format with homogeneous reclassification, i.e. attributing the established weight to each class, between 1, 2 and 3, taking into account anthropic use capacity observed in situ (Table 1) and geological and climatic aspects, dialogued according to the final classification key (Table 2).

$$GA= ((S \cdot \mathcal{P}) + (D \cdot \mathcal{P}) + (V \cdot \mathcal{P}) + (AU \cdot \mathcal{P}))/4 \quad \text{Equation 1}$$

Where GA = Geoecological Adequability; S = Soil Classes; D = Terrain Slopes; V = Vegetation charges; AU = Types of Anthropic Uses; $\mathcal{P}$ = Variable weights (1, 2 or 3). As a result of the GA calculation, values between 1 and 3 are obtained, which indicate the three levels of land use and coverage adequability. The intervals were planned from equidistant thresholds between the maximum 1 and 3, where "2" would be the limit of the classes in the following order of intervals: 1 - adequate (1 to 1.6); 2 - partially adequate (1.7 to 2.3); and 3 - unsuitable (2.4 to 3) (Table 2). As a final result, the data of the classification key were spatialized in thematic maps, with GA quantification levels as suitable, partially suitable and inadequate.

Table 1: Variables for calculating the geoecological adequability of land use and land cover.

Variables				
Pesos	Soil (S)	Terrain slope (D)	Vegetation (V)	Anthropic Use (U)
1	Regosols Luvisols	0 to 8%	Herbaceous and absence of vegetation	Anthropic Agricultural Areas
2	Planosols Acrisols	8 to 45%	Shrubby	Other areas and water
3	Leptosols	> 45%	Shrubby and tree/ shrubby	Natural Vegetation Areas

Table 2: Classification key for adequability levels.

Reference Value	Level	Classification Key
1 to 1.6	Adequate	Soil areas with potential agricultural uses, on flat to gently undulating land, with herbaceous vegetation or without primary or secondary vegetation and precipitation may be favorable to the local water regime or not. Most of the geoecological factors are favorable to the development of human activities.
1.7 to 2.3	Partially adequate	Soil areas with potential agricultural uses, on undulating and heavily undulating land, with herbaceous vegetation or without primary vegetation, precipitation is not always favorable. Some of the geoecological components are not favorable to human uses, which makes socioeconomic activities more difficult.
> 2.4	Inadequate	Crystalline basement areas with exposed rocks, not very developed soil on steep slopes, steep and/or mountainous, areas where natural vegetation predominates, recommended for preservation, as they comprise local phytogeography such as shrubby bushes and high-altitude forests. Comprises a geoecological environment unfavorable to the development of socioeconomic activities.

Results and Discussion

Geoecological characterization of Brazilian semiarid basins

The assessed semi-arid basins are located on geological structures of the crystalline basement, consisting mainly of igneous and metamorphic rocks, featuring rocky outcrop areas, the presence of shallow soils, not very developed, with a sandy texture and stony composition, all common aspects to the northeast [4,16] in which the climatic regime and pedogenesis act on the geological substrate, forming different materials and soils, on which erosive processes and degradation will be triggered [36]. For the São José creek -PE and São José River-RN basins a common example comprises Leptosols, classified as the world's most extensive soil reference group, particularly widespread in mountainous areas (FAO, 2015), associated with higher basin levels, where the predominant relief is undulated, strong mountainous and steep undulated, with a sandy and stony texture, which gives it high erodibility. Another soil class associated with these relief features, with a sandy/clayey texture, comprises Acrisols present in the Southeast of the BRSJ-RN. The flattened portions of the basins exhibit soils with a sandy/clay texture, as follows: Planosols to the west of the BRSJ-PE (Sertaneja Depression) and Luvisols along the central extension of the BRSJ-RN, associated with flat and smooth undulated slope areas, such as those observed in the slope map of the semiarid basins. Another class of soil located on flat and smooth undulated reliefs consists of Regosols to the Northeast and Southeast of the BRSJ-PE (Figure 2). The geomorphological structure of the basins is related to the pedological and geological characteristics presented herein. At the BRSJ-PE, pediplanation processes are observed in the high and low course, while in the medium course mountains, valleys and escarpments with strong unevenness and exposure of the crystalline basement are observed. At the BRSJ-RN, on the other hand, the surface is flattened everywhere in the central portion, where denudational processes express greater influence than agradational ones, called backwood depression, with the occurrence of residual masses arising from granitic intrusions [37]. At the basins, geomorphological features comprise flat, smooth undulated, undulated, strong undulated, mountainous and steep slope classes (Figure 3).

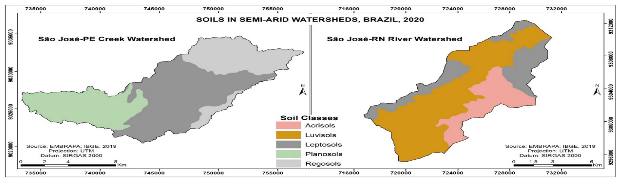

Figure 2: Soil classes in Brazilian semiarid basins. Prepared by the authors, 2020.

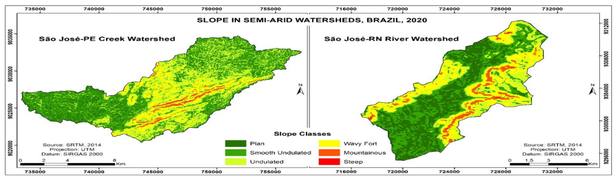

Figure 3: Slope of Brazilian semi-arid basins. Prepared by the authors, 2020.

The relationship between soil and slope concerning the influence of precipitation, is reflected in different phytophysiognomies (Figure 4) and in the modes of land use and land cover of the assessed basins (Figure 5). Both basins are part of the caatinga domain, and BRSJ-PE in its final portion, east of Borborema, comprises the formation of an altitude swamp with arboreal species typical of a tropical montane cloud forest and mountains transition formation features consisting of tree and shrub species and, in the depression area, shrub vegetation and riparian forest predominating in water courses. The BRSJ-RN vegetation, on the other hand, expresses the characteristics of a semi-arid hinterland, completely composed of species from the Caatinga domain, with a predominant shrub extract and few trees, due to the fact that the area has a history of human exploitation [38]. Thus, more flattened areas exhibit more intense land use and occupation, while massif areas and steeper slopes consist of vegetation displaying natural characteristics. In the phytogeographic context, native and exotic plant species are found in the semiarid basins in different strata, such as: Aspidosperma pyrifolium Mart./Apocynaceae (pereiro), Prosopis juliflora (Sw) DC/Fabaceae (algaroba), Myracrodruon urundeuva Allemão/Anacardiaceae (white aroeira), Poincianella pyramidalis (Tul.) L. P. Queiroz var/Fabaceae (catingueira), Anadenanthera colubrina (Vell.) Brenan var./Fabaceae, (angico), Mimosa tenuiflora (Willd.) Poir./Fabaceae (jurema preta), Sideroxylon obtusifolium (Humb. ex Roem. & Schult.) T.D.Penn./ Sapotaceae (quixabeira), Cereus jamacaru DC./Cactaceae (mandacaru), Sida cordifolia L./Malvaceae (malva-branca), Croton spp. H.B.K. and C./Euphorbiaceae (velame), Cnidoscolus urens L. Arthur/Euphorbiaceae (urtiga), among other species.

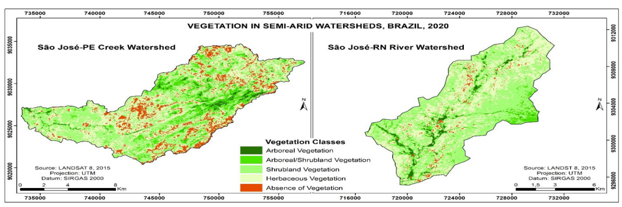

Figure 4: Vegetation of Brazilian semi-arid basins. Prepared by the authors, 2020.

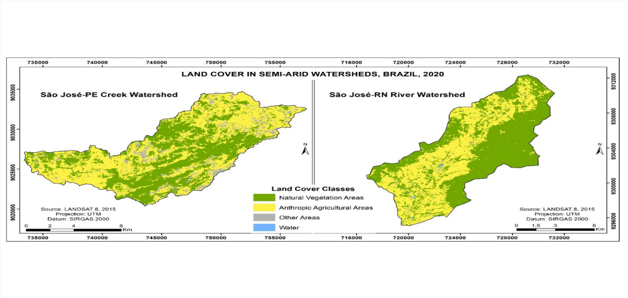

Figure 5: Land use and land cover in Brazilian semi-arid basins. Prepared by the authors, 2020.

The LULC of both basins were classified as follows: natural vegetation areas, arranged over areas of strong undulated, mountainous and rugged declivity and less developed soil conditions; anthropic agricultural areas, are mainly located on a flat and smooth undulating relief, where subsistence agriculture and extensive livestock farming occurs; and water classes and other areas (referring to exposed soil, rocky outcrops or unidentified uses). The field surveys indicate that it is common to raise cattle (BRSJ-RN) and cattle and goats (BRSJ-PE) loose in the caatinga in areas of natural vegetation, leading to a certain amount of anthropic pressure.

Geoecological adequability levels in semiarid basins

It is observed (Table 3) the quantitative expressions shows the quantitative expressions of each of the geoecological components of the semi-arid basins (in km² and %) and the weight related to each map layer used in the calculation of geoecological adequability through map algebra. Therefore, the analysis and observation of the interactions occurring between the components of the landscape (soil, slope, vegetation and land cover) allow for indications of which areas are priorities for preservation and which are more suitable for the development of human activities. From the weights associated with the cartographic layers presented in the characterization of the study areas in the GIS environment, the GA calculation was performed to estimate levels of geoecological adequability for BRSJ-PE and BRSJ-RN, verifying which areas can be considered adequate, partially adequate and inadequate for the development of human activities in semiarid environments (Figure 6). Bearing in mind that the classification of the GA levels was established from an equidistant threshold, with reference to the number 2 (limit of extreme classes 1 and 3), adequate level presents values ranging from 1 to 1.6 while, at the other extreme, inadequate classes display combinations of geoecological components unfavorable to human use with values ranging from 2.4 to 3 and partially adequate levels include the transition between the appropriate and inadequate classes, ranging from 1.7 to 2.3. In general, the GA map reveals that areas with a flat relief and little slope associated with deeper soils present greater intensity of anthropic uses in the studied semi-arid basins, where vegetation has been removed for the development of activities such as pastures for livestock development extension, breeding of smaller animals and subsistence farming. On the other hand, on land characterized by steep slopes (undulating, mountainous and strongly steep) and poorly developed soil, the map revealed unfavorable environments for agricultural activities, allowing for a more preserved vegetation cover. In a quantitative context, a predominance of areas suitable for human activities is noted in the basins of more than twice the inadequate areas (Table 4), where: adequate areas comprised 43.00% of the total area of the BRSJ-PE and 42.79% of the BRSJ-RN; partially adequate areas comprised 33.64% (BRSJ-PE) and 40.49% (BRSJ-RN), and lower values indicating inadequate areas consisted of 23.37% and 16.72%, respectively. In specific aspects, the São José creek-PE basin comprises, in the greater extent of its medium course, areas categorized as unsuitable for anthropic uses, featuring a landscape of mountains and valleys and escarpments in the transition between the Borborema Plateau and the Sertaneja Depression marked by changes from a shrubby tree vegetation to a more shrubby phytophysiognomy, which occurs due to the influences of climatic conditions, since the predominance of lower rainfall and humidity and higher temperatures are observed leeward after the plateau. The São José-RN River basin, on the other hand, is noteworthy for being located between a massif which, to the west, comprises areas unsuitable for anthropic uses, consisting of leptosols and acrisols, and conservation of vegetation cover.

Table 3: Quantification of the geoecological aspects of the assessed semiarid basins.

Comparative Analysis Between Semiarid Basins							
Component	Peso	BRSJ-PE / Km/%			BRSJ-RN / Km/%		
	1	Planosols	39.37	26.84%	Luvisols	61.94	56.75%
	2	Regosols	39.01	26.59%	Acrisols	21.72	19.90%
	3	Leptosols	68.31	46.57%	Leptosols	25.49	23.35%
Pedology		Total	146.69	100.00%	Total	109.15	100.00%
	1	Flat	19.21	13.10%	Flat	30.69	28.12%
		Smooth Undulated	57.04	38.89%	Smooth Undulated	30.36	27.81%
	2	Undulated	46.58	31.75%	Undulated	19.71	18.06%
		Strong Undulated	20.08	13.69%	Strong Undulated	22.72	20.82%
	3	Mountainous	3.63	2.48%	Mountainous	5.54	5.08%
		Cliff	0.14	0.10%	Cliff	0.13	0.12%
Slope		Total	146.69	100.00%	Total	109.15	100.00%
	1	Absence of vegetation	17.75	12.10%	Absence of vegetation	2.64	2.42%
		Herbaceous	52.25	35.62%	Herbaceous	42.96	39.36%
	2	Shrubby	55.15	37.59%	Shrubby	52.3	47.92%
	3	Tree-shrubby	17.73	12.09%	Tree-shrubby	7.84	7.18%
		Arboreal	3.82	2.60%	Arboreal	3.41	3.12%
Vegetation		Total	146.69	100.00%	Total	109.15	100.00%
	1	Anthropic agricultural	100.1	68.24%	Anthropic agricultural	47.52	43.54%
	2	Natural vegetation	40.46	27.58%	Natural vegetation	60.87	55.77%
	3	Other areas	5.9	4.02%	Other areas	0.58	0.53%
Land Use		Water	0.23	0.16%	Water	0.18	0.16%
and Cover		Total	146.69	100.00%	Total	109.15	100.00%

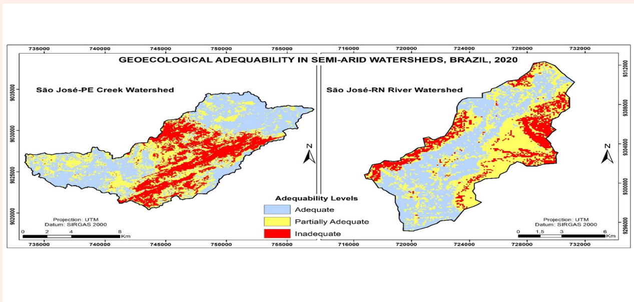

Figure 6: Mapping of geoecological adequability levels in Brazilian semiarid basins. Prepared by the authors, 2020.

Table 4: Quantification of the levels of geoecological adequability of the assessed semiarid basins.

Levels	São José creek-PE		São José river-RN	
	Area (Km²)	%	Area (Km²)	%
Adequate	63.07	43.00%	46.7	42.79%
Partially adequate	49.34	33.64%	44.2	40.49%
Inadequate	34.28	23.37%	18.25	16.72%
Total	146.69	100%	109.15	100%

Geoecological comparison

Concerning the geoecological components used in calculating the GA of the studied semiarid basins, only pedology does not display the same classes, with both comprising three types of soil, with only leptosols in common, representing approximately 46% of the BRSJ-PE and 23% of the BRSJ-RN. Regarding slope, the variation between classes fluctuates for the flat, smooth undulated and undulated features, but they follow the same trend for the strong undulated class, decreasing for mountainous features and reaching almost zero in steep slopes (Figure 7). With regard to vegetation, a similar behavior is observed for the growth trends of classes with no vegetation, as well as herbaceous and shrubby vegetation, and a subsequent decline for shrubby and tree plant physiognomies (Figure 8). Variations in LULC are also observed (Figure 9), as BRSJ-PE comprises greater proportions of agricultural anthropic areas, while for the BRSJ-RN areas of natural vegetation predominate. But for the other two classes, i.e. other uses and water, a sharp decline was observed. Such relationships reflect the trend observed in the geoecological adequability classification levels (Figure 10), revealing a sequential decrease from adequate to partially adequate classes and from partly adequate to inadequate classes. The LULC patterns of the studied basins in relation to slope are similar to those reported by [4] in another Brazilian semiarid basin and the Little Zab river basin in northeastern Iraq and northwestern Iran studied by [2], comprising areas of anthropic agricultural uses associated with flat and smooth undulating reliefs, while natural vegetation predominates the most steep slopes. Such relationships reflect the trend observed in the geoecological adequability levels classification, revealing a sequential decrease from the adequate class to the partially adequate class and from partly adequate to inadequate. Given the above, some reflections on the possibilities of environmental planning to be developed in the semiarid basins are indicated, since which areas are the most and the least adequate for the development of human activities are known. Thus, as stated previously, in view of the negligence committed to the only Brazilian biome, which comprises a seasonally dry tropical forest presenting a late discovery of its biodiversity by [39], it is important to assess semi-arid watersheds regarding their vegetation cover. In this regard, for the present study, vegetation was determined by the normalized difference vegetation index, which has shown good results for the caatinga biome vegetation [23,24,40].

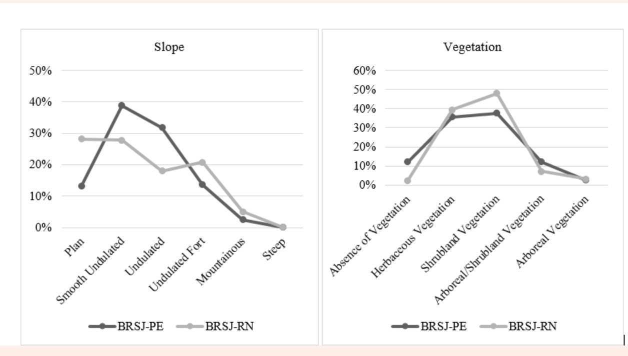

Figure 7 and 8: Variation between slope classes and between vegetation classes in the assessed semiarid basins.

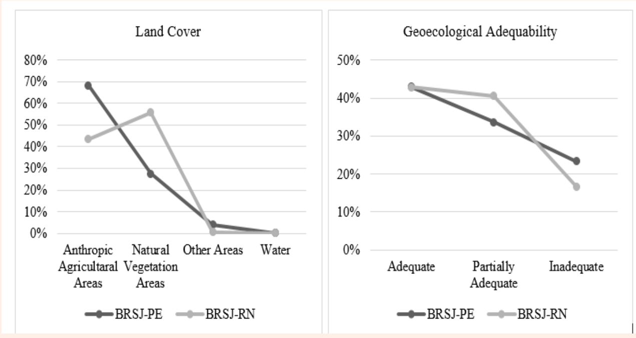

Figure 9 and 10: Variation between land use and cover classes and variation between geoecological adequatibility classes of the assessed semiarid basins.

The NDVI makes it possible to identify the spatial relationships between vegetation and precipitation, relief, soil moisture and drought phenomena, which are captured by the satellite images analyzed in the GIS environment, distinguishing the different plant strata and their spatial diversification on the ground. Areas with higher moisture content, phytogeographic changes in relation to differences in relief, rainfall distribution and the behavior of vegetation during the dry and rainy periods can, thus, be identified [2,4,19,23,25]. Thus, one must consider environmental planning aiming at the conservation and increase of areas with tree and shrub vegetation, as these classes express less spatial representations. To this end, not only the portions included as inadequate geoecological levels, but also part of the transition areas determined as partially adequate, with special attention to water courses, should also be taken into account, since studies in semiarid basins have revealed concerns regarding decreased water flow due to LULC changes, particularly reduced natural vegetation [1,7]. In this regard [1], when comparing changes in water flows in western US basins, concluded that the majority of harmful changes to hydrology are caused by effects introduced by humans, whose future consequences will consist in water scarcity and insufficient storage for agricultural and urban area activities. In the same manner, the study carried out by [7] indicates a direct relationship between vegetation changes and decreased hydrological responses in semi-arid water courses in southwest USA, verifying a 50% annual water yield depletion.

Such scenarios have encouraged the development of studies that seek to outline alternatives for the recovery and improvement of hydrographic basins and the quality of water resources, with consumers paying for Environmental Services (AS) and/or Ecosystem Services (SE) of water to landowners where the basins are located [14,41,42]. However, the aforementioned research indicates that conflicts between the different actors and sectors involved, such as either political relations of individual interests or unfriendly relations between landowners and other water resource users, appear as limiting factors that result in disadvantages concerning the development of projects aimed at basin regeneration through the payment of taxes or SA and SE. Another observation concerns the different realities experienced in these environments regarding great landscape and socioeconomic contracts, since, in the case of the studied semi-arid environments, water is not present in local water courses all year round, with reservoirs and wells being the most permanent water sources. Thus, projects for these environments requires research that can identify weaknesses and potentialities, and urgent concrete actions aimed at vegetation conservation and protection. Concerning the studied basins, which are formed in greater proportions by flat and smooth undulating terrain, exhibiting the predominance of adequate levels for anthropic uses, at 43.00% for the BRSJ-PE and 42.79% for the BRSJ-RN, we believe it is necessary to take into account the impacts that agricultural activities can cause to these environments, i.e. erosion, river silting and water eutrophication in reservoirs, in search of alternatives to mitigate or reverse this situation. This is due to the fact that the deforestation of the natural vegetation cover directly reflects in the acceleration and development of erosive processes, whereas agriculture makes use of chemical and organic fertilizers and animal husbandry generates high loads of nutrients from the animal excretions, which in turn increases sediments and soil nutrient input to water courses and reservoirs during rainfall events by runoff [5,43,44]. Therefore, despite the anthropic uses occurring in areas classified as adequate, they should be performed in a sustainable manner, so that they do not cause damage to water resources. In this sense, the need to maintain areas of natural vegetation and plant regeneration in the studies basins is reinforced, with urgency concerning the surrounding water courses, mainly due to the fact that the landscape act directly on sediment connectivity, disrupting transport processes [16,45-47]. For this to occur, it is important to understand how to proceed and which tree species are most suitable for the semi-arid environment, in order to contribute to soil protection by efficiently reducing the occurrence of erosive processes, facilitating the infiltration of precipitation events and reducing surface runoff and the transport of sediments and substances to river beds, streams and reservoirs. In order to do this, studies on plant, pedological and climatic dynamics are required, highlighting the need to perform the restoration of the semi-arid environment from scientific evidence on the functional characteristics of plant species concerning the environment in which they will be inserted [48-50]. Thus, projects aimed at protecting, conserving and/or regenerating the vegetation of the caatinga biome in semi-arid basins will be more efficient and financially viable when planned and structured based on scientific evidence (taking as an example the studies presented herein) [4,16, 45, 48-51] seeking to understand the existing geoecological interactions that configure the landscapes [3, 20,26,27,30]. In this sense, geoecological adequability indexes, when used to estimate adequate and inadequate areas for anthropic uses for the studied semiarid basins, comprise a flexible classification that is easy to apply to other environments, and can be used as a proxy for the design of public policies, such as payment by environmental/ecosystem services in basins, mainly in areas that still remained conserved.

Conclusions

The presented study carried out a comparative analysis between two Brazilian semiarid basins, focusing on the application of a flexible methodology, developed through algebra maps in a GIS environment, termed Geoecological Adequability - "GA". The aim was to classify the most and least adequate areas for anthropic uses through the combination of geoecological components that make up the landscape, i.e. soil, slope, vegetation and land use and land cover. Given the landscape similarity concerning the configuration of the semiarid basins, which favored the methodological application, significant results were obtained, since interactions between soil, slope and vegetation influence land use and land cover and, consequently, the determination of geoecological adequability levels. In these relationships, the soil classes differed among basins, as the areas only have leptosols in common, which did not interfere with the results. The application of the "AG" calculation allowed for the identification, classification and quantification of the areas most adequate for human use in the studied semiarid landscapes, consisting of terrains with flat and smooth undulating relief in association with more developed soils (planools, regosols and luvisols) and the absence of tree and shrubby vegetation, where anthropic uses are already present. This was observed in both the high and medium course of the São José creek -PE basin and in the central portion of the São José-RN river basin. It was also possible to indicate environments inadequate for anthropic uses, which must be conserved in their natural states without anthropic intervention, safeguarding basin fauna and flora. These areas reflect interactions between steep reliefs, such as strong undulating, mountainous and scarped and with less developed soils (leptosols and acrisols) and more conserved tree and shrub cover. These characteristics are marked in the mountain and valley landscapes of the medium course of the BRSJ-PE and of the massif that surrounds the BRSJ-RN. Such findings lead to the need to rethink areas classified as partially adequate, with special attention to uses developed close to water courses, which should include riparian forest. Thus, these areas are in need of conservation planning aimed at the recovery of native vegetation and the development of its essential functions in riverbed protection. In this process, importance should be given to tree species appropriate to semiarid environment dynamics. The results, through the calculation and mapping of geoecological adequability, reflect an integrated study based on spatial analysis in a GIS environment to generate scientific data and information that allow for rethinking land use and land cover in semi-arid basins, seeking conservation in the caatinga, a unique biome in Brazil that consists of seasonally dry tropical forests. This leads to the need to outline an environmental and landscape planning compatible with the reality of the assessed environment, and even the development of sustainable human actions, such as, for example, the development of leisure or tourist activities like Ecotourism and Geotourism. Therefore, new studies in semiarid environments are paramount, which should explore the different realities in the light of the relationships established between the geoecological components and different land use and land cover modes, covering landscapes at different scales, as well as applying different methods presented in different software programs, with preference for free access programs.

Acknowledgements

The authors would like to thank the Graduate Programs in Geography at the Federal University of Sergipe and the Seridó Higher Education Center at the Federal University of Rio Grande do Norte, the Research Groups in Geoecology and Territorial Planning (GEOPLAN) and in Biogeography of Tropical Ecosystems (TRÓPIKOS). The first author also thanks the Coordination for the Improvement of Higher Education Personnel (CAPES) for granting a PhD scholarship - Finance Code 001, at the Postgraduate Program in Geography - PPGEO/UFS and Grupo do Vale de São José for the support.

Conflict of Interests: The authors declare no conflict of interest.

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