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Interrelations between LULC and water resources in the Brazilian Semiarid region: a systematic and bibliometric analysis

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A B S T R A C T

This study carries out a bibliometric and systematic analysis of the literature related to the use of Land Use and Land Cover (LULC) spatial data in the Brazilian Semiarid, with the aim of quantifying anthropogenic impacts on water resources and their implications for urban water resource management. The bibliometric analysis, conducted with the bibliometrix tool in the R language, examined 133 publications from the Scopus and Web of Science databases. Subsequently, a systematic review, guided by the PRISMA guidelines, was applied to 22 selected scientific papers. This methodological approach highlighted the importance of LULC data in understanding environmental dynamics and promoting the sustainable use of natural resources. The results reveal that changes in LULC are linked to variations in the quality and availability of water resources, affecting water resource management and urban development. The study emphasizes the need to incorporate LULC data into urban planning and development strategies in order to mitigate negative impacts on water resources and encourage management practices that promote sustainability in urbanized and semiarid environments.

Keywords: natural resources, anthropogenic actions, spatial data, urban water.

Interrelações entre LULC e recursos hídricos no Semiárido Brasileiro: uma análise sistemática e bibliométrica

R E S U M O

Este estudo realiza uma análise bibliométrica e sistemática da literatura relacionada ao uso de dados espaciais de Uso do Solo e Cobertura da Terra (LULC) no Semiárido Brasileiro, com o intuito de quantificar os impactos antropogênicos sobre os recursos hídricos e suas implicações para a gestão urbana de águas. A análise bibliométrica, conduzida com a ferramenta bibliometrix na linguagem R, examinou 133 publicações das bases de dados Scopus e Web of Science. Subsequentemente, uma revisão sistemática, orientada pelas diretrizes PRISMA, foi aplicada a 22 artigos científicos selecionados. Essa abordagem metodológica ressaltou a importância dos dados de LULC na compreensão das dinâmicas ambientais e no fomento ao uso sustentável dos recursos naturais. Os resultados revelam que alterações no LULC estão ligadas às variações na qualidade e disponibilidade dos recursos hídricos, afetando a gestão de recursos hídricos e o desenvolvimento urbano. O estudo enfatiza a necessidade de incorporar dados de LULC nas estratégias de planejamento e desenvolvimento urbano, a fim de mitigar impactos negativos sobre os recursos hídricos e incentivar práticas de gestão que promovam a sustentabilidade em ambientes urbanizados e semiáridos.

Palavras-chave: recursos naturais, ações antrópicas, dados espaciais, águas urbanas.

Introduction

The relationship between human activities and natural systems has resulted in significant changes in water resources, which are essential for ecological and societal stability (Jiang et al., 2024). Anthropogenic actions such as industrial discharge, urbanization, deforestation, and agricultural practices have affected both the quality and availability of water globally (Priyan, 2021). In arid and semiarid regions, these challenges are compounded by climatic conditions that limit water availability and amplify the impacts of these activities (M. da C. de Sousa et al., 2021). These pressures underscore the need

for effective strategies to manage and protect water resources in such environments.

Land use and land cover (LULC) changes are central to understanding the dynamics of hydrological systems (Dogan and Karpuzcu, 2022; Leta et al., 2021; Shukla et al., 2023). The conversion of natural landscapes into agricultural or urban areas modifies evapotranspiration, soil permeability, and water retention, directly affecting water resource availability (Roy and Inamdar, 2019). In Brazil, which has the largest freshwater reserves in the world, the paradox of abundance coexisting with scarcity is increasingly evident. Rising consumption, water quality degradation, prolonged droughts, and distribution and treatment infrastructure deficiencies have intensified resource pressures (Val et al., 2019). These challenges are especially acute in the Brazilian Semiarid (BSA), where anthropogenic actions such as deforestation, agricultural intensification, and unplanned urban expansion have placed water resources under severe stress (J. F. C. B. da C. Silva et al., 2021a; M. da C. de Sousa et al., 2021). The semiarid climate, characterized by low and irregular rainfall, further compounds these pressures, creating a context where water management strategies must address both natural and human-induced challenges (Morante-Carballo et al., 2022).

In recent decades, advances in LULC scenarioizing have enhanced methodologies and improved the accuracy of results, enabling more robust predictions and analyses of landscape dynamics (Rivas-Tabares et al., 2022). These advances have been driven by integrating remote sensing, geospatial technologies, and machine learning models, which allow for synthesizing diverse datasets. LULC modeling, therefore, has evolved to address critical gaps in understanding how landscape changes unfold, their drivers, and their cascading effects on ecological and hydrological systems (Yonaba et al., 2021). By providing multi-scale and multi-temporal perspectives, Al-Taei et al. (2023) and Dinda et al. (2022) highlight that these models support a differentiated view of LULC change, allowing stakeholders to identify vulnerable regions and prioritize mitigation strategies.

According to Akhtar et al. (2021), different land use types present distinct challenges to water resources. With impervious surfaces such as roads and buildings, urban areas disrupt natural infiltration processes, intensify surface runoff, and increase pollutant loads in nearby water bodies (C. S. S. Ferreira et al., 2021). Similarly, agricultural zones contribute to water resource degradation through sedimentation, pesticide runoff, and nutrient leaching, which promote eutrophication and compromise aquatic ecosystems (Ilampooranan et al., 2022). Urban and agricultural land uses are recognized as the primary drivers of global water quality degradation (Mello et al., 2020). However, quantifying the hydrological consequences of LULC changes remains a complex task due to the inherent variability of hydrological systems, gaps in high-resolution spatial and temporal data, and the challenges associated with limited financial and technical resources (Astuti et al., 2019).

Integrating advanced modeling techniques with LULC data has proven to be an effective approach to addressing the hydrological and environmental challenges of the BSA. Models such as SWAT (Soil and Water Assessment Tool) simulate hydrosedimentological processes, making it possible to analyze water dynamics in river basins under different LULC and climate change scenarios (A. K. P. Rocha et al., 2023). In addition, the use of platforms such as Google Earth Engine and remote sensing tools, integrated with indices such as NDVI (Normalized Difference Vegetation Index) and MNDWI (Modified Normalized Difference Water Index), make it possible to map the relationship between LULC and climate variability with high spatial and temporal precision (W. J. S. F. Rocha et al., 2024; L. de B. de Sousa et al., 2023). In the BSA, these methods have been applied to identify desertification patterns, evaluate the efficiency of agricultural practices and measure the impacts of extreme climatic events, such as droughts and intense rainfall (B. F. da Silva et al., 2023; L. A. P. da Silva et al., 2024). These tools support predicting changes in the water balance and prioritizing sustainable management actions in vulnerable areas.

Considering the studies on water resources already carried out in the BSA, this study hypothesizes that LULC changes directly influence the quality and availability of water resources in the BSA. Integrating LULC spatial data provides insights into quantifying anthropogenic impacts on hydrological systems, supporting urban water resource management and sustainable development in semiarid environments. The study conducts a systematic and bibliometric review of scientific literature on LULC applications in the BSA to test this hypothesis. This approach aims to investigate how these data have been applied to quantify

anthropogenic impacts on water resources and identify these studies' main scientific contributions to urban water resource management. By synthesizing existing research, the study seeks to inform strategies that integrate ecological preservation with the socioeconomic needs of the BSA.

Methodology

In order to recognize the scientific production on the use of LULC data applied to water resources in the BSA, a systematic literature review associated with a bibliometric analysis was carried out, structured as established by (Boloy et al., 2021). These methodologies, when combined, can demonstrate qualitatively (through the systematic review) and quantitatively (through the bibliometric analysis) the evolution of scientific studies on various topics (Pizzi et al., 2020).

Quantitative Analysis

According to Boloy et al. (2021) bibliometrics is a quantitative method used to analyze and build indicators on the behavior and evolution of a given scientific field, its focus, areas, organizations, or countries. Initially, a search was carried out on the Scopus and Web of Science databases for studies published between January 1, 1945 and July 31, 2022, using the terms "Brazil", "water", "land-use" and "semiarid". The Boolean operators used in the search are shown in Table 1.

To analyze the collected data, we used the *bibliometrix* tool, developed in the R language. We used all the acquired records in the Scopus and Web of Science databases at this stage, excluding duplicates. The *bibliometrix* tool, proposed by Aria and Cuccurullo (2017), provides a set of functions for quantitative research in bibliometrics and scientometrics. This way, *bibliometrix* can extract valuable knowledge from data and represent it using tables, intuitive graphs, maps, and dendrograms.

Therefore, four bibliometric indicators were chosen for this study: annual production, most cited documents globally, thematic map of keywords, and trending topics.

Table 1. Research series used for the bibliometric review process

Database	Keywords and search terms
Web of Science	TS = ((Brazil AND water AND (land-use* OR "land use*" OR LULC) AND (semiarid OR semiarid)))
Scopus	TITLE-ABS-KEY ((Brazil AND water AND (land-use OR lulc OR "land use") AND (semiarid OR semi-arid)))

Qualitative Analysis

Systematic reviews can summarize the state of knowledge in a field from which research trends and priorities can be identified. The results obtained during the quantitative analysis stage were used to begin the systematic review.

Subsequently, the qualitative analysis followed the guidelines of the *Preferred Reporting Items for Systematic reviews and Meta-Analyses* (PRISMA) (Page et al., 2021). The title and abstract of each paper identified were screened for relevance according to the selection criteria. After the initial screening, the full-text papers were assessed for eligibility.

The exclusion reasons during the screening of titles and abstracts were: I) papers not written in English; II) gray literature (conference papers, book chapters, books, proceedings, among others). We then checked which papers needed to have the full text available. The eligibility criteria were: I) study area encompassing some region of the BSA; II) use of LULC spatial data; III) application in water resources.

A PRISMA flow diagram model was used to structure the systematic review (Figure 1). The flow diagram was divided into four phases. The identification phase involves choosing the keywords and database and removing duplicate records. The second phase, screening, included the records after removing the duplicates, which were analyzed according to the exclusion criteria, so the documents that could not be analyzed were also released. The third phase evaluates the entire text of the papers according to the pre-defined eligibility criteria. Finally, the included stage counts the ones that will be included in the review.

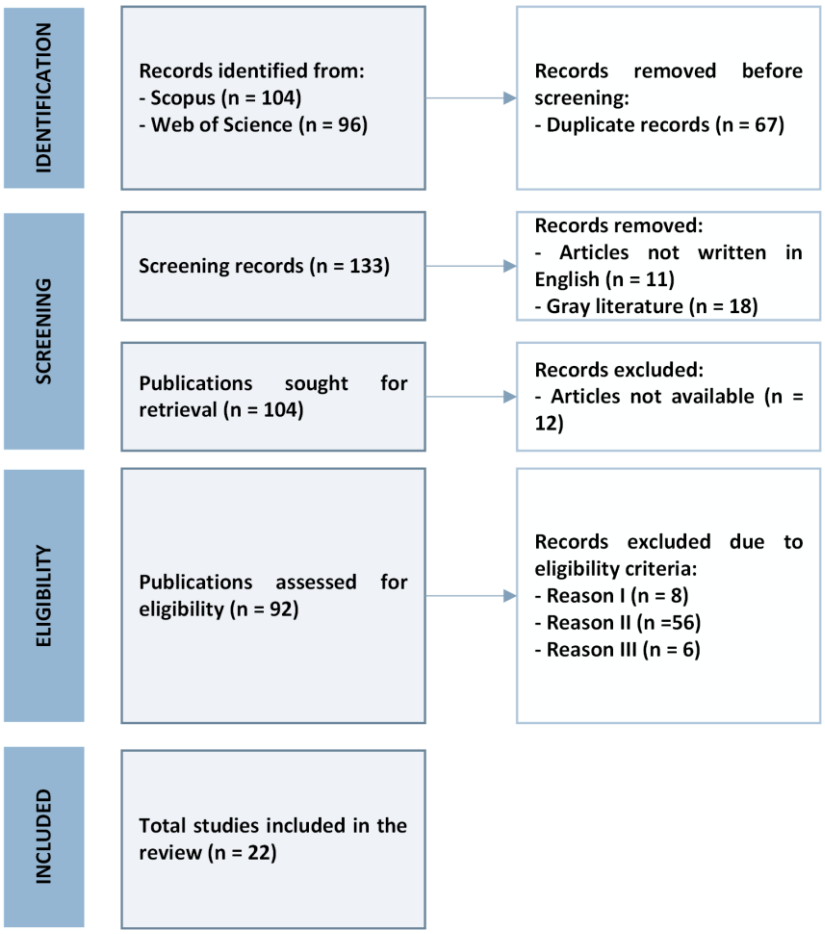

Figure 1. Flow diagram for the PRISMA 2020 declaration. Source: Adapted from Page et al. (2021).

Subsequently, a matrix of theoretical determinants was drawn to ascertain how LULC data helped water resource studies, its characteristics, and the main results obtained. Such matrices help classify data and optimize content analysis (Drakes and Tate, 2022). The evaluated variables facilitated comparative assessment and identified trends in spatial analysis focusing on water resources. Finally, the data was exported with complete records and references cited saved in tabular format in Microsoft Excel.

Results and discussion

The systematic review and the bibliometric analysis indicate the current state of water resources research using LULC databases to conduct analyses, experiments, models, and simulations. Based on previously published studies, Bibliometric indicators help map scientific gaps and opportunities. In turn, in the systematic review using the PRISMA method, the results can identify the main objectives of the research, how LULC data was used, and the main contributions from the studies.

Bibliometric analysis

The overview of bibliometric information (Figure 2) provides an overview of the research. From the data, it can be seen that publications involving water resources and LULC in the BSA began in 1983. Since then, 89 publication sources (including journals, publishers, and events) have been used for scientific dissemination.

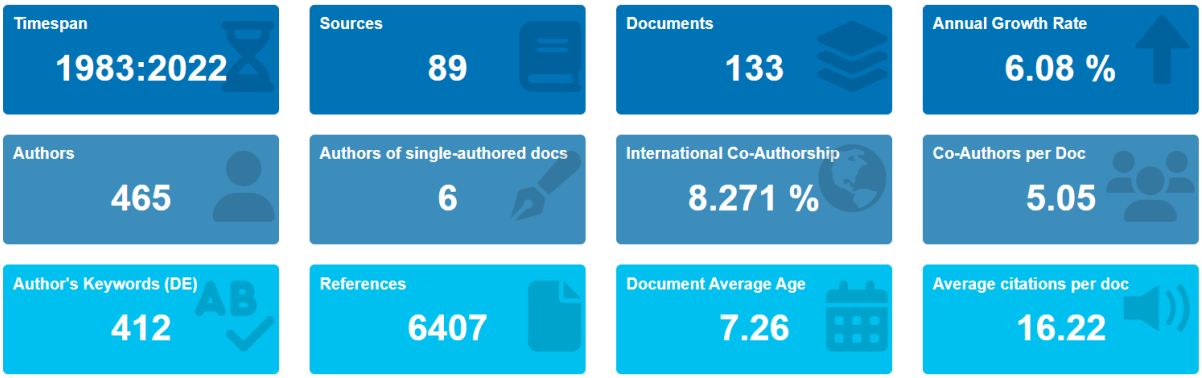

Figure 2. General information from bibliometric analysis.

The information highlights that among the 133 records analyzed, 465 different authors took part in the research, with 8.27% comprising authors from other countries. The annual growth rate for the theme totals 6.08%, with an average of 16 citations per publication.

Based on the information in the productivity graph (Figure 3), it is possible to visualize the time distribution of publications and the average number of citations per record. It can be seen that the years 2021 and 2020 saw the highest volume of publications, with a total of 16 and 15 documents, respectively. About the annual average of citations per record, the year 2000 stands out, with an average of 89 citations per record.

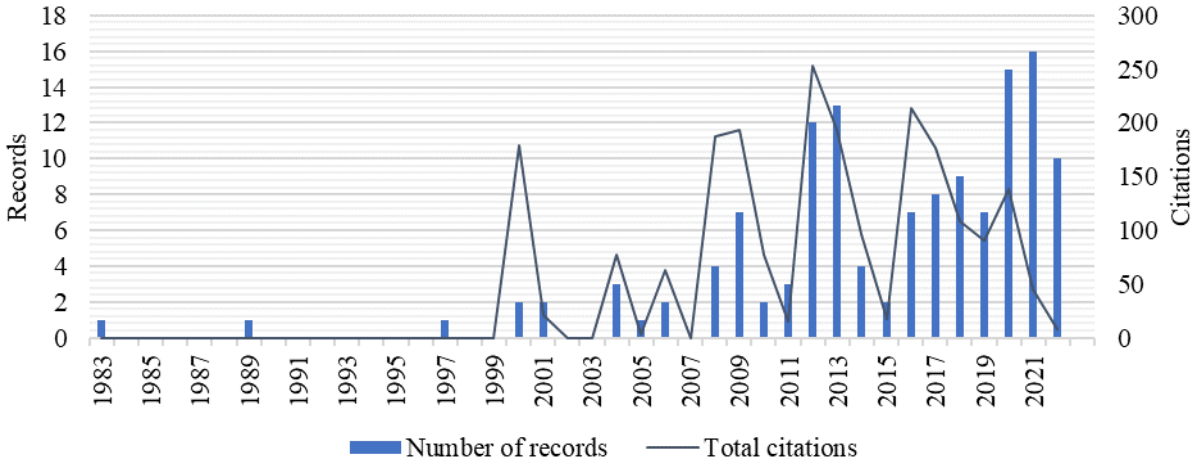

Figure 3. Time distribution of scientific productions.

Figure 4 shows the trend of the most frequent topics calculated from the keywords in the documents. The figure shows the periods in which the words were most used and their frequency. There are 14 terms in the representation, with a minimum frequency of 10 appearances.

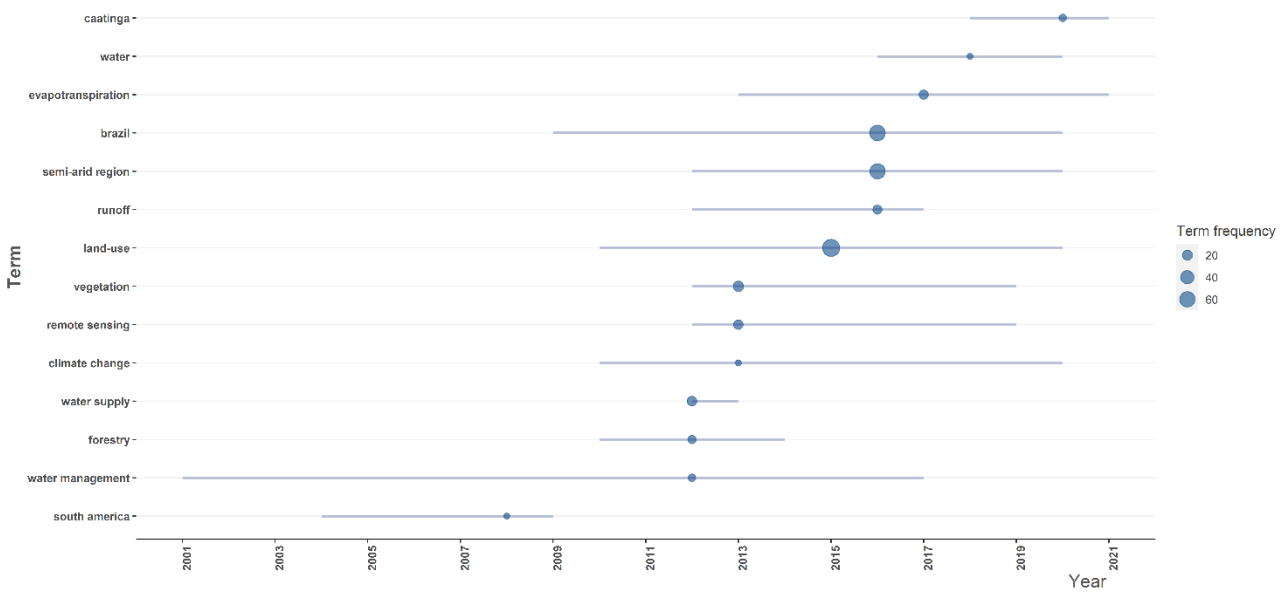

Figure 4. Trend of the most frequent words.

Among the most frequent words, "*remote sensing*," "*climate change*," "*land-use*," "*semiarid region*," and "*vegetation*" have appeared since 2010. These words show the expansion of remote sensing to collect land-use data in semiarid regions, which has substantially contributed to environmental research. In turn, the term "*caatinga*" has been gaining ground since 2018 due to growing concern about preserving the biome, which has seen accelerated deforestation in recent decades due to the increase in inappropriate farming practices in the region (Miranda et al., 2018). Also, in this context, the word "*evapotranspiration*" reflects advances in developing models that simulate the components of evapotranspiration, which is fundamental for monitoring hydrology and improving water management practices (Kool et al., 2014).

Word analysis drew groups of keywords considered themes, whose density and position can be used to classify themes in a two-dimensional diagram. Figure 5 illustrates the thematic map, capable of classifying themes according to the quadrant in which they are located.

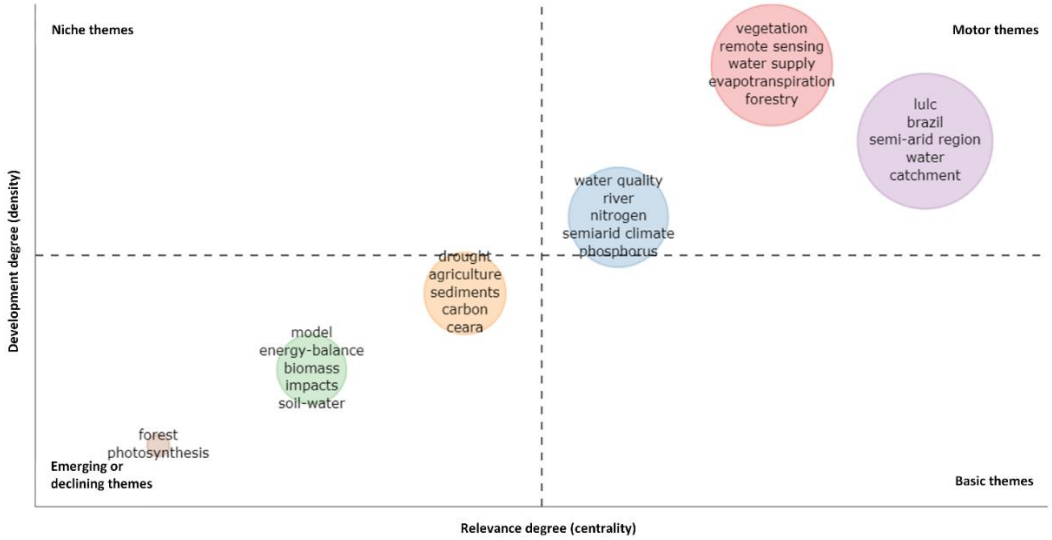

Figure 5. Thematic map of the topics discussed.

There were emerging or declining themes and driving topics (third and first quadrants, respectively). The driving themes, or *hot topics*, are well-developed and relevant themes for structuring the conceptual framework. In one of the themes, words such as LULC, *Brazil*, and *Semiarid region* (used in the bibliographic search) stand out, as well as *water* and *catchment* (referring to the resource studied and its catchment area).

On the other hand, another theme includes remote sensing, vegetation, evapotranspiration, forested areas, and water supply, which has been gaining more space in publications since 2010. The third driving theme encompasses words linked to water quality, such as nitrogen and phosphorus, as well as semiarid climate, which highlights studies on the impacts of climate change on the hydrology and water quality of rivers and reservoirs in the Brazilian semiarid region (Raulino et al., 2021).

Concerning emerging or declining themes, words that have gradually increased or decreased in frequency over the years stand out. In this respect, based on the analysis of trending topics, it is possible to infer that the themes encompassing words such as *drought*, *agriculture*, *sediments*, *energy balance*, and *model* are emerging since the terms had a higher frequency in more recent publications (from 2010 onwards), while the words *forest* and *photosynthesis* have become increasingly less frequent in publications (which include the terms chosen in the initial criterion).

Among the driving and emerging themes listed, the research nuclei focused on studies of water resources and the environment stand out, focusing on studies of water supply, evapotranspiration, vegetation, and water quality, highly relevant topics for the BSA, which have been undergoing significant changes as a result of the anthropization and vegetation suppression of the caatinga and cerrado biomes. According to the Annual Mapping of Land Cover and Use in Brazil (Mapbiomas), between 1985 and 2021, the Caatinga and Cerrado biomes lost 10.1% and 20.9% of their native vegetation, respectively, which is equivalent to 34 million hectares of vegetation lost.

Systematic review

In order to structure the information on the 22 papers included in this review, Table 2 was drawn up and divided into five columns: authors and year of publication, title, research objective, application of LULC, and principal conclusions, to establish a precise, qualitative, and convenient evaluation of the works.

Table 2. Matrix of theoretical determinants

Authors and year of publication	**Title**	**Objective**	**Application of LULC**	**Main conclusions**
Alves et al. (2020)	Land-Use and Legislation-Based Methodology for the Implementation of Sustainable Drainage Systems in the Semiarid Region of Brazil	Evaluate the efficiency of sustainable drainage systems, considering the analysis of runoff reduction in areas prone to severe flooding and their restoration capacity.	Land use was used to map urban infrastructure and calculate impermeability indices.	It identified priority blocks with severe cases of flooding. The results can be used as guidelines for the construction of legislation and support integrating urban planning and water resource management.
Araújo Neto et al. (2017)	Influence of land use/occupation on water quality in the Trussu river valley, Ceará, Brazil	Assessing the influence of land use and occupation on the temporal dynamics of surface water quality and groundwater in the perennial valley of the Trussu River.	The changes in the LULC were analyzed to justify the changes in the water quality indices in the reservoirs.	The results show that groundwater quality has changed due to the increase in agricultural areas, showing that the change in land use has had a more significant impact on groundwater.

Authors and year of publication	Title	Objective	Application of LULC	Main conclusions
Chaves et al. (2019)	Water quality and anthropogenic impact in the watersheds of service reservoirs in the Brazilian semiarid region	To evaluate the quality of water in surface reservoirs in the Brazilian semiarid region in the face of rainfall variability and the degree of anthropization of the watersheds.	The LULC was used to obtain the degree of anthropization of the contributing watersheds.	The quality attributes of surface water in the study area are directly influenced by the reservoir basins' degradation and the rainfall's temporal variability. In the three reservoirs analyzed, pH showed the strongest correlation with the percentage of anthropization of the reservoir basins.
Coelho et al. (2017)	Alluvial groundwater recharge estimation in the semiarid environment using remotely sensed data	Integrating remote sensing and geographic information system data to estimate the spatial distribution of groundwater recharge in a semiarid watershed in northeastern Brazil, which includes spatially variable runoff and soil moisture in the water balance equation	Land use data was used in the NRCS method to estimate the monthly runoff from the basin.	It showed that the input and output components of the water balance equation (precipitation, evapotranspiration, and runoff) from remote sensing and geographic information system techniques enabled groundwater recharge to be spatialized over the study area. The remote sensing data provided reasonable estimates of groundwater recharge.
L. M. R. Ferreira et al. (2019)	Impact of the Urbanization Process on the Availability of Ecosystem Services in a Tropical Ecotone Area	Describe the remote sensing techniques used to classify the LULC and the benefit transfer method applied to estimate the ecosystem service values for each LULC.	LULC data was used to quantify relative gains and losses in ecosystem service values	It first assesses temporal changes in ecosystem service values in the Brazilian agreste, a tropical ecotone between the Atlantic Forest and the Caatinga biome.
Flach et al. (2020)	Water productivity and footprint of major Brazilian rainfed crops - A spatially explicit analysis of crop management scenarios	Analyze how changes in nutrient inputs affect yields and water productivity, and investigate how the intensification of food production in Brazil affects the productivity of agricultural water use. Estimate the geographical distribution of irrigation potential throughout the country.	Land cover maps were used to map cultivated and harvested areas in Brazil.	The study replicated the range of historical yields and observed water productivity of cotton, corn, soybeans, and wheat in Brazil, where green water was identified as the primary water resource for producing these crops. The results also showed that increasing productivity related to reducing nutritional stress has the most significant potential for improving green water productivity.

Authors and year of publication	Title	Objective	Application of LULC	Main conclusions
Jardim et al. (2022)	Using Remote Sensing to Quantify the Joint Effects of Climate and Land Use/Land Cover Changes on the Caatinga Biome of Northeast Brazilian	Determine and analyze changes in land cover, use, and occupation in biophysical parameters in the Caatinga biome in the Brazilian semiarid region.	Assess the impacts of changes in the LULC on biophysical variables in the municipality.	There has been a significant trend towards an increase in agricultural areas, resulting in the progressive reduction of the Brazilian Caatinga biome. The Caatinga biome has particular biophysical parameters according to land cover and soil exposure at intra- and inter-annual scales.
Knighton et al. (2020)	Alignment of tree phenology and climate seasonality influences the runoff response to forest cover loss.	Present evidence for the hypothesis that mean annual temperature and the phase shift between precipitation peaks and enhanced vegetation index explain a significant amount of the variation in hydrological response to forest cover loss.	Forest cover data was used to identify forest loss.	Increased runoff following forest loss was observed in most catchments where precipitation peaks followed the peak growing season (USA). In contrast, where precipitation peaks preceded the growing season (South Africa and Australia), there was less evidence of increased runoff (25% of catchments). The findings support the conservation and enhancement of the study sites as a means of limiting future hydrological extremes, as well as providing more comprehensive ecosystem services.
Lima et al. (2021)	Assessment of automated evapotranspiration estimates obtained using the GP-SEBAL algorithm for dry forest vegetation (Caatinga) and agricultural areas in the Brazilian semiarid region	Evaluate the applicability of the Python surface energy balance algorithm for land (GP-SEBAL) from the Geographic Resources Analysis Support System (GRASS) to calculate real evapotranspiration for Caatinga vegetation and agricultural areas in the BSA.	To choose the hot and cold pixels needed to calculate evapotranspiration, we used spatial LULC data, surface temperature, and albedo.	The study evaluated the applicability of the GP-SEBAL algorithm for calculating real evapotranspiration for dry forest vegetation (Caatinga) and agricultural areas in the BSA. GP-SEBAL proved to be a less complex task with considerably less execution time than SEBAL, making it an efficient tool for multi-image applications.

Authors and year of publication	Title	Objective	Application of LULC	Main conclusions
Maillard and Santos (2008)	A spatial-statistical approach for modeling the effect of non-point source pollution on different water quality parameters in the Velhas River watershed - Brazil	Develop and test a simplified methodology to determine the effect of LULC on water quality in a large-scale watershed.	Establishes the relationship between water quality, land use, and distance to streams	The results indicate that LULC classes can be used to model turbidity, fecal coliforms, nitrogen, and, to a lesser extent, phosphorus. The approach takes advantage of existing water quality data and LULC to represent an essential tool in the Brazilian context.
A. Montenegro and Ragab (2010)	Hydrological response of a Brazilian semiarid catchment to different land use and climate change scenarios: a modeling study	Investigate the hydrological processes of a watershed in the BSA and analyze the impact of climate change scenarios and different land use patterns on the water resources available in the region.	Vegetation cover data was used to carry out the daily hydrological simulation, and the impacts of different land use scenarios on runoff were also analyzed.	The model successfully predicted the flow for the study area. Future climate change scenarios are expected to affect water resources in the region drastically. The results are relevant to management strategies in the area. They can contribute to the challenge of biofuel production in an environment prone to climate change in semiarid areas of the world.
S. Montenegro and Ragab (2012)	Impact of possible climate and land use changes in the semiarid regions: A case study from North Eastern Brazil	To test the suitability of the distributed basin model for simulating the hydrological behavior of a semiarid basin and to study the hydrological responses of the basin to different climate change scenarios and the impact of land use change on the availability of water resources.	Changes in land use were considered for the basin's water balance and their impact on water flows.	The model was able to simulate the hydrological behavior of the study area. The results showed a reasonable performance of the model to simulate the stream's flow (while considering the inter-annual and intra-annual variation of the rainfall regime) and the soil moisture scaled at selected depths.
Moraes et al. (2018)	The impact of global change on economic values of water for Public Irrigation Schemes at the São Francisco River Basin in Brazil	Estimate the economic values of water for a reference year, along with future projections for 2035.	A spatially explicit global economic land use model was used to calculate a weighted average of yields for all crops grown, water demand, and cost per hectare.	The allocation of sugarcane and fruit crops projected with climate change impacted average yields and water costs. The economic values for all the regimes in the reference year were higher than the water prices established for agricultural use in the basin.

Authors and year of publication	Title	Objective	Application of LULC	Main conclusions
Palácio et al. (2016)	Effective precipitation, soil loss, and plant cover systems in the Caatinga biome, Brazil	To investigate the influence of anthropogenic action on adequate precipitation and soil loss in micro-watersheds subjected to different land uses in a tropical dry forest region.	Influence of LULC on soil losses in precipitation events	The lowest sediment production and surface runoff were found in the Caatinga area with sparse vegetation, and this was the area that showed the most significant loss by dragging, unlike the other areas, which indicates the need to assess whether soil losses in managed areas in the semiarid region can be evaluated considering only suspended sediments.
A. dos Santos et al. (2020)	Causes and consequences of seasonal changes in the water flow of the São Francisco river in the semiarid of Brazil	Evaluate the causes and consequences of changes in the flow of water in the São Francisco River.	The Normalized Difference Vegetation Index (NDVI) was calculated from Landsat images to establish vegetation classes and subsequently establish the land vulnerability index.	Spatio-temporal monitoring via orbital products and soil vulnerability classes has efficiently highlighted changes in the conditions and dynamics of vegetation cover and water conditions in the study area. Soil vulnerability directly impacts the increase in resting areas.
C. A. G. Santos et al. (2017)	Estimation of evapotranspiration for different land covers in a Brazilian semiarid region: A case study of the Brígida River basin, Brazil	To test the application of the SEBAL model for analyzing evapotranspiration and energy balance for different land cover types in a semiarid basin, using the digital elevation model (DEM) for transmittance correction.	During the SEBAL model process for calculating evapotranspiration, spatial coverage data from the NDVI was used, along with surface temperature and albedo.	The results showed that correcting SEBAL by DEM for the dry year increased the values of the biophysical parameters calculated in the study. The evapotranspiration values obtained with the SEBAL model could accurately represent the observed low evapotranspiration of the canopy.
J. C. N. dos Santos et al. (2017)	Sediment delivery ratio in a small semiarid watershed under conditions of low connectivity	Using the Universal Soil Loss Equation, Map soil erosion and calculate the average annual sediment input ratio and individual events from hydro sedimentological measurements.	Land use was used to calculate the soil management factor, indicating soil erosion vulnerability.	Applying the Universal Soil Loss Equation indicated the range of soil loss values. High rainfall depth events resulted in much sediment disintegration in the area.

Authors and year of publication	Title	Objective	Application of LULC	Main conclusions
J. L. B. da Silva et al. (2020)	Changes in the water resources, soil use, and spatial dynamics of Caatinga vegetation cover over the semiarid region of the Brazilian Northeast.	To monitor and evaluate the spatial dynamics of Caatinga vegetation cover and water availability using the vegetation index and the estimation of biophysical parameters of the energy balance using remote sensing techniques with satellite images.	LULC data was used to analyze the Caatinga vegetation's behavioral pattern and the water bodies' representation.	The conditions of repeated land use over time have extinguished the spatial dynamics of the Caatinga vegetation, which has promoted the loss of vegetation cover and water bodies, contributing to conditions of change in the local microclimate and accentuating water deficit.
J. F. C. B. da C. Silva et al. (2021b)	Analysis of the response of the Epitácio Pessoa reservoir (Brazilian semiarid region) to potential future drought, water transfer, and LULC scenarios.	Analyze future impacts on the volume of a reservoir based on possible future droughts, water transfer, population growth, and recent changes in land use and cover.	Simulations were made of future LULC scenarios, which served as input data for hydrological modeling and calculation of the weir's volume between 2020 and 2030	It assessed how and to what extent climate variability, population growth, and changes in LULC affect the reservoir's water availability and sought to predict how long it will be able to meet the population's demand.
J. R. I. Silva et al. (2022)	Morphometric characterization and land use of the Pajeú River basin in the Brazilian semiarid region	Integrating a river basin's morphometry and land use using satellite data and various remote sensing techniques.	LULC is used to assess the spatial variation of cover and determine the percentage of permanent protection areas that are preserved and those that need to be regenerated.	It demonstrated the potential of QGIS and QSWAT tools for application in morphometric and land cover studies. The integration of morphometry with the analysis of land cover and soil characteristics provides more robust interpretations of the hydrological trend of river basins.
K. D. P. da Silva et al. (2022)	Influence of land use and occupation on water quality and the diatom community of reservoirs in Northeast Brazil	To learn about the characteristics of the diatomology community and the use and occupation of the land around the three reservoirs according to limnological variables and types of land use and cover.	Based on the LULC around the reservoirs and limnological variables, a principal component analysis was carried out, which separated the reservoirs by trophic state based on total phosphorus in the water.	The results showed low species richness and high similarity between water bodies with different trophic gradients. Occurrence of epiphytic, benthic, and planktonic diatoms, with distribution and frequency adapted to tolerance to organic pollution.
Van Oel et al. (2008)	The impact of upstream water abstractions on reservoir yield: the case of the Orós Reservoir in Brazil	Analyze the impacts of water abstraction for irrigation upstream of a reservoir and its impact on reservoir performance and reliability.	Land use was used to establish a relationship between the volume of the reservoir and the irrigated area in the floodplain zone.	The study shows that changes in land use in semiarid regions can have a significant impact on the reliability of reservoir yields.

Main objectives

Among the papers analyzed, the focus of the research was on evaluations of water availability (4 papers), water quality (3 papers), drainage (2 papers), ecosystem services (2 papers), and soil erosion (2 papers). Concerning the common objectives, it is possible to note the analysis of anthropogenic factors and their influence on water resources. In this context, Alves et al. (2020) highlight the deficit of drainage systems to the rate of impermeability caused by human occupation. As far as this is concerned, Maillard and Santos (2008) highlight the role of land use changes in the hydrological cycle, where anthropized areas directly affect water quality, percolation, and soil erosion.

Another common objective in some studies was to analyze river basins' water and energy balance. Thus, Coelho et al. (2017), Lima et al. (2021), and C. A. G. Santos et al. (2017) used the SEBAL (*Surface Energy Balance Algorithms for Land*) algorithm to estimate the energy balance and subsequently model the water balance of the basins; on the other hand, S. Montenegro and Ragab (2012) quantified the different components of the water balance using flow and soil moisture data.

The BSA fully or partially encompassed all study areas to meet the objectives. In the publications analyzed, 17 papers used river basins or regions as study areas; the others used urban areas, municipal boundaries, simulation units, or river valleys.

LULC applications

Most spatial LULC data has been used to identify and quantify spatial patterns of LULC. Alves et al. (2020), Chaves et al. (2019), L. M. R. Ferreira et al. (2019), Flach et al. (2020), Jardim et al. (2022), Knighton et al. (2020), Moraes et al. (2018), C. A. G. Santos et al. (2017), J. L. B. da Silva et al. (2020), J. R. I. Silva et al. (2022) and K. D. P. da Silva et al. (2022) used this data for analyses capable of identifying vegetation loss, changes in cover patterns and types of use. This made it possible to identify classes of use and cover, verify temporal changes in LULC, priority zones for applying interventions, more vulnerable areas, degrees of anthropization, and behavioral patterns of vegetation.

Another portion of LULC spatial data has been used in research as input data for hydrological simulations and modeling. Coelho et al. (2017), Lima et al. (2021), A. Montenegro and Ragab (2010), S. Montenegro and Ragab (2012), Palácio et al. (2016), J. C. N. dos Santos et al. (2017), and J. F. C. B. da C. Silva et al. (2021b) used LULC as input data to establish relationships with hydrological parameters, identify hot zones and make estimates of runoff flow.

Unlike the abovementioned applications, Araújo Neto et al. (2017) and Maillard and Santos (2008) used LULC data to establish a relationship between water quality and land use. Through statistical analysis and modeling, these studies established relationships between water quality parameters (such as turbidity, nitrate, nitrite, phosphorus, and fecal coliforms) and LULC. Still, from this perspective of association, Van Oel et al. (2008) used LULC data to relate the volume of a reservoir to the number of areas classified as irrigated in a river basin.

Contributions to urban water management

The interaction between urban expansion, land use, water resource management, and environmental sustainability can be seen based on the research analyzed. As identified by Araújo Neto et al. (2017) and K. D. P. da Silva et al. (2022), urban expansion and agricultural activities significantly impact water quality, highlighting the need for careful planning that considers the interdependence between urban and rural areas.

The implementation of sustainable drainage strategies, analyzed by Alves et al. (2020), such as permeable sidewalks, green roofs, and rain gardens, shows how innovation in urban infrastructure can mitigate problems such as flooding. In addition, the analysis of water quality in reservoirs by Chaves et al. (2019) and the methodology for estimating groundwater recharge by Coelho et al. (2017) are essential for the sustainable use of water resources, especially in drought-prone regions.

The quantitative analysis of the impact of urbanization on the availability of ecosystem services carried out by L. M. R. Ferreira et al. (2019) suggests the need for policies that balance urban development with environmental conservation. Flach et al. (2020) and Jardim et al. (2022) provide insights into the interaction between land use, ecosystems, and food security changes, highlighting the importance of sustainable urban planning and managing protected areas near urban centers.

Understanding the runoff response to the loss of forest cover, addressed by Knighton et al. (2020), is important for planning resilient urban infrastructure, particularly in cities prone to flooding and extreme weather events. Lima et al.

(2021) present a methodology for estimating evapotranspiration, which can assist in managing water resources and developing urban infrastructure.

Maillard and Santos (2008) highlight relationships between land use, diffuse pollution, and water quality that are important for managing urban water resources. This aligns with Montenegro and Ragab's detailed understanding of hydrological dynamics in response to different land uses and climate change scenarios (2010; 2012).

Moraes et al. (2018) emphasize the implications for efficient water allocation in different uses, including agriculture in or near urban regions. Palácio et al. (2016) help to understand the relationship between land use, vegetation cover and hydrological processes, which are important for conserving water resources and preventing land degradation.

The identification of areas vulnerable to desertification and soil degradation by A. dos Santos et al. (2020), as well as the techniques for monitoring and managing land use and water resources on a large scale by C. A. G. Santos et al. (2017), are important for efficient urban and regional planning. J. C. N. dos Santos et al. (2017) point out the importance of identifying areas susceptible to erosion and sediment deposition patterns for developing soil conservation and stormwater management strategies.

The analysis of changes in land use in the Caatinga by J. L. B. da Silva et al. (2020), the modeling of future precipitation scenarios by J. F. C. B. da C. Silva et al. (2021b) and the identification of areas with low soil infiltration capacity by J. R. I. Silva et al. (2022), provide data for sustainable soil management and water conservation strategies, relevant elements in sustainable urban planning. In addition, Van Oel et al. (2008) study highlights the importance of upstream water abstractions for reservoir performance in semi-arid environments.

Main research contributions

The results of the studies analyzed contribute to scientific advances in various fields of hydrology. They have also made it possible to quantify the value of ecosystem services, support mapping risk areas, and identify sites of environmental degradation.

In this respect, Araújo Neto et al. (2017), Chaves et al. (2019), Maillard and Santos (2008), and K. D. P. da Silva et al. (2022) demonstrated quality changes in surface and groundwater caused by the process of anthropization of river basins. Jardim et al. (2022) and J. C. N. dos Santos et al. (2017) pointed out the causes and consequences of environmental degradation, resulting in increased sediment disaggregation and vegetation suppression.

Several studies have identified substantial changes in the hydrological cycle due to LULC changes. Alves et al. (2020), Coelho et al. (2017), Knighton et al. (2020), A. Montenegro and Ragab (2010), S. Montenegro and Ragab (2012), Palácio et al. (2016), A. dos Santos et al. (2020) and J. R. I. Silva et al. (2022) have identified, through modeling and simulations, changes in the flow of surface runoff and its impacts on the urban environment, sediment production, peak flows, and groundwater recharge, as well as the influence of anthropogenic factors and climate change on flows. As far as this is concerned, Lima et al. (2021) and C. A. G. Santos et al. (2017) calculated evapotranspiration in different cover conditions and their impact on biophysical parameters in different climatic seasons.

Therefore, the studies by J. F. C. B. da C. Silva et al. (2021b), J. L. B. da Silva et al. (2020) and Van Oel et al. (2008) have shown the impacts of LULC on water availability, ranging from yield reliability to changes in the local microclimate. Finally, L. M. R. Ferreira et al. (2019) and Moraes et al. (2018) quantified economic impacts resulting from anthropization in semiarid basins, which alter ecosystem service values and impact the region's agricultural productivity.

Discussion

LULC changes in semiarid regions encompass more than just technical issues. These changes directly impact communities that depend on small reservoirs and native vegetation for their livelihoods, exacerbating water insecurity and economic vulnerability. Regions like the BSA, rich in culture and biodiversity, face increasing pressure on water resources due to human decisions and environmental forces. Recent studies demonstrate how the expansion of agricultural and urban areas has drastically altered water availability and quality in semiarid regions worldwide (Mohammad and Ranga, 2023; Morante-Carballo et al., 2022; Shirmohammadi et al., 2020).

In this context, science and technology offer tools to better understand and address these challenges. Remote sensing, spectral indices, and predictive models have been applied to map land-use changes and predict their future impacts. Tahiri et al. (2021) highlight the importance of

water management strategies, such as efficient irrigation, the use of non-conventional water sources, and water conservation, to mitigate the impacts of water scarcity and promote agricultural sustainability.

The integration of satellite data and modeling reveals how LULC changes, as emphasized throughout this review, exert pressure on surface reservoirs and underground aquifers, jeopardizing water security for future generations (Banjara et al., 2024; Halipu et al., 2022; Lei et al., 2021; Nkosi et al., 2021). Spatial modeling tools and mapping techniques have proven effective in identifying priority areas for watershed actions, simulating water flows in heterogeneous soils, and evaluating the effectiveness of different water management practices (Ammar et al., 2023; Vishwakarma et al., 2021).

The history of the BSA region cannot be told without recognizing the role of the Caatinga, a biome that sustains not only ecological balance but also human life (Jardim et al., 2022). The results of this study align with those of Salazar et al. (2021) , who identified a reduction in Caatinga connectivity between 1985 and 2018 due to agricultural expansion. This fragmentation compromises local biodiversity and hydrological functionality, creating barriers to species movement and water redistribution in degraded landscapes.

Similarly, the findings also resonate with those of Alcântara et al. (2021), who analyzed the effects of land-use changes on hydraulic properties in semiarid regions. Comparing areas of Caatinga and pastures, the authors observed that compaction and reduced porosity in pastures lead to lower water infiltration and increased surface runoff, thereby amplifying erosion risks.

Conclusions

Through the bibliometric review, it was possible to see how publications involving water resources and LULC in the BSA were distributed over time. The most cited studies are those published more than ten years ago, which are taken as a reference for new research in the area. On the other hand, the trend of the most frequent topics shows the development of studies using remote sensing data, as well as the analysis of the impacts of climate change on water resources in the BSA.

Among the main objectives raised during the systematic review, it was possible to identify the main focus of the studies, which analyzed issues such as water availability, quality, and runoff, highlighting the impacts of human's actions on water. In the 22 papers analyzed, LULC was mainly used to quantify spatial patterns of use and cover, identify land-use and land-cover classes, and provide input data for simulations and models. Consequently, the main contributions of the papers occurred in the field of hydrology through results that identified changes in surface runoff, water availability, and the quality of surface and groundwater.

The findings presented throughout the reviews can aid debates on a subject with growing publications and great governmental and economic interest for a region of great extension. The information provides a general overview of the structure and thematic evolution of studies using LULC data in water resources studies in the BSA, capable of guiding researchers on research already carried out and methodologies applicable to this region.

Thus, based on the bibliometric and systematic review, it was possible to identify the importance of using LULC data to study water resources in the BSA. The studies included in the reviews found that these data are essential for understanding anthropogenic impacts on water in the region, allowing for the monitoring and evaluating of changes in land use and vegetation cover. The results also showed that using LULC data from remote sensing techniques has proved to be an essential tool for managing water resources, allowing for planning and implementing environmental conservation and preservation measures. It is therefore concluded that integrating LULC data with water resources studies in the BSA can significantly contribute to understanding the ecological dynamics of the region and promoting sustainability in the use of natural resources.

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