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Technology and policy integration: modelling morphometric characterization and land use change using artificial neural networks in the Western Amazon

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A B S T R A C T

This study aims to analyze in an integrated way the application of morphometric indices elaborated in geographic information systems and aspects of environmental management of water resources for the Micro Watershed of Garças River, located in the state of Rondônia. It used images with Digital Elevation Models (DEM) obtained by TOPODATA and Landsat 8 images obtained by INPE (the Brazilian Institute for Space Research). Subsequently, with the aid of the QGIS 2.18.0 software, the watershed was delimited, the NDVI and the slope were calculated and, based on initial data, morphometric characteristics were calculated. The watershed has an area of 1621.101 km², perimeter of 438.661 km and length of 82.04 km, with altimetry ranging from 77.8 to 177.8 meters, and form factor of 0.24, which characterizes a rectangular shape, indicating that the basin has a low propensity for floods. NDVI ranged from 0.187 to 0.49, and it has a coverage area of native vegetation superior to that of anthropized areas. Thus, the watershed morphometric study, together with data on use and occupation, provide essential elements for the planning of actions to be carried out in the watershed.

Keywords: Morphometry. Watershed management. GIS, cellular automata markov change prediction

Integração de tecnlogia e política: modelando caracterização moformétrica e mudança de uso da terra usando redes neurais artificiais na Amazônia Ocidental

RESUMO

Este estudo tem como objetivo analisar de forma integrada a aplicação de índices morfométricos elaborados em sistemas de informações geográficas e aspectos de gestão ambiental de recursos hídricos para a Microbacia Hidrográfica do Rio Garças, localizada no estado de Rondônia. Foram utilizadas imagens com Modelos Digitais de Elevação (DEM) obtidas pelo TOPODATA e imagens Landsat 8 obtidas pelo INPE (Instituto Brasileiro de Pesquisas Espaciais). Posteriormente, com o auxílio do software QGIS 2.18.0, delimitou-se a bacia hidrográfica, calculou-se o NDVI e a declividade e, com base nos dados iniciais, foram calculadas as características morfométricas. A bacia possui área de 1621,101 km², perímetro de 438,661 km e extensão de 82,04 km, com altimetria variando de 77,8 a 177,8 metros, e fator de forma de 0,24, o que caracteriza um formato retangular, indicando que a bacia possui baixa propensão a inundações. . O NDVI variou de 0,187 a 0,49, e possui uma área de cobertura de vegetação nativa superior à de áreas antropizadas. Assim, o estudo morfométrico da bacia, juntamente com os dados de uso e ocupação, fornecem elementos essenciais para o planejamento das ações a serem realizadas na bacia.

Palavras-chave: Morfometria. Gestão de bacias hidrográficas. GIS, autômatos celulares predição de mudança de markov

Introduction

Water is a valuable natural resource, of paramount importance for life maintenance (Pereira et al., 2021), and is widely found throughout the planet, although only 2.6% is considered fit for human consumption. Lakes, rivers and reservoirs are the main sources of these resources and are directly linked in the water dynamics linked to the watershed (Sousa et al.

2016). The Amazon Biome is one of the richest biomes regard water resources (Vale et al., 2021), but due to unsustainable models of land use water security is at stake. Since the 1970's the Amazonian rainforest is the new frontier of agribusiness in Brazil. Strategies to tackle this unsustainable model of development scientific tools must be applied to assist a technology-based decision-making process towards sustainability (Stabile et al., 2020).

According to Yassuda (1993), the watershed "is the unitary stage of water interaction with the physical environment, the biotic environment and the social, economic and cultural environments." This requires a full management of these resources, which has as its central object the integration of the multiple aspects that interact in the use of water resources and their environmental protection (Vale; Da Costa; Da Silva Pimentel, 2021).

Several experiences with the management of watersheds emerged during the years, but in 1997, with the Law No. 9,433, a new water resources policy was implemented in Brazil, and watershed management was then implemented. Many difficulties appear when dealing with these geographical areas, as water resources have shared management with the public administration, institutions connected with agricultural activity, sanitation agencies, environmental management, among others, in which these sectors are a distinct administrative watershed division (Ribeiro et al., 2021).

This Law initiated the insertion processes of regional organizations which are in the level of watersheds. Three groups represent and integrate stakeholders: (a) water resources users, (b) public administration, and (c) civil society. Watersheds that extend to more than one state are supervised by the federal power, while those which are limited to only one state collaborate with state water agencies (Siegmund-Schultze, 2015).

In this sense, the Geographic Information Systems (GIS) was one of the tools for better understanding watersheds (Cavalcante; Grigio; Diodato, 2021), which according to Ferreira (1997), maps and points out answers to the various questions about planning, survey resources, and assists in a better understanding of these elements. Among the analyses for watershed characterization, we find the morphometric analysis, which is used to characterize quantitatively with numerical processes that can be extracted from topographic maps and from Digital Elevation Models (DEM) (Rennó, 2004).

Lupinacci; Stefanuto (2022) mention that the watershed morphometric characterization is in the primordial and most commonly performed steps in environmental or hydrological analyses, and aims to elucidate the understanding of environmental, regional and local dynamics. Antonelli and Thomaz (2007) state that with these analyses, it is possible to point out specific indicators for a given locality and to qualify environmental changes using the parameters that are calculated.

The land use and land change studies are key for identifying trends of anthropic activities in a watershed (Pereira et al., 2021). The model of social and economic development in the watershed has direct influences in land use changes, being responsible for alterations in the landscape and the dynamics of hydrological processes (Fernandes; Collares; Corteletti, 2021). In the specific case of the Amazonian Biome, one of the major biodiversity hotspots of the world, such alterations have impacts on local and global environment (Silva et al., 2020).

Information obtained by morphometric indices calculations is of paramount importance in planning processes, as they can serve as a subsidy in environmental management (Jesus; Berezuk; Medeiros, 2021) to better understand the dynamics of water quality, land use and cover, exploration of natural resources, socioeconomic performance, erosive potential of a given area, granting a better integrated management contribution to the watersheds (Sousa et al., 2016; Lira; Francisco; Feiden, 2022).

The hypothesis of this research is that morphometry influences the land use and land change patterns in the watershed. Thus, this study aimed to analyze the main morphometric characteristics of the Garças river watershed and its use and occupation, aiming to provide elements to assist in a better management, using GIS.

Material and methods

Study area

The study area is the Garças river subbasin, and is located in the Jamari River watershed, in the lower Candeias, Garças, belonging to the municipality of Porto Velho, Rondônia (Figure 1).

According to the Köppen climate classification, the climate that conditions the watershed area is Aw—tropical wet dry climate. The state of Rondônia goes through a dry season, then another longer rainy season during the year, in which rains tend to occur from September to May, which causes a rainfall index exceeding 2,000 mm (Brasil, 1978; Piontkowski, 2014).

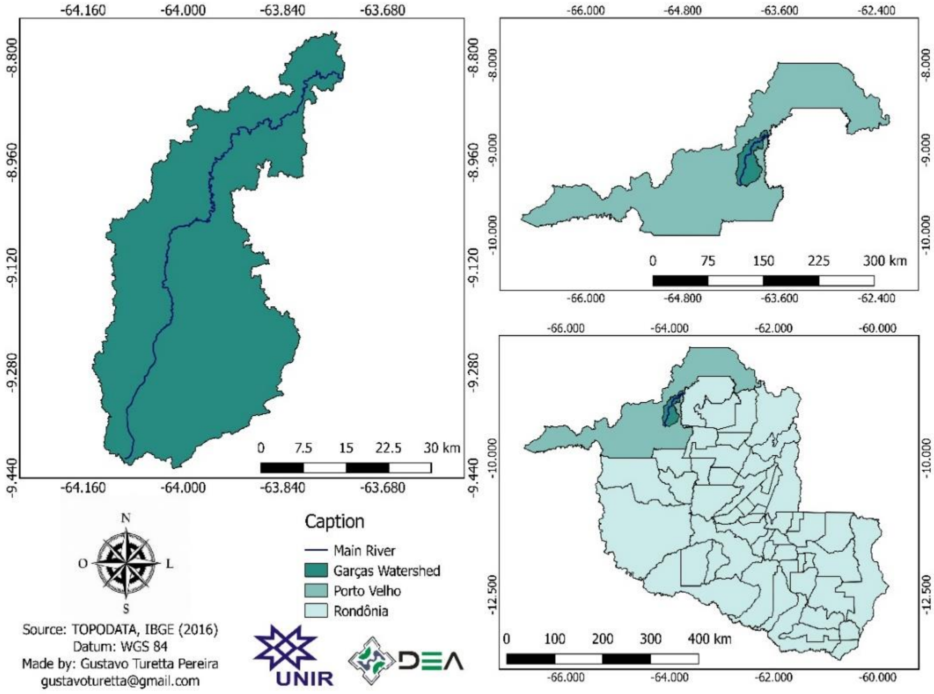

Figure 1. Location map of the Garças river watershed, Porto Velho-RO

General workflow of the research

The research was deployed according to the workflow displayed in Figure 2.

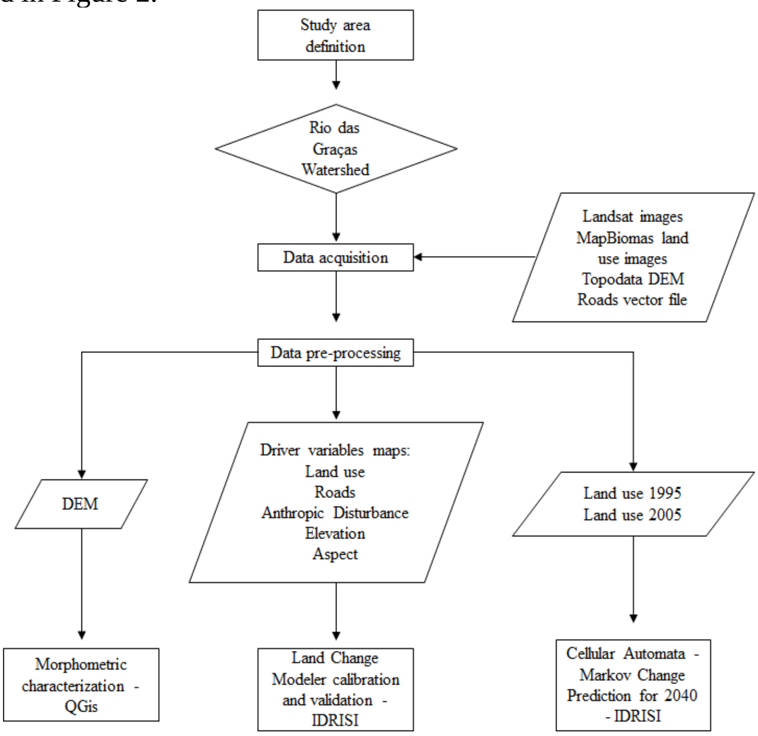

Figure 2. Flowchart with research steps.

Delimitation, morphometric analysis and land use and occupation

Data from the Digital Elevation Model (DEM) with 30 meters resolution used were obtained from the TOPODATA program platform. To delimitate the subbasin, the QGIS 2.18.0 software was used, in which we used the r.watershed and r.water.outlet tools. The Strahler plugin was used to classify the stream order.

For morphometric analysis, the indices described in Table 1 were calculated.

Table 1. Morphometric indices and equations used for calculation. A- Drainage Area; L- length; P- basin perimeter; Lt- total length of call channels (km); Dd- Drainage density.

Variable	Equation	Reference
Form Factor	$F = A \div L^2$	(Villela; Matos, 1975)
Correlation coefficient	$Kc = 0.28P \div \sqrt{A}$	(Tonello et al., 2006)
Circularity Index	$CI = (12.57 \times A) \div p^2$	(Müller, 1953 and Schumm, 1956)
Drainage Density	$Dd = Lt \div A$	(Horton, 1945)
Maintenance Coefficient	$Mc = (1 \div Dd) \times 1000$	(Schumm, 1956)

The watercourses present an order that represents the branching degree of the system corresponding to the watershed drainage (Tucci, 2001). Its determination can be performed according to the criteria of Horton (1945) and Strahler (1957). This study used the classification of Strahler (1957).

The slope of a given passage is said as the height variation between two points, related to the original distance between the points (Mioto, 2014). The intervals for the slope classes to be divided were based on what EMBRAPA (1979) suggested, as in Table 2.

Table 2. Classification of relief according to EMBRAPA (1979)

Slope (%)	Relief
0 – 3	Flat
3 – 8	Soft-wavy
8 – 20	Wavy
20 – 45	Strong-wavy
45 – 75	Mountainous
>75	Strong-mountainous

Source: EMBRAPA (1979)

Land Change Modeler

The land use classification images were deployed by the MapBiomas Brazilian program with 30 meters of spatial resolution. Images were collected for years 1995, 2005 and 2018 (Projeto MapBiomas, 2020).

The Land Change Modeler is a set of tools in IDRISI Selva version 17.2 that enables one to deploy land use and land change analysis in different temporal and territorial scales. In this work it was used to quantify gains and losses for the studied watershed and to deploy a prediction of land use and land change for 2040.

Land Change Modeler is based on a Multi-Layer Perceptron (MLP), a feedforward Artificial Neural Network (ANN), that through a number of iterations composed by interactions between nodes, or elements, creates a web of connections that through a backpropagation algorithm distributes the errors from the outputs to the inputs, training the network (Megahed et al., 2015). The LCM is divided in two steps, the first is the calibration, where an earlier image, t1 and a later image t2 are used to train the ANN. And the validation phase, where the outputs image from the calibration phase is overlaid with the actual image to analyze hits and missing results.

The LCM was calibrated using an image from 1995 as t1, an image from 2005 as t2. The calibration process reached a 98.26% accuracy rate. After calibration, the model was validated by overlaying the 2018 IDRISI's predicted image and the actual MapBiomas' 2018 image. The driver variables used in model calibration, validation and the construction of the transition probability matrix are presented in Table 3.

Table 3. Driver variables characteristics used in the model calibration and validation

Driver Variable	Spatial resolution	Source	Type

Distance to roads	30 meters	DNIT	Static
Elevation	30 meters	Topodata	Static
Aspect	30 meters	Topodata	Static
Distance to anthropic disturbance	30 meters	MapBiomas	Static

The roads driver variable was prepared by importing the vector file in IDRISI, converting to a raster file and calculating the Euclidian distance.

After the validation, the Cellular Automata Markov Land Change Prediction, translated as a tool in IDRISI, was used to predict land use and land change for 2040 (Clark Labs, 2020). This stochastic modelling approach concept is that a certain state of a system can be predicted if the previous state of the system is known. In this sense, the rate of change can be observed in a calibration moment using a prior image t1 and a later image t2, and the prediction, therefore, can be simulated using t2 and t3 (Gibson et al., 2018).

Normalized Difference Vegetation Index

The images used to calculate the Normalized Difference Vegetation Index (NDVI) were obtained free of charge on the INPE online platform, in which the bands used correspond to 4 (red) and 5 (near infrared), both of the Landsat 8 OLI sensor satellite (Operational Land Imager).

Normalized Difference Vegetation Index (NDVI) was calculated to quantify vegetation losses in the watershed. The values range from -1 to 1, with the later meaning dense healthy vegetation. The NDVI was calculated according to the equation proposed by Rouse et al. (1973), described below:

$$NDVI = (NIR - RED) \div (NIR + RED)$$

ØNIR – Wavelength in the near infrared band
ØRED – Wavelength in the red band

Results and discussion

Values for the morphometric indices of the Garças river watershed are described in Table 4.

Table 4. Morphometric characteristics of the watershed, Porto Velho-RO Garças river

Morphometric Characteristics	Results
Area (km²)	1621.10 km²
Perimeter (km)	438,66 km
Length (km)	82.04
Length of the main river (km)	126.73
Form factor	0.24
Conformation index	0.24
Coefficient of compactness	3.05
Form factor	0.24
Conformation index	0.24
Coefficient of compactness	3.05
Circularity index	0.106
Total length of watercourses (km)	935.04
Drainage density (km/km²)	0.57
Maintenance coefficient (km²/km)	1.74
Drainage pattern	Dendritic
Main course order	5
Minimum slope (%)	0.02
Maximum slope (%)	46.16
Maximum altitude (m)	177.80
Minimum altitude (m)	77.80

The watershed under study has conformation and circularity indices, and form factor that, according to Nardini et al. (2013), demonstrate that its shape is elongated, which remotes the area with low propensity to floods. The drainage pattern verified was dendritic.

The drainage density found, according to the watershed environmental interpretation of Nardini et al. (2013), provides low surface runoff and a higher infiltration rate, and, according to the methodology proposed by Strahler (1957), which refers to the waterbody orders, the main watershed watercourse is of fifth order.

The use of morphometric parameters and the slope analysis of a river basin proved to be adequate as a tool in as a tool to assist in decision-making regarding the aspects of use and occupation and adequacy of hydraulic works. Due to the elongated shape of the sub-basin of the Garças River, it is less susceptible to flooding, presenting different concentration times of the various areas of the basin, which generates a distributed hygrogram

Analyzing the slope of the watershed terrain (Figure 3), one can perceive the predominance of the soft relief class according to the classification of (EMBRAPA, 1979), with values between 0.022% and 46.157%, with a higher frequency between 1% and 3%.

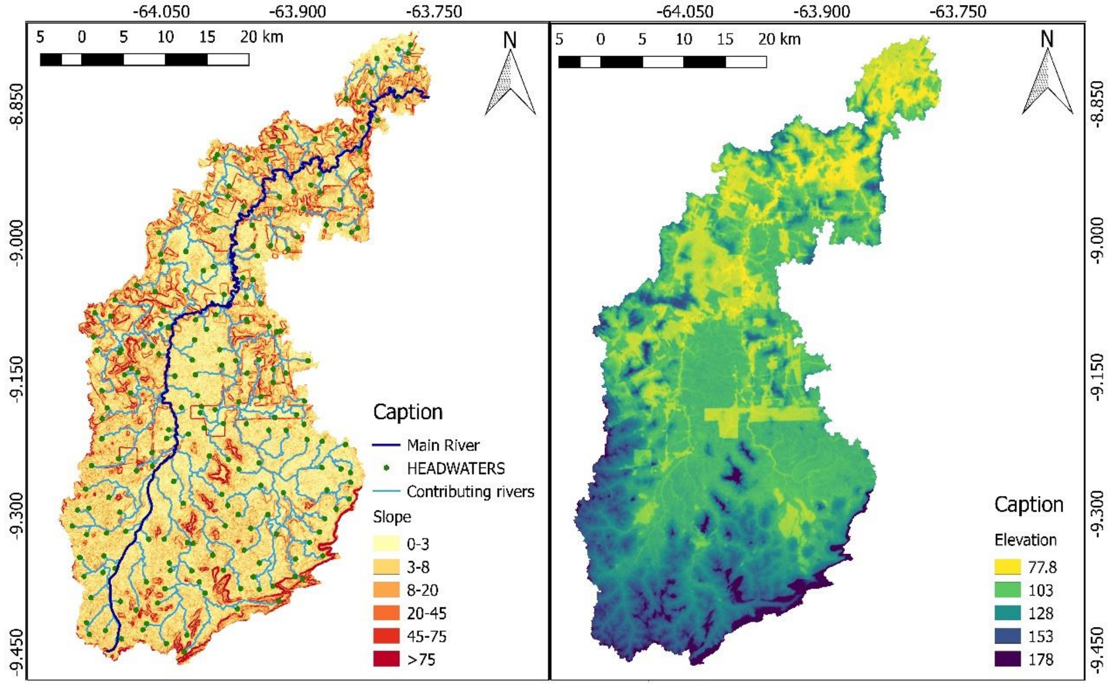

Figure 3. Slope, watercourses (left) and elevation (right) of the Garças river watershed, Porto Velho-RO.

The use of morphometric parameters and the slope analysis of a river basin proved to be adequate as a tool to assist in decision-making regarding the aspects of use and occupation and adequacy of hydraulic works (Cavalcante; Grigio; Diodato, 2021).

Due to the elongated shape of the sub-basin of the Garças River, it is less susceptible to flooding, presenting different concentration times of the various areas of the basin, which generates a distributed hygrogram.

Thus, the physical and morphometric characteristics of the basin are important indicators of its hydrological behavior, and, in this way, their understanding can provide greater efficiency of the interventions that may be carried out in the basin, facilitating its planning and management, in order to minimize environmental impacts and natural disasters (Vale et al., 2021).

However, it is recommended that these parameters be used in conjunction with other parameters, since the response of the components of the hydrological cycle in a management unit depends, in addition to the physical characteristics, on other elements, among which the uses of the basin and edaphic characteristics, hydrography and the local climate stand out. The NDVI presented values between 0.187 and 0.49, corresponding to the analyzed image referring to the dry period. The areas that correspond to the highest values are native vegetation, as the map of use and occupation shows (Figure 4), because it is characterized as having pivoting roots, which allows them to seek water in deeper soils.

In turn, the lowest values are mostly related to pasture areas, which have fasciculate roots. This makes them suffer more from the lack of water in the dry period, emphasizing the importance of vegetation in the basin area (Teramoto et al., 2018; Vale; Da Costa; Da Silva Pimentel, 2021). The values displayed in the histograms allows to identify a reduction in pixel reflectance from 1985 to 2018, from 0.5 to 0.4.

The loss of natural vegetation cover has major impacts over the hydrological cycles. In the specific case of the Garças river watershed, the main type of forest in the watershed is the dense ombrophiles forest, responsible for maintaining, through evapotranspiration processes, the regularity of precipitation. With alterations in the precipitation cycles, several implications can be observed, specially related to water and food security of Amazonian traditional communities (Humphries et al., 2020).

The loss of dense forest cover also implicates in soil loss and further increase of water sedimentation and turbidity, compromising the availability of this resource (Lupinacci; Stefanuto, 2022). Also, this process causes forest fragmentation, one of many threats to the Amazonian biodiversity and genetic flow. The process of deforestation in the Amazon is intimately linked to a pattern of criminal fires, jeopardizing the air quality (Brito et al., 2020).

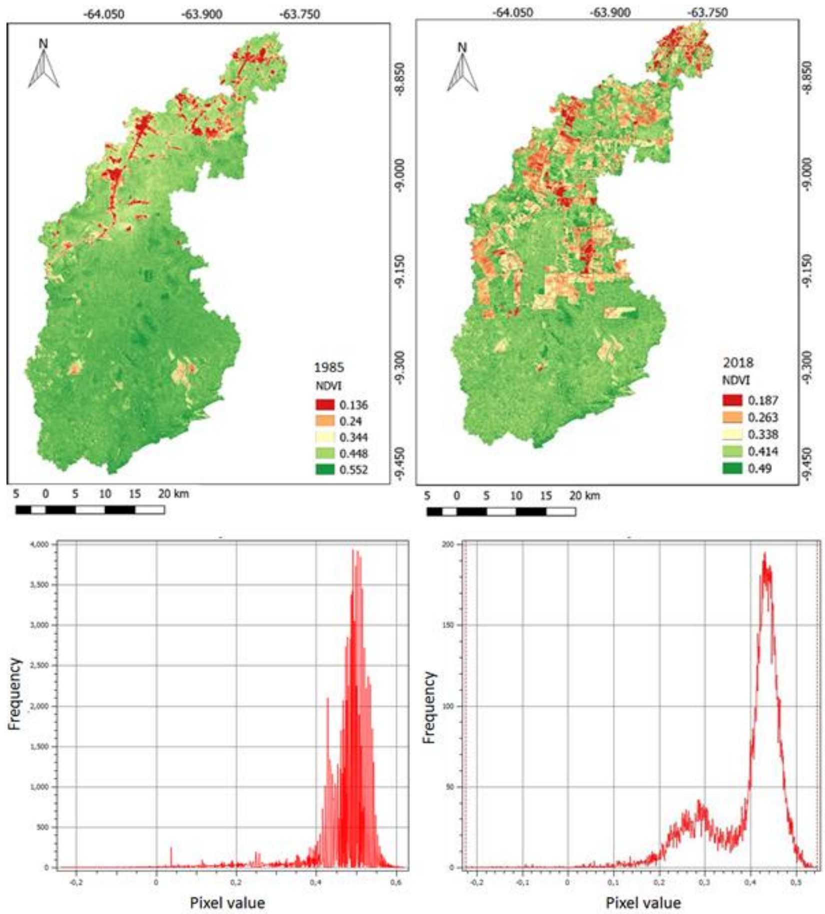

Figure 4. NDVI values for the Garças river watershed, Porto Velho-RO.

Land use and Land Change for the Garças river Watershed

The model used for the prediction was the Markov Chain, which is based on the notion of probabilistic modeling and is widely used in simulations of future changes in land use and occupation. Transitions between time periods are driven by probability matrices that are estimated from previously existing data. The Markov Chain Models seek to follow a simple and intuitive logic and are interesting for forecasting models in the medium and long term.

Figure 5 presents the land use and land change for the study area. It can be noticed a significant increase of pasture and significant reduction of forest cover. This can be explained due to deforestation for livestock production purposes. Urban and agriculture also present increase. The water increase can be explained by the increase in fishing farms.

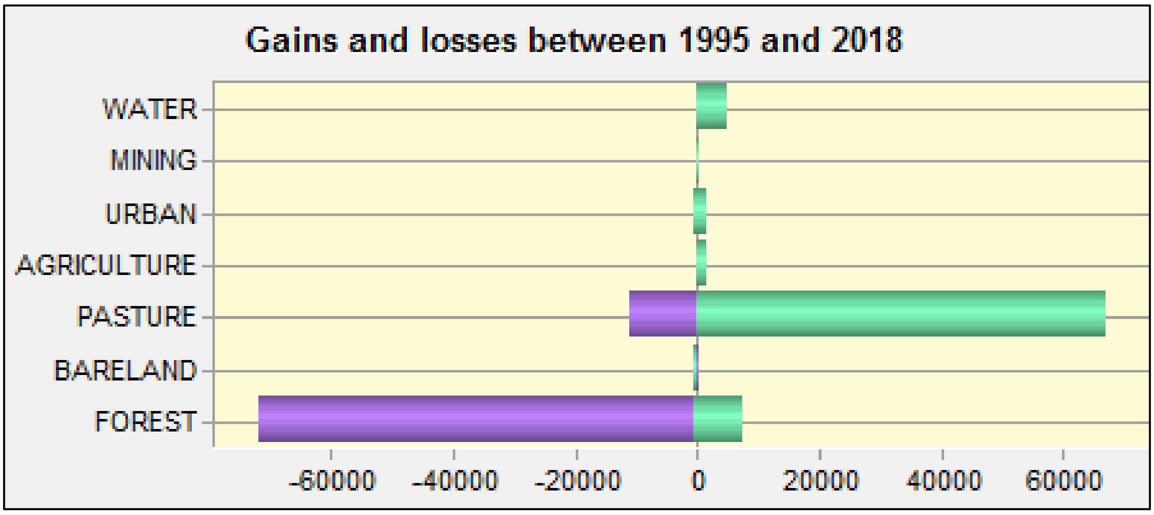

Figure 5. Gains and losses for land use land change for years 1995 to 2018.

The main changes through which the areas forests were affected were for pasture cultivation, this due to intensification of livestock in the basin, being also one of the main economic activities developed in the State. Another important feature is the increase in the "forest-water" transition area, which evidences the occurrence of the discovery of riparian forest areas, thus making the water bodies visible by satellite images and more vulnerable.

It is possible to note that the occurrence of urban settlements and highways in the territory belonging to the basin were essential for the considerable increase in deforestation, as they serve as a gateway, as they facilitate occupation and degradation. The areas with lower altitudes were the ones with the highest occupancy rates, as they are areas that facilitate the transport and spatial distribution of immigrants throughout the territory.

Figure 6 present the main forest conversions to pasture, agriculture and urban, characterizing an increase in anthropogenic disturbances in the watershed.

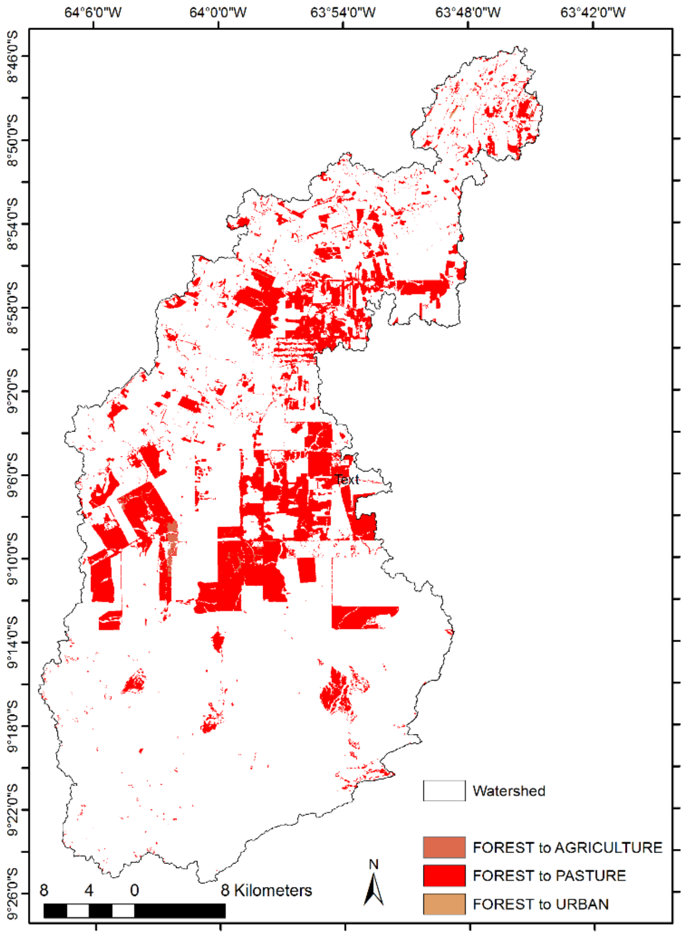

Figure 6. Forest conversion to agriculture, pasture and urban areas from 1995 to 2018.

Integration between technological tools and water resource management

Geosystemic cycles are threatened by society's demands such as: 1. Extensive production and consumption patterns; 2. Unplanned urbanization; and 3. Land use and land change. In many regions of Brazil, surface and groundwater quantity and quality decreased resulting in negative environmental impacts and life quality loss (Mendes et al., 2019). Lack of planning for water exploration and other externalities has increased pressure on water supplies at national, regional and local scale (Fernandes; Collares; Corteletti, 2021). These uses are distributed among activities such as irrigation, energy generation, industry, household purposes, among others (Empinotti; Budds; Aversa, 2019).

Changes in the watershed replenishment patterns, lack of planning and of use regularization create uncertainties for water managers. At the same time, climate change adds a new level of uncertainty regarding the supply of drinking water and the main sectors of water use, such as agriculture, industry and energy (Ruffato-Ferreira, 2017). Change in the quality and quantity of water available projections become increasingly uncertain and scarcity increases continuously (Pereira et al., 2021). Companies have found themselves in situations in which they are more vulnerable to a wide range of risks associated with inadequate water supply in quantity and/or quality (Galdino et al., 2016).

The use of GIS is key to the management of water resources (Folhes; Rennó; Soares, 2009). Still, hydrological models are fundamental tools for the sustainable planning of the demand for water resources (Vale; Da Costa; Da Silva Pimentel, 2021). The integration of these technologies brings great benefits in terms of monetary cost and time. Hydrological indicators are an alternative to understand the physical and climatological aspects of watersheds (Bressiani et al., 2015).

The integration of technologies to assess and deploy policies, plans and programs are key strategies to tackle society's conflicts. As a response to these demands, Brazil's environmental policy is composed by several acts. However, the applicators of these policies have found it difficult to operationalize their management instruments, such as the lack of human resources, of polítical interest, and of financial resources. The instruments are also centrally applied in large industrial centers; in the case of this study area, where the main activities are in agriculture and livestock farming, a deficit in the application of these environmental policy instruments is seen.

In this context, the use of GIS allows the creation of geographic databases filled with qualitative and quantitative information that are key to decision making. As shown by this manuscript, this method may potentially be replicated to other basins, aggregating even more information, facilitating storage, search, processing and integrated analysis of data. For example, assisting watershed committees.

Regarding aspects of environmental management focused on water resources, the Brazilian Environment Policy (PNMA), Law No. 6,938/1981 is a legal framework in which the country's re-democratization on environmental issues began to occur. Sometime later, the so-called Water Law No. 9,433/97 was created, which is the National Water Resources Policy (PNRH). This, in turn, has several instruments, which are set out in the Article below:

Art. 5 The instruments of the National Water Resources Policy are:

I – Water Resource Plans;

II – The framing of water bodies in classes, according to the predominant water uses;

III – The granting of rights to use water resources;

IV – The charge to use water resources;

V – Compensation to municipalities;

VI – The Water Resources Information System.

The Watershed Committees use these instruments and bring society closer to decision making, being able to express the aspect of several sectors.

The state laws, after January 1997, were based on the well-known Water Law, Federal Law No. 9,433/1997, which has foundations related to sustainability, thus being progressively set up management and operation systems. With this in mind, numerous Brazilian states are providing mechanisms for water resource management, which includes the Watershed Committees of state rivers (Zuffo e Abreu, 2010).

Because of this, the Watershed Committees formation and functioning are highly important from the viewpoint of participatory management, since the Federal Law establishes that among its duties are: to promote debates on the actions with which water resources are related, articulating the actions of intermediary entities; in administrative sphere, to arbitrate, in relation to conflicts in which water resources may be involved; to approve the Water Resources Plan of the watershed; to suggest measures to meet the goals set out in the Water Resources Plan; to stipulate charge amounts to use the resource and also establish charge mechanisms (Zuffo e Abreu, 2010).

Jamari River Watershed Committee (CBH-JAMARI-RO), to which the Garças watershed is inserted, was established by the Human Resources Coordination of Rondônia (CRH/RO) Resolution No. 5 of June 11, 2014.

According to the notorious social participation together with Acqua Viva Rede UNIR, considering the results, the process of Watershed Committees implementation should be carried out gradually, according to the stages described by (Zuffo e Abreu, 2010), which should go from the initial mobilization to the management of the Hydrographic Basin Committees (CBHs).

The Jamari-RO watershed is now considerably harmed due to occupation and use of water for various purposes, such as power generation, navigation, recreation, industries, mining, animal thirst-quenching, among others. This is a worrisome situation and therefore the rational use of this resource and the creation of watershed committees are requested. In this context, Acqua Viva Rede UNIR corroborates with several dissemination centers that operate in the Jamari Watershed. At the end of the 1990s, an attempt was made to form an intermunicipal consortium in the watershed, with resources belonging to a government project, but it was unsuccessful due to the commitment of some authorities and involvement of the population.

Thus, data from the Garças river watershed demonstrated the importance of characterizing a watershed, because with it, its multiple uses can be managed, the implementation of basic sanitation services and the urbanization process of the intersection areas of urban perimeter and basin area can be planned.

Almeida Sobrinho (2006) emphasizes the importance of this water resource in the region for the population’s quality of life, mainly traditional communities, small farmers and ribeirinhos (people who live in the riparian area), as it acts directly with the regional economy, serving as source for supply, consumption, sand production, irrigation, having an important role for society.

With this, we see how geoprocessing tools can be of great help as a technology to process gross data, being able to provide a wide range of information in a simple way, which gives the possibility of working with free software, reconciling the cost-benefit theme, and being a rich tool capable of assisting in data understanding, serving as a means for decision making, being remarkable for the management of watersheds.

Final considerations

According to the assessed data, the watershed has a low susceptibility to floods, due to the factors related to its elongated shape, which contributes to a longer period of water movement from its headwaters to delta.

Regarding the use and occupation and vegetation cover, it has a considerable area of natural vegetation, especially due to the presence of conservation units in its territorial limits, which is important for water maintenance in the watershed.

Knowledge of such aspects of a watershed is of paramount importance for its better management. In the study, we can also see the applicability of the remote sensing tool for studies in this area, because it allows an agile data collection and a visual analysis that enables an easier discussion of the results, and may be highly important, for example, to provide information that supports decision making by the watershed committees.

References

“Projeto MapBiomas – Coleção [4.1] da Série Anual de Mapas de Cobertura e Uso de Solo do Brasil, acessado em [19/02/2020] através do link: [http://mapbiomas.org]"

Almeida Sobrinho, A. Sub-bacia hidrográfica do baixo Rio Candeias e a viabilidade da piscicultura em tanques-rede. Porto Velho, RO: UNIR, 2006. Dissertação (Mestrado em Desenvolvimento Regional e meio ambiente), Universidade Federal de Rondônia.

Antonelli, V; Thomaz, E.L, 2007. Caracterização do meio físico da bacia do Arroio Boa Vista, Guamiranga-PR. Rev. Caminhos da Geografia, 8,.46-58.

Brasil. Departamento Nacional de Produção Mineral. Projeto RADAMBRASIL. Levantamento de recursos naturais. Rio de Janeiro; 1978.

Bressiani, D.A., Gassman, P. W., Fernandes, J. G., Garbossa, L. H. P., Srinivasan, R., Bonumá, N. B., & Mendiondo, E. M., 2015 (2015). Review of soil and water assessment tool (SWAT) applications in Brazil: challenges and prospects. International Journal of Agricultural and Biological Engineering, 8, 9-35.

Brito, Janaina G. et al, 2020. Small forest losses degrade stream macroinvertebrate assemblages in the eastern Brazilian Amazon. Biological Conservation, 241, 108263.

Cavalcante, A. E. Q. M.; Grigio, Alfredo Marcelo; Diodato, Marco Antônio, 2021 Morfometria e diagnóstico físico conservacionista (dfc) em 19 sub-bacias da bacia hidrográfica Apodi Mossoró. Revista Brasileira de Geografia Física, 14, 3891-3909.

Clark Labs. TERRSET SOFTWARE. 2020.

Silva, E. L. P., Xavier, A. P. C., Da Silva, R. M., & Santos, C. A. G. (2020). Modeling land cover change based on an artificial neural network for a semiarid river basin in northeastern Brazil. Global Ecology and Conservation, 21, e00811.

Empinotti, Vanessa Lucena; BUDDS, Jessica, 2019 AVERSA, Marcelo. Governance and water security: The role of the water institutional framework in the 2013–15 water crisis in São Paulo, Brazil. Geoforum, 98, 46-54.

Empresa Brasileira de Pesquisa Agropecuária – EMBRAPA. Serviço Nacional de Levantamento e Conservação de Solos. Súmula da 10. Reunião Técnica de Levantamento de Solos. Rio de Janeiro, 1979. 83p.

Fernandes, Fernanda De Moura; Collares, Gilberto Loguercio; Corteletti, Rafael, 2021 A água como elemento de integração transfronteiriça: o caso da Bacia Hidrográfica Mirim-São Gonçalo. Estudos Avançados, 35, 59-77.

Ferreira, C. C. M. Zoneamento agroclimático para implantação de sistemas agroflorestais com eucaliptos em Minas Gerais. 158p. 1997. Tese de Doutorado. Dissertação (Mestrado em Meteorologia Agrícola) -Universidade Federal de Viçosa, Viçosa, MG.

Folhes, M. T.; Rennó, C. D.; Soares, J. V, 2009. Remote sensing for irrigation water management in the semi-arid Northeast of Brazil. Agricultural Water Management, 96, 1398-1408.

Galdino, S.; Sano, E. E.; Andrade, R. G.; Grego, C. R.; Nogueira, S. F.; Bragantini, C.; Flosi, A. H, 2016. Large-scale modeling of soil erosion with RUSLE for conservationist planning of degraded cultivated Brazilian pastures. Land degradation & development, 27, 773-784

Gibson, Lesley et al, 2018. Future land cover change scenarios in South African grasslands–implications of altered biophysical drivers on land management. Heliyon, 4, 00693.

Horton, R.E, 1945. Erosional development of streams and their drainage basins: hidrophysical approach to quantitative morphology.

Geological Society of America Bulletin, 56, 807-813.

Humphries, Shoana et al, 2020. Searching for win-win forest outcomes: learning-by-doing, financial viability, and income growth for a community-based forest management cooperative in the Brazilian Amazon. World Development, 125, 104336.

Jesus, Cleiton Soares; Berezuk, André Geraldo; Medeiros, Rafael Brugnolli, 2021 Morfometria da rede de drenagem da Unidade de Planejamento e Gerenciamento Iguatemi, Mato Grosso do Sul/Brasil. Revista Entre-Lugar, 12, 63-81.

Koppen, W. 1931. Grundriss der Klimakunde. 2 ed. W. de Gruytu, Berlin.

Lira, Karen Carrilho Da Silva; Francisco, Humberto Rodrigues; Feiden, Aldi, 2022. Classificação de fragilidade ambiental em bacia hidrográfica usando lógica Fuzzy e método AHP. Sociedade & Natureza, 34.

Lupinacci, Higor Lourenzoni Bonzanini¹ Cenira Maria; Stefanuto, Estêvão Botura, 2022. A Erosão linear e sua relação com a morfometria do relevo na alta Bacia do Rio Capivara–Botucatu (SP). Revista Brasileira de Geografia Física, 15, 1947-1964.

Megahed, Y., Cabral, P., Silva, J., Caetano, M, 2015 Land cover mapping analysis and urban growth modelling using remote sensing techniques in Greater Cairo Region-Egypt. ISPRS Int. J. Geo Inf. 4, 1750 - 1769.

Mendes, A., Galvão, P., De Sousa, J., Da Silva, I., & Carneiro, R. N, 2019. Relations of the groundwater quality and disorderly occupation in an Amazon low-income neighborhood developed over a former dump area, Santarém/PA, Brazil. Environment, Development and Sustainability, 21, 353-368.

Mioto, Camila Leonardo et al 2014. Morfometria de Bacias Hidrográficas Através de SIGs Livres e Gratuitos. Anuário do Instituto de Geociências - UFRJ. ISSN 0101-9759 e-ISSN 1982-3908 37 - 2 /22.

Müller, V.C, 1953 A quantitative geomorphology study of drainage basin characteristic in the Clinch Mountain Area. New York: Virginia and Tennesse. Dept. of Geology. 30.

Nardini, Rafael Calore et al, 2013 Análise morfométrica e simulação das áreas de preservação permanente de uma bacia hidrográfica. Irriga, p. 687-699.

Pereira, M. C S. et al, 2021 Melhoria da qualidade da água de rios urbanos: novos paradigmas a explorar–Bacia hidrográfica do rio Pinheiros em São Paulo. Engenharia Sanitaria e Ambiental, 26, 577-590.

Piontkowski, Valderli Jorge et al 2014. Avaliação do desmatamento no estado de Rondônia entre 2001 e 2011. Floresta e Ambiente, Seropédica, 21, 297-306, jul./set..

Rennó, Camilo Daleles. Construção de um sistema de análise e simulação hidrológica: aplicação a bacias hidrográficas. 2004. Tese de Doutorado. Tese de Doutoramento, Instituto Nacional de Pesquisas Espaciais, INPE, 148p.

Ribeiro, M. E. et al, 2021 Análise de Séries Hidrológicas na Bacia Hidrográfica afluente à Usina Hidrelétrica Castro Alves, RS. Revista Brasileira de Geografia Física [online], 14.

Rouse, J.W.; Haas, R.H.; Schell, J.A.; Deering, D.W. , 1973 Monitoring vegetation systems in the great plains with ERTS. In: Third ERTS Symposium, Proceedings, NASA SP-351, NASA, Washignton, DC,1, p. 309-317.

Ruffato-Ferreira, V., Da Costa Barreto, R., Júnior, A. O., Silva, W. L., De Berrêdo Viana, D., DO Nascimento, J. A. S., & De Freitas, M. A. V, 2017 A foundation for the strategic long-term planning of the renewable energy sector in Brazil: hydroelectricity and wind energy in the face of climate change scenarios. Renewable and Sustainable Energy Reviews, 72, 1124-1137.

Schumm, S.A, 1956. Evolution of drainage systems and slopes in badlands of Perth Amboy. Geological Society of America Bulletin, 67, 597-646.

Siegmund-Schultze, Marianna et al 2015. Paternalism or participatory governance? Efforts and obstacles in implementing the Brazilian water policy in a large watershed. Land Use Policy, 48, 120-130,

Soares, Leonardo Silva et al, 2016. Análise morfométrica e priorização de bacias hidrográficas como instrumento de planejamento ambiental integrado. Revista do Departamento de Geografia, 31, 82-100.

Sousa, N. C. F.; Gazola, H. Q. G. B.;Alves, E. R. S.; Silva, O. B, 2016.. Análise físico-química e bacteriológica de coliformes totais e termotolerantes da água de consumo distribuída aos alunos de 3 creches privadas do setor leste da cidade de Porto Velho – Rondônia. Saber Científico, Porto Velho, 5, p. 24–32.

Stabile, Marcelo CC et al, 2020 Solving Brazil's land use puzzle: Increasing production and slowing Amazon deforestation. Land Use Policy, v. 91, p. 104362.

Strahler, A.N. Quantitative analysis of watershed geomorphology. Transaction of American Geophysical Union, p. 913-920, 1957.

Teramoto, Elias Hideo et al, 2018 Séries temporais do índice NDVI na avaliação do comportamento sazonal do Aquífero Rio Claro. Revista Brasileira de Cartografia, 70, 1135-1157.

Tonello, K. C.; Dias, H. C. T.; Souza, A. L.; Ribeiro, C. A. A. S.; Leite, F. P, 2006 Morfometria da bacia hidrográfica da Cachoeira das Pombas, Guanhães – MG. Revista Árvore, 30,.849-857.

Tucci, C.E.M. Hidrologia: ciência e aplicação. Porto Alegre: UFRGS/Edusp/ABRH, 2001. 943p.

Vale, J R., B.; C., Letícia Soares; Da Silva P., M., A., 2021. Análise da morfometria e do uso e cobertura da terra da bacia hidrográfica do rio Mocajuba, zona costeira amazônica.Geosul, 36, . 537-557.

Villela, S. M.; Mattos, A. Hidrologia aplicada. São Paulo: McGraw-Hill, 1975, p.245

Yassuda, Eduardo Riomey, 1993. Gestão de recursos hídricos: fundamentos e aspectos institucionais. Revista de Administração pública, 27, 5-18.

Zuffo, C. E., Abreu, F. A. M, 2010. Gestão participativa das águas em Rondônia: ações e propostas para a formação dos comitês de bacias hidrográficas. Revista Formação, , 2 – p. 43-62.