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Dynamics of Land Use and Scenario Simulation in the Alto Batalha Watershed, Brazil

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Abstract: The study of the dynamics of land use and the prediction of a future scenario may help in decision-making in land-use management. The computational tools for Geoprocessing, called Geographic Information Systems (GIS), allow future land-use scenarios simulation based on past information plans. The objective of this paper was to model the land use of the Alto Batalha watershed in the years 1987, 2000, and 2015, and simulate a scenario for 2030. To this end, we used the Land Change Modeler (LCM), Markov chain and Cellular Automata. The primary results were the identification of the main changes of land use from the data of gains, losses, and persistence. Results concluded that the elaboration of a future scenario for the year 2030 made it possible to identify the reduction and expansion trends of land use classes based on the probability matrix and land-use map from 2015. The temporal analysis from 1987 to 2000 and from 2000 to 2015 has enabled a better understanding of the environmental pressures on natural areas that have led to the degradation of water resources in the Upper Battle watershed.

Key words: GIS, watershed, remote sensing, space-time evaluation

1. Introduction

The increasing demand for natural resources has been very intense in the last years, negatively impacting on the environment. The inadequate use of the soil due to incompatible practices, such as the substitution of the vegetation remainders for plantations that are usually monocultures and the intensive use of agrochemicals added to the fast and disordered urban expansion and the eviction of sewages and solid waste in inappropriate locals drastically affect the hydrographic basins. These factors intensify the problems related to the water resources and, consequently, to the public water supply.

The concern about the change of vegetation cover and the use of soil has been overgrowing since the way these two factors are manipulated influence directly the human way of life.

The availability of water from a hydrographic basin is strongly influenced by the soil use and management, and its quality and amount may be modified by the presence or absence of vegetation cover [1].

According to D. D. Silva et al. (2005) [2], the vegetation cover conserves the water supply and avoids the loss of soil and nutrients. The explanation may be the action of the cover on dissipating the kinetic energy from the direct impact of the raindrop over the surface, decreasing the initial disintegration of soil particles and, consequently, the sediment concentration in flood. Besides, the vegetation cover represents a mechanical obstacle to the free water surface drainage, causing the decrease of speed and capacity of disintegration and sediment transport.

N. M. M. Donadio, J. A. Galbiatti, and R. C. Paula (2005) [3] evaluated the influence of remaining natural vegetation and agricultural activities on the water

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quality of four springs and concluded that the sampling periods, as well as the characteristics of the soil and its different uses, influence on the watershed water quality.

The Paulista populations, both from the capital city and from several other regions of the state have been recently affected by an intense water crisis. According to the Bauru Water and Sewage Department [4] which represents about 40% of the population supplied by the Batalha River, during the months of crisis, the level of the catchment pond was below half of the normal volume that is 2.60 m. Due to this low level, the capture was insufficient to take water to the highest regions of the city, leaving many users without access to the service.

The recent and quick development of the GIS and the remote sensing technology has contributed to the evolution of the environmental and soil sciences, and it facilitates the interrelation between them. As W. Baker (1992) [5] stated new techniques in any scientific field are not relevant by themselves, but for permitting new discoveries that stimulate scientific progress.

Also, these techniques are indispensable for analyzing the temporal changes of soil use and soil cover and provide the planner with relevant information related to the occupancy of a particular territory. The employment of mathematical models contributes to a better understanding of the changing process in the land use and land cover and helps to predict future alterations, which will generate scientific contributions to the ordered planning of an area [6].

The simulation can predict probable events in a given region according to its peculiarities and simulate future scenarios. In this regard, the purpose of Dynamic Modelling is to simulate spatial-temporal changes linked to a region, which permits an understanding of the variables that influence that change to obtain a view of the landscape evolution [7].

The Land Change Modeler (LCM) falls into this since it is a module that belongs to the SIG IDRISI Selva, which allows the evaluation and design of changes on land cover and implications for species, habitats, and biodiversity. LCM shows a fixed structure that divides modelling into stages such as the analysis of changes in land cover, the calculation of transition potentials, the simulation of future changes, as well as tools to evaluate planned interventions on land cover and impacts on biodiversity [8].

A. A. C. Sartori, V. D. P. Polonio, R. N. Argentin, and C. R. L. Zimback (2013) [9] identified the processes of changes in land use and land occupation by multitemporal analysis, data on the gain, loss, and persistence of land-use classes within the years studied, which allowed the identification of the main changes, regarding quantity and spatial distribution. In this aspect, the module Land Change Modeler (LCM) had a potential for processes of prediction concerning changes on soil use and occupation.

Therefore, the objective of this study was to conduct the land use modelling in 1987, 2000, and 2015 and the simulation of a scenario for 2030 in the landscape of the Alto Batalha watershed.

2. Material and Methods

The Alto Batalha watershed is located in the State of São Paulo geographic center, between the parallels 22°20′ and 22°30′ South and the meridians 49°00′ and 49°10′ WG. It has an approximate area of 14654.6 ha, covering the territory of the cities of Agudos, Bauru, and Piratininga (Fig. 1).

To cover the Alto Batalha watershed, we used spectral images of the American satellite Landsat 5 and 8; the images were located in the 221 orbit and 75 and 76 spots.

2.1 Land Use (1987, 2000, and 2015)

The procedure in the elaboration of the land use information plan followed these steps: image registration, contrast enhancement, and land-use classification on screen, field work/aerial photograph, and final classification. Image registration: the image georeferencing consisted of a geometric transformation which associated the image coordinates (lines and columns) with coordinates of the reference system used, in this case, the Universe Transverse Mercator (UTM) coordinate system, with the Datum SIRGAS 2000. Contrast enhancement:

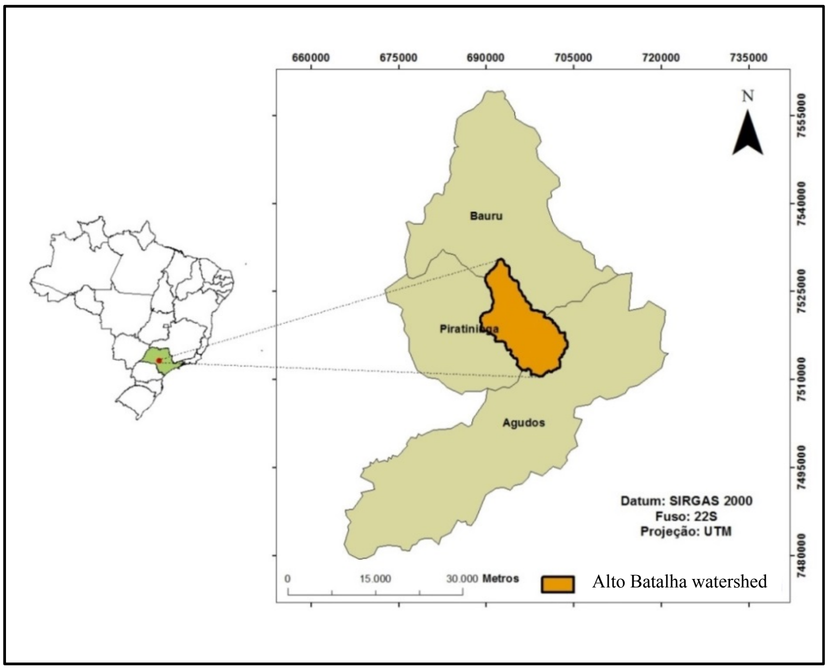

Fig. 1 Illustrates the studied area regarding the State of São Paulo and the cities of Agudos, Piratininga, and Bauru. All the information plans were designed in UTM coordinates Datum SIRGAS 2000, Time Zone 22 South.

RGBs of the land-use maps were generated (1987, 2000 and 2015). Thus, we studied the interpretation keys that explain the best combinations of spectral bands to reach a better visual interpretation. Classification: the polygons were digitalized in particular areas to characterize the different types of land-use in satellite images. Land-use maps were created from the screen classification, avoiding the mixture of pixels spectral responses. Fieldwork/aerial photograph: to classify the 2015 image, we conducted fieldworks and took aerial photographs during a helicopter flight over the Alto Batalha watershed. The aim was to check if the generated information was consistent with reality. Final classification: drawing of 1987, 2000, and 2015 land-use thematic maps.

2.2 Land-Use Change Modeling

After the land-use maps had been drawn in a vector format through the visual interpretation of satellite images from Landsat 5 and 8, they were transformed into raster and inserted in the module Land Change Modeler (LCM) of the IDRISI Selva software. The results were generated in charts and maps allowing the analysis of the dynamics of the different classes of land-use in gains, losses, and persistence between the two periods studied, which allowed identifying changes in land-use regarding quantity and spatial distribution.

2.3 Land-Use Predictions Based on MARKOV Chains and CELLULAR AUTOMATA

To predict a future scenario, we applied the Environment Simulation module of the IDRISI Selva software, which was a useful tool to simulate the dynamics of the different use classes. The prediction was based on the stochastic projection through MARKOV chains and CELLULAR AUTOMATA.

2.3.1 MARKOV Chains

The MARKOV chain analysis demonstrated the future state of a system based on previous states. This analysis described the change of land use from one period to another and used this information as a basis for projecting future changes by developing a land-use transition probability matrix. The negative point of this analysis was the non-generation of any geographical sense, i.e., there is no spatial component in the result of the simulation.

The MARKOV module of the IDRISI SELVA was applied using the land-use map from 1987 (old) and 2015 (current). We specified the period in years from one image to another (28 years) and also for the period for future projection (15 years). After, we assigned 0.0 for the background cells and a proportional error of 0.15 (which is typical for most land-use maps that are 85% accurate).

The transition probability matrix was generated. This matrix registers the probability that each land-use category will change for all other categories. It is the result of the cross tabulation of two images adjusted by the proportional error.

2.3.2 MARKOV Chains and CELLULAR AUTOMATA

The MARKOV chains and the CELLULAR AUTOMATA are among techniques that can be linked and provide spatial relationships. As previously stated, the MARKOV chains are mathematical data, which provide the rules that operate the cellular automata.

The CELLULAR AUTOMATA is an agent or object that can modify its state based on the application of a rule that associates the new state with its previous state and the states of neighboring cells.

For the spatial component, we used the CA_MARKOV module of the IDRISI SELVA, which used as an input the 2015 land-use map and the Probability Matrix of changes. To determine the transition of the pixels considering the neighboring state, we used a 5×5 filter so that the future state of the central pixel is influenced by the current state of the neighboring 24 pixels. The future scenario was designed for 15 years, resulting in the land-use for the year 2030.

3. Results and Discussion

3.1 Land-Use: Analysis of Changes between 1987 and 2000

The elaboration of land-use maps from 1987, 2000, and 2015 allowed us to establish a comparison among the studied years to detect the main changes of use. It was possible to model the classes of use in losses, gains and persistence. The result of the modelling 1987 and 2000 is in Table 1.

Table 1 Land-use gain, loss, and persistence analysis in the years 1987 and 2000.

Use Class	Area 1987 (ha)	Area 2000 (ha)	Gain	Losses	Persistence
Urban Area	243.05	322.29	125.0	45.76	197.29
Forest	4151.08	3944.43	876.35	1083.0	3068.07
Pasture	9469.11	9471.31	1572.5	1570.3	7898.7
Agriculture	657.5	785.72	707.15	578.92	78.57
Roads	43.91	40.89	17.54	20.56	23.34
Total	14564.65	14564.64	3298.54	3298.54	11265.97

It was possible to verify the predominance of the pasture in the two periods, the advance of the urban area, the reduction of the forest areas and the increase of the changes in agricultural areas. The pasture is predominant in the watershed in different management forms and different levels of degradation and/or regeneration, in 1987 this class occupied 9,969.1 ha, in 2000 it obtained a small increase and began to occupy 9,471.3 ha. Brazil has approximately 180 million hectares of pasture, of which more than half is at some stage of degradation, a good part of which is already at an advanced stage [10]. The data of gains, losses and persistence in pasture show that a large portion persisted, gains and losses were close, that is, losses were compensated in new places in the watershed.

The urban area in 1987 occupied 243 ha, in 2000, it occupied 322.2 ha. The registered growth was 32.5% in relation to the urban area existing in the year 1987. The population growth of the period helps to confirm the observed territorial expansion, the population of Bauru city in 1987 was 234,234 residents, in 2000 that number increased to 316,064, i.e., the city had a population increase of approximately 34.9% [11].

From the data losses, gains and persistence was observed that the area occupied by agriculture in 1987, only 78.5 ha persisted, totalling a loss of 578.92 ha and a gain of 707.15 ha, as it was possible note that agriculture has to be practiced in new areas, showing a great dynamic in the study area.

With the expansion of urban, pasture and agriculture use classes, the class called native forest, riparian forest and floodplain areas (forest) were reduced from 4151.1 ha in 1987 to 3944.4 ha in 2000. To better illustrate this dynamics, Fig. 2 shows the locations where gains, losses and persistence occurred.

From the class native forest modelling for the period 1987-2000, it was possible to note that the main losses and gains occurred in areas close to water bodies, i.e., Permanent Preservation Areas (PPA's). As a result there was uncontrolled deforestation of native vegetation in a watershed, regardless of its size; it can cause negative impacts on local and regional water resources [12].

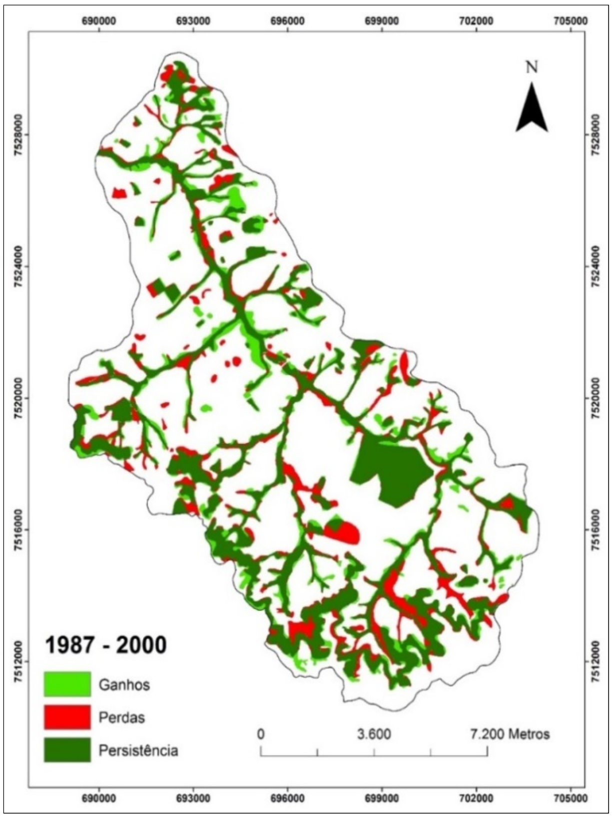

Fig. 2 Losses, gains, and persistence of the forest class between the years 1987 and 2000 in Alto Batalha watershed.

3.2 Land-Use: Analysis of Changes between 2000 and 2015

Analyzing land use dynamics in 2000 and 2015 (Table 2), it was possible to see the progress of the urban, the reduction in pasture areas, increasing areas of forest, agriculture and roads.

Table 2 Land-use gain, loss, and persistence analysis in the years 2000 and 2015.

Use Class	Area 2000 (ha)	Area 2015 (ha)	Gain	Losses	Persistence
Urban Area	322.29	674.55	377.66	25.4	296.88
Forest	3944.43	4649.65	1351.24	646.02	3298.4
Pasture	9471.31	7309.93	782.04	2943.42	6527.88
Agriculture	785.72	1853.36	1404.03	336.39	449.33
Roads	40.89	77.15	53.37	17.11	23.78
Total	14564.64	14564.64	3968.34	3968.34	10596.27

We can see the great advance in urban area for the study period was 322.2 to 674.5 ha, so the increase was more than double (109.34%). Unlike 1987 and 2000, the reason is not due to population growth. From 2000 to 2015 was predicted growth of 16.11%, from 316.064 inhabitants in 2000 to 366.992 inhabitants in 2015 [13]. The main reasons for the growth of real estate sector witnessed in recent years, especially since the year

2005 are: changes in legislation regarding the mortgage, the stability of prices, the drop in interest rate, the expansion of directed credit, the expected future appreciation of property prices after a long period of stagnation. [14].

In agriculture class was great expansion in 2000 this class occupied 785.72 ha, after 15 years, increased by 135.8%. Observing the dynamics of land use in losses, gains and persistence the study period (2000-2015) the gains values show that agriculture was expanding into new areas. This increase occurred mainly in the initial part of the watershed, where much of its agricultural land is cultivated with eucalyptus and pine reforestation, due to the demand of local industries.

The native forest class showed an increase of 17.87% in the period. The loss was exceeded by gains and persistence, thereby obtaining a positive balance. The increase can be explained mainly by reforestation projects in Permanent Preservation Areas (PPA), funded by the State Water Resources Fund (FEHIDRO). Altogether it has been performed seven FEHIDRO projects in the study area and are currently ongoing four projects, two by FEHIDRO, one by the National Water Agency (NWA) and a project signed with the Environmental Company of the State of São Paulo - to compliance with Environmental Recovery Commitment Agreement (ERCA) [15].

The dynamics of occupation of native forest class is present in Fig. 3. It's possible to spatially verify the main changes in losses, gains and persistence. It was possible to verify that the gains occurred mainly in the areas near the water courses (Permanent Preservation Areas - PPA) and more expressively in the initial part of the watershed, where it is the source of the Batalha river, a region that was prioritized with a reforestation project. The losses had a higher incidence in the cities of Bauru (SP) and Paratinga (SP), the largest occurring disorders in areas of native vegetation near the water courses and in isolated fragments, since the persistence was mainly courses (Permanent Preservation Areas (PPA)).

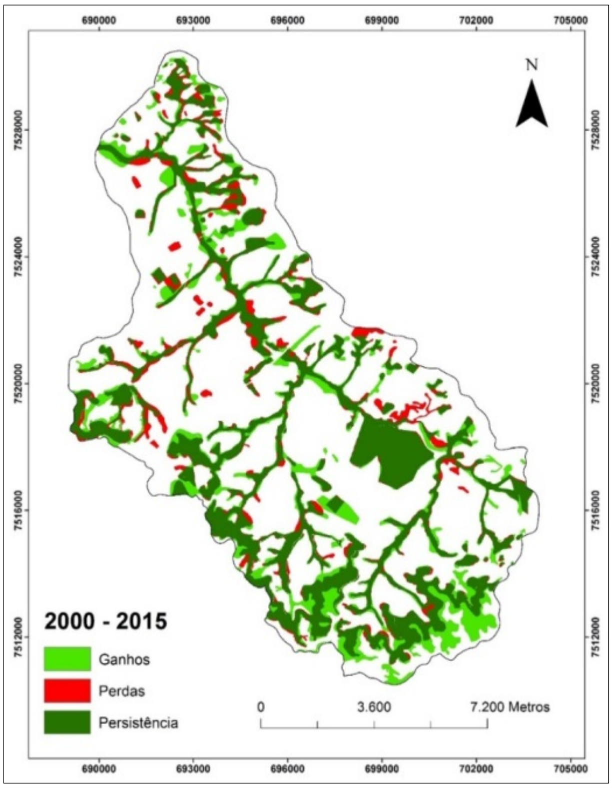

Fig. 3 Losses, gains, and persistence of the forest class between the years 2000 and 2015 in Alto Batalha watershed.

3.3 Prediction of Land-Use for the Year 2030

The prediction of the land use future scenery was based on the Markov chain, using as input data the land-use between the years of 1987 and 2015, with five classes of use. The result was the transition probability matrix (Table 3).

This matrix represents the probability of a particular use class to remain the same. Diagonally, we observe the real probability of classes not suffering transformations.

The transition probability matrix and the information plan of land-use from 2015 allowed us to determinate the prediction for the year 2030 (15 years), using the Markov chain and the cellular automata. The result obtained for land-use from 1987, 2000, and 2015 and the prediction for 2030, it was generated a graphic (Fig. 4) in lines to verify the classes' performance during the study period.

Analyzing the information in Table 3, it was observed that, among the other classes, after the road class, the forest has a greater probability of not being modified, with a probability of approximately 73% of remaining in the same class. The probability of this class to become an urban area is 24.72%, which in practice normally occurs.

According to P. R. Ribas (2015) [16], this finding is pertinent to the reality that has been occurring in several parts of Brazil, where areas with vegetation cover have been decimated to give space to urban areas and different types of cultures related to an anthropic use.

Table 3 Changes probability matrix for Prediction of land-use for the year 2030.

Land uses	Urban Area	Pasture	Native Forest	Road	Agriculture
Urban Area	**0.6290**	0.1937	0.1368	0.0381	0.0024
Pasture	0.4567	**0.4725**	0.0439	0.0249	0.0020
Native Forest	0.2472	0.0152	**0.7323**	0.0041	0.0013
Road	0.0998	0.0000	0.0719	**0.7830**	0.0453
Agriculture	0.2700	0.0000	0.0184	0.0000	**0.7117**

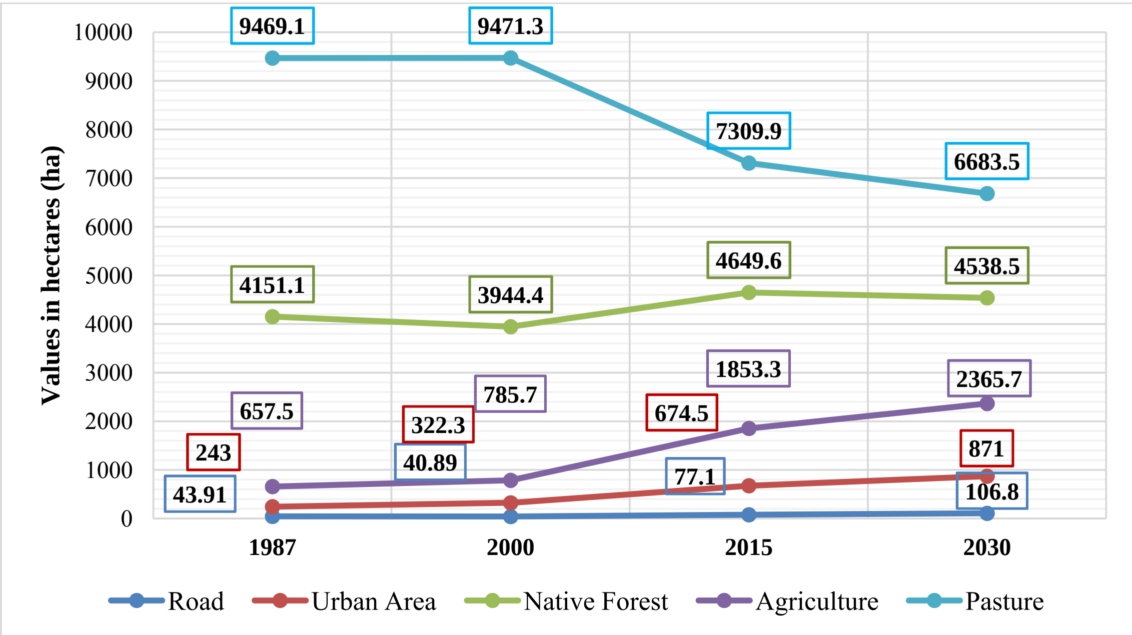

Fig. 4 General analysis of land use in the Upper Batalha watershed.

Regarding the urban area, its probability of not undergoing transformations is 62.9%, since the possibility of pasture and agriculture becoming urban areas is 45.6% and 27%, respectively.

By comparing the values 2015 and 2030 future scenario (Fig. 4) it was possible to verify the increase of the agriculture class and the urban area class in a more expressive way, with an increase of 512.4 and 196.5 ha, respectively.

In other words, a possible trend was observed in the increase in the number of roads, from 77.1 to 106.8 ha. The native forest and pasture classes showed a decrease in the analyzed period, totaling a loss of 111.1 and 626.4 ha, respectively.

According to S. I. P. Santos (2014) [17] scenario building is a great alternative for strategy and decision support about future planning.

Based on Fig. 4, it was possible to detect that the pasture class tends to decrease its occupation in the future scenario. The decline started in 2000, and the prediction is that, by 2030, it will occupy 6683.5 ha corresponding to 45.88% of the total area. This decline is mainly due to the increase in the urban area and agriculture, which over the decades has been increasing its occupation in the watershed.

A worrying fact is the prediction of the decline of the native forest class. From the 14565.5 ha in the watershed, only 4538.5 ha (31.15% of the total area) will be occupied and protected by this class.

The Alto Batalha watershed goes through serious problems due to the lack of vegetation, especially in Permanent Preservation Areas (PPA). The absence of native vegetation has caused silting in the Batalha River, consequently reducing both the quantity and the quality of the water. Studies conducted by the Pró-Batalha Forum show that at least 150 areas of springs need to be reforested. A reality that becomes truly worrying, because the Batalha River is responsible for supplying approximately 40% of the population of Bauru [18].

D. D. Silva et al. (2005) [2] explain that the presence of land cover has a fundamental role in land conservation. In a study, there was a marked decrease in land losses with an increasing percent cover. It was also observed that land cover has a greater influence on land losses than the precipitation intensity and that as land cover increased the erosive potential of heavy rainfall was reduced.

The heavy rains that hit the city of Bauru and its region during January 2016 proved the fragility of the study area. The expected climatological average for the first month of 2016 (January) was of 290 mm of precipitation, between the days 9 to 13 of the same month; increased almost 72 hours uninterruptedly, accumulating a volume of 310 mm until the 15th. On the 18th, the city of Bauru (São Paulo) decreed an emergency situation after the damages caused by the heavy rains that reached the region [19].

In response to extreme weather events, the researchers affirmed that in the Metropolitan Region of São Paulo in recent years, extreme weather events will become increasingly common in São Paulo and other cities around the world. Also, if the current pace of urbanization and greenhouse gas emissions is maintained, events may intensify. In the metropolitan region, there was also an increase in the frequency of heavy rainfall, causing floods and landslides, distributed among dry periods that can extend for months [20].

4. Conclusion

It was possible to conclude the data on the gain, loss, and persistence of land use classes between the years studied allowed us to identify the main changes regarding quantity and spatial distribution.

In addition to simplifying the complexity of the analyses, the Land Change Modeler (LCM) was fundamental for understanding the dynamics of land use changes. An important aspect to be considered is the input data, which must be carefully elaborated to achieve consistent results.

The temporal analysis in the periods from 1987 to 2000 and 2000 to 2015 allowed a better understanding of the environmental pressures in the natural areas that have led to the degradation of water resources in the Alto Batalha watershed. This process has proved to be of great importance since the complex and dynamic changes in the environments are related to natural aspects, human activities, and their interrelationships.

The simulation model used was very necessary to determine a future scenario, allowing the verification of the principal reduction and expansion trends of land use classes. This model is important as it allows the prediction and simulation of different scenarios, in the short and long term, thus allowing us to evaluate and define different informed strategies to protect the area studied.

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