

Impact of land use/land cover changes on water quality and hydrological behavior of an agricultural subwatershed

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Abstract Knowing the influence of land use/land cover changes on the hydrological behavior of a subwatershed is essential to land use planning. The Alto Paraguaçu Watershed is a major producer of fruits and vegetables, and currently the largest producer of English potato in the north/northeast of Brazil. The water availability in the region can be considered the limiting factor to the expansion of agricultural frontiers. Therefore, in order to assess the influence of land use/land cover on the quality and quantity of the water resources in the subwatershed, three sampling campaigns were carried out (two in the rainy season and one in the dry season) at ten points throughout the watershed, as well as the hydrological analysis and land use/land cover changes assessment for both seasons. The objective was to relate land use/land cover indicators with hydrological indicators in order to fit a model to predict water changes in the studied

subwatershed. The results showed that the changes that occurred in land use/land cover for the development of the current agriculture have significantly impacted the hydrological behavior in the Alto Paraguaçu watershed. It was possible to observe that the quality and quantity of water were directly influenced by the anthropization process. This study highlights the importance of suitable land use/land cover for the conservation of water resources.

Keywords Agriculture · Water resources conservation · Land change modeler · Multivariate statistics

Introduction

The use of geographic information system (GIS) tools has become essential to the planning and zoning of land use and land cover. Several studies (Fang et al. 2012; Yan et al. 2013) show that when it is possible to ally GIS tools, statistical methods and environmental data, the efficiency in obtaining responses with respect to these issues is increased.

With increasing deterioration of the global environment due to problems such as the greenhouse effect, acid rain, ozone depletion, and global climate change, ecosystem damage has become increasingly severe, resulting in a potential global crisis (Wang et al. 2014). Land use change analysis is useful in the planning and management of the occupation of the physical environment. Studies on this matter, and mainly the predictions with respect to growth trends and urban expansion, allow managers to intervene in a given location in order to optimize the use of such territory and consequently minimize the environmental impacts from the disorderly occupation, which would occur

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without the adoption of specific practices (Brinkmann et al. 2012).

The agricultural activity is of great importance for the world development, and Brazil has one of the largest agricultural areas in the world. The land use changes such as the opening of areas for agriculture have a direct influence on the components of the hydrological cycle such as infiltration, surface runoff and evapotranspiration, which, in turn, modify the flow behavior in the watershed, and may also compromise the water quality.

Forest cover losses may be detrimental to the water resources. During precipitation events, if surface runoff is increased, more sediment is carried into the water bodies; if soil infiltration is increased, the volume of water that reaches the water bodies decreases, although it contributes to the recharge of groundwater aquifers. In addition, the anthropic activities result in a significant decrease in the water quality of aquatic systems in watersheds (May et al. 2006), resulting in serious ecological and sanitary problems. Land use change is directly related to changes in surface water resources in a water source area, and so land use changes (Deng et al. 2015).

The objective of this study was to investigate the impact of land use and land cover changes on the hydrological behavior of an agricultural watershed, in terms of water quality and quantity availability. The potential for irrigable land in this Brazilian watershed exceeds 100,000 hectares, thus the water availability can be considered the limiting factor for the expansion of agricultural frontiers in this region (Fernandez 2001).

Materials and methods

Study area

The study was carried out at the Alto Paraguaçu watershed (Fig. 1), which has an area of 1660 km² (3 % of the Paraguaçu River watershed) and comprises the Paraguaçu River headwaters. The district of Mucugê is the main urban area in the Alto Paraguaçu watershed, with an estimated population of 10,400 people in 2014 (Instituto Brasileiro de Geografia e Estatística 2014). The Chapada Diamantina National Park represents 4.1 % of the watershed area, and 43.4 % refer to the park's buffer zone. The other portions of watershed comprise the municipalities of Barra da Estiva (7.4 %), Ibicoara (31.1 %) and Mucugê (61.4 %).

The study area presents low slopes and a predominantly smooth plane relief of sedimentary origin and pedological cover of Latosols. The predominant vegetation is Cerrado, in the Campo Cerrado physiognomy (Gerais). The mean pluviosity is 960 mm/year and the climate is characterized

by mild temperatures with annual means of 19 °C, being locally influenced by the Sincorá Hills, which influences the predominant winds and the spatial distribution of rainfall, providing exceptional conditions for agricultural production.

Analyses of land use/land cover changes

The Land Change Modeler of Idrisi Taiga[®] was used to model the land use/land cover changes. The software allows the fitting of a model to predict changes considering the analyses of the changes occurred in different periods. Thematic information such as soil type, as well as continuous information such as slope and distance features can be added to the model. In this case, we obtained land use/land cover images from 1987, 2004 and 2010. The survey was carried out through the classification of the Landsat-TM images acquired from the collection of the National Institute for Space Research (INPE).

According to the selected explanatory variables, the probability of occurrence of each transition was calculated through the application of neural networks of the multi-layer perceptron (Pijanowski et al. 2002), which is the comprehension model of the relationship existing between the changes and the explanatory variables.

The modeling of land use/land cover change for the horizon year (2001) was developed through the application of Markov chains, using the land cover map for the limit-date (1996) and the probability of transition. This modeling enabled the obtention of areas of gains and losses for each category in the horizon year.

For validation purposes, the map extracted from the 2010 image was considered as a reference. The overall reliability of the classification was calculated as the ratio between the number of pixels which were correctly placed and the total number of pixels of the image used to adjust the reference map to those which were generated through the Kappa index. Therefore, the land use maps from 1987 to 2004 were used to model the change, whereas the map from 2010 was used for validation.

Modeling water changes in the subwatershed

The SisCAH 1.0 (Hydrological Analysis System—<http://siscah.software.informer.com/>) software, developed by the Water Resources Research Group of the Federal University of Viçosa, was used for the hydrological analysis. Time series of rainfall data from 1980 to 2010 and fluvimetric data from 1980 to 2005 were obtained from the National Water Agency, HIDROWEB portal (<http://hidroweb.ana.gov.br/>).

For each period, the following hydrological indicators were determined: rainfall vs streamflow model, monthly

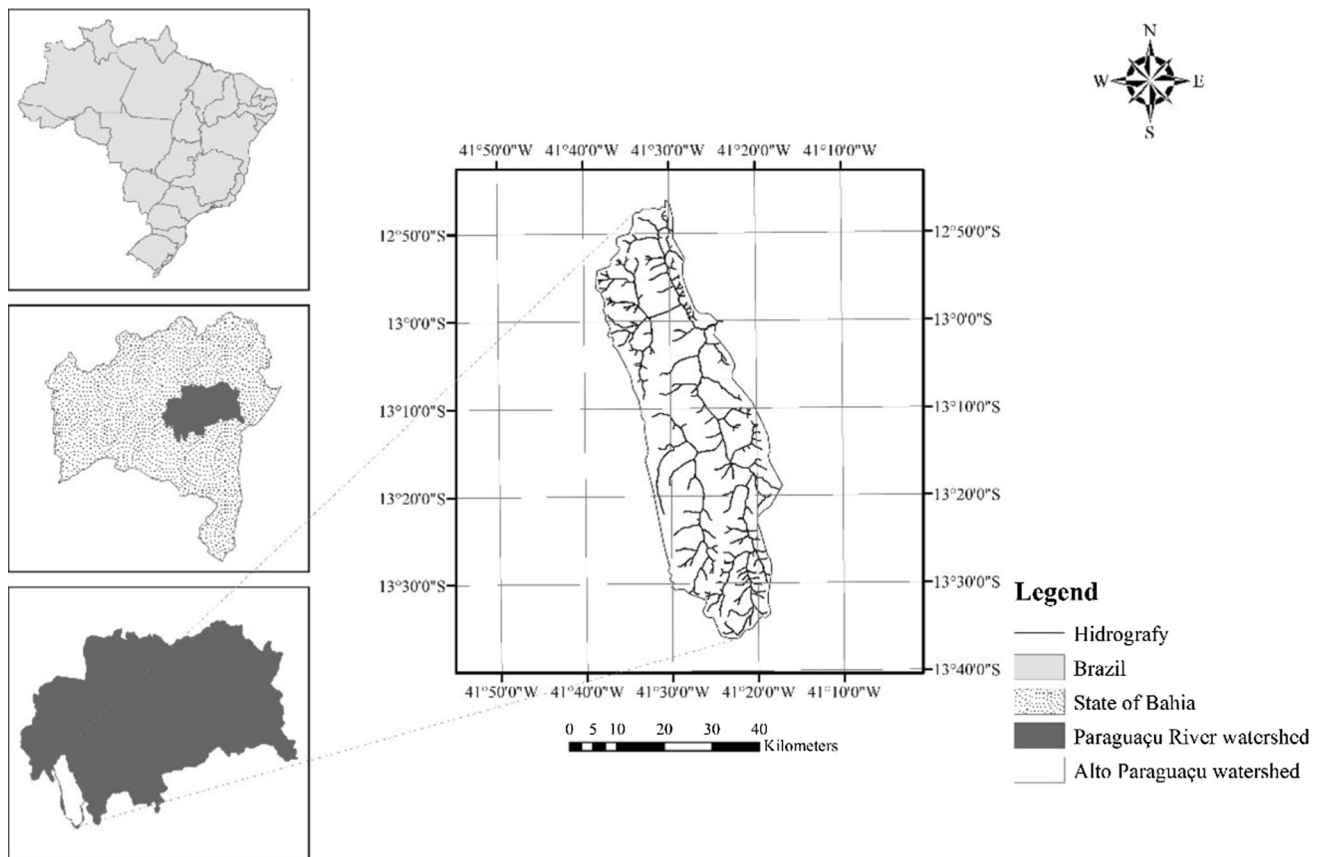


Fig. 1 Location of the study area

mean rainfall, total annual mean rainfall, average long-term flow, minimum mean flow, maximum mean flow, Q_{95} and Q_{90} flows.

In order to model the water changes, the exponential regression models were initially fitted to the hydrological indicators (mean flow, maximum flow, minimum flow, Q_{95} and Q_{90}) and the anthropic areas of the watershed in each period.

Water quality analysis

Three campaigns were carried out to assess the water quality at ten sampling points (Fig. 2). These points were selected in order to significantly comprise the several land use types in the entire area of the subwatershed; point 10 receives contribution from points 6, 1, 5, 7, 8 and 9.

Table 1 presents a brief description of the sampling points, based on field observations.

The three water sampling campaigns comprehended both rainy and dry periods. The parameters dissolved oxygen (DO), pH and turbidity were measured in the field using a multiparameter meter (HACH, HQ40d) at all sampling points. We highlight that there was rain during

the third campaign, which contributed to increase the flow as well as to changes in the water color.

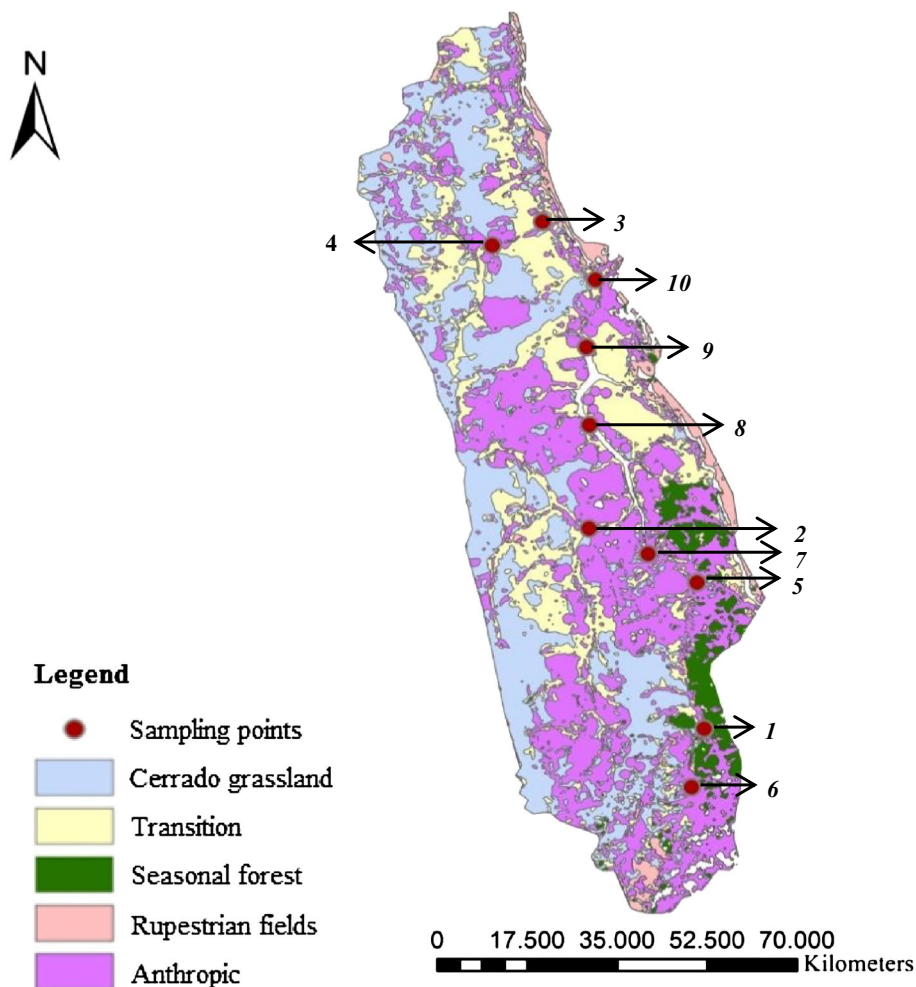
The physical, chemical and microbiological parameters assessed were the biochemical oxygen demand (BOD), total nitrogen (TN), nitrate ($N-NO_3$), total phosphorus (TP), phosphate (PO_4^{3-}), total solids (TS), total suspended solids (TSS) and total coliforms (TC). The samples were collected and analyzed according to APHA (2005).

The objective of the cluster analysis is to detect resemblances among values at different sampling points and classify them into groups based on their similarities (Panda et al. 2006). This analysis was carried out using the agglomerative hierarchical cluster (average distances) and the Euclidean distance as a dissimilarity measure. The statistical analyses were carried out using the version 3.0.2 of the statistical software R (Development Core 2013).

Results and discussion

Land use/land cover change analysis

The land use/land cover changes are shown in Fig. 3.

Fig. 2 Location of the sampling points**Table 1** Description of the sampling points based on field observations

Sampling point	Characteristics
Point 1 (P1)	Located near the spring and on the back of a rural property. It reflects the drainage conditions of an anthropic area with forest remains
Point 2 (P2)	Located at a valley, near a paved road. Water is used for bathing, laundry and washing kitchenware. It reflects the conditions of a subwatershed with intense agriculture and transition vegetation areas
Point 3 (P3)	Located near an unpaved road, under the bridge. The occupation of the area is incipient, with some agricultural areas. It reflects the conditions of a yet little disturbed subwatershed, with areas of headwaters
Point 4 (P4)	Located near an unpaved road. Along the margins, there is a predominance of undergrowth vegetation and plane relief. It reflects the conditions of a subwatershed with advance in agricultural traces
Point 5 (P5)	Located near residences that use water for showers, washing kitchenware and livestock in small farms. It reflects the conditions of drainage of an anthropic area with intense agriculture
Point 6 (P6)	The point closest to the spring. There is little land occupation for agricultural or residential purposes
Point 7 (P7)	Located within the municipality of Cascavel. Discharge of raw domestic sewage is observed
Point 8 (P8)	Located in a lentic environment. The area was flooded for the construction of the dam, and there is fishing. It presents a plane relief and is surrounded by undergrowth vegetation
Point 9 (P9)	Located near the Apertado dam, with reduced occupation in its surroundings. We highlight the sand banks due to the construction of the dam. Lentic environment
Point 10 (P10)	Located near the road and characterized as a lentic environment with predominance of aquatic plants. The occupation in the surroundings is reduced, with only a few residences

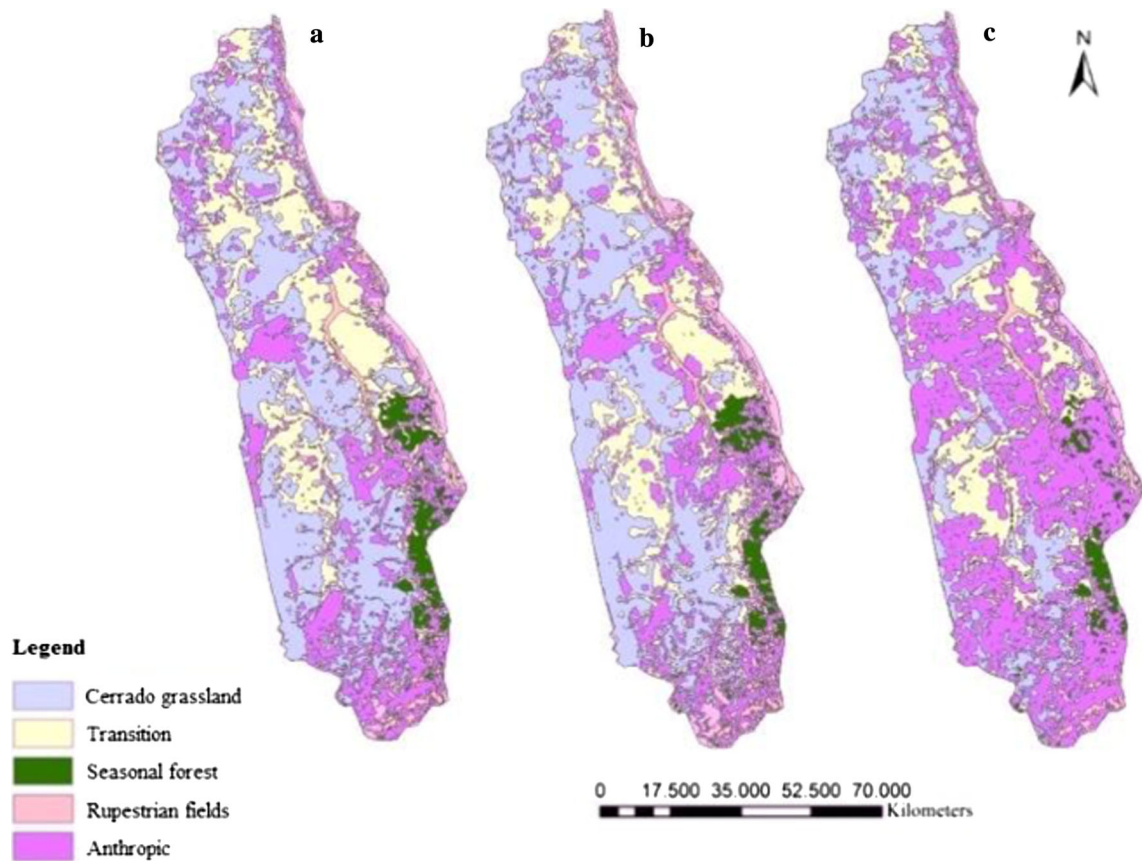


Fig. 3 Land use/land cover images for the studied period. **a** 1987, **b** 2004 and **c** 2010

Figure 3 shows the land use/land cover changes occurred in the subwatershed during the analyzed period. It is important to highlight that the class “Anthropic” refers mostly to agriculture, which is the predominant anthropic activity in this region. It is possible to notice a clear increase of this class from 2004 to 2010, mostly over areas of native forest, Cerrado and transition.

With respect to the land uses in the period between 1987 and 2004, a tendency of increase was only observed for the anthropic areas, beginning with the construction of the Apertado Dam for the development of irrigated agriculture, mainly vegetables cultivation. The great potential for the production of vegetables and irrigated grains made the State Government, in addition to investing in the dam, also extend the energy matrix and provide agricultural credit for funding and investments. This partnership between companies and the State started a new phase of development in the region, which, in less than a decade, expanded the irrigated area from 1600 hectares to 16,000 hectares annually cultivated (changes from 2004 to 2010).

Figure 4 presents the gains and losses for each land use class in the studied period.

The result of changes analysis provides a quantitative assessment of change, plotting gains and losses for each

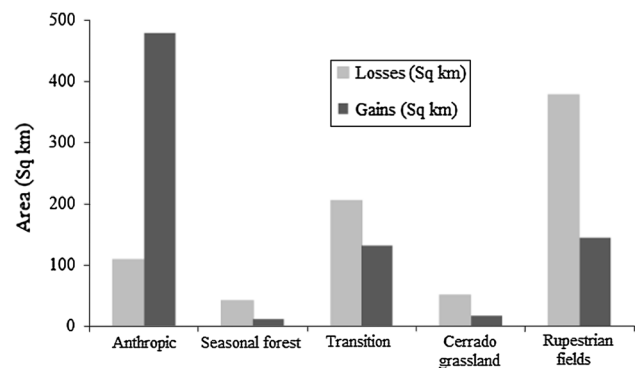


Fig. 4 Gains and losses for each land use class in the studied period

land use class. It is important to notice that the same land use class may change when it loses areas to another class type and can also gain territory from other classes. For example, the transition class lost areas to anthropogenic class but gained areas from other land uses.

The production of irrigated vegetables is currently the main socio-economic activity in the subwatershed. In the current production model, the producers have been incorporating new areas in order to minimize the risks associated with pests and soil diseases. In general, for each

planted hectare there are five other hectares in rotation with grass or being prepared for crop planting. The class transition has undergone less modifications, in terms of proportion, given that the costs for opening and preparing these areas for cultivation area high; also, they are close to the National Park, which somehow inhibits their incorporation to the productive process without the authorization of the competent environmental authority. However, due to the natural tendency of development of the region, these areas are likely to be disturbed and replaced by irrigated crop. The seasonal forest class was substituted by coffee, since these areas are prone to higher rainfall over deep soils with high levels of organic matter, which are suitable conditions for family rainfed coffee farming. Finally, the class which has undergone greater changes throughout the studied period was the Cerrado grassland, mostly because of the deep soils and plane relief, conditions that favor mechanized agriculture.

Future scenario

In order to predict the changes in land use/land cover for a future scenario, the changes described in “[Land use/land cover change analysis](#)” were modeled into transition sub-models using the LCM.

Transition sub-models

As shown in “[Land use/land cover change analysis](#)”, the anthropic class received most contributions of the other land use/land cover classes, thus a unique transition sub-model was simulated, considering the change of all classes to anthropic.

Table 2 shows the variables included in the transition sub-model and the probability of transition calculated for each type of land cover.

Land use change model

The application of multilayer perceptron neural networks (MLP) for studying the relationship between the analyzed

transitions and the possible explanatory variables reached a precision of 76.4 % in the modeling, and a pixel trial and error of 42.86 %. According to the Idrisi Taiga Tutorial (Eastman 2009), this result suggests the reasonably good identification of the overall change locations, but there is room for improvements in the specifications. The Kappa index was near 0.81. Such value reaches acceptable levels that guarantee the fit between the simulated model (Fig. 5a) and the reference map (Fig. 3c).

Figure 5 shows the land use/land cover results for 2010 and the prediction performed for 2050, carried out with the LCM of Idrisi Taiga. The simulation of changes in land use is important for several issues related to planning and management of the territory, since it provides information of great importance about the impacts such changes may bring.

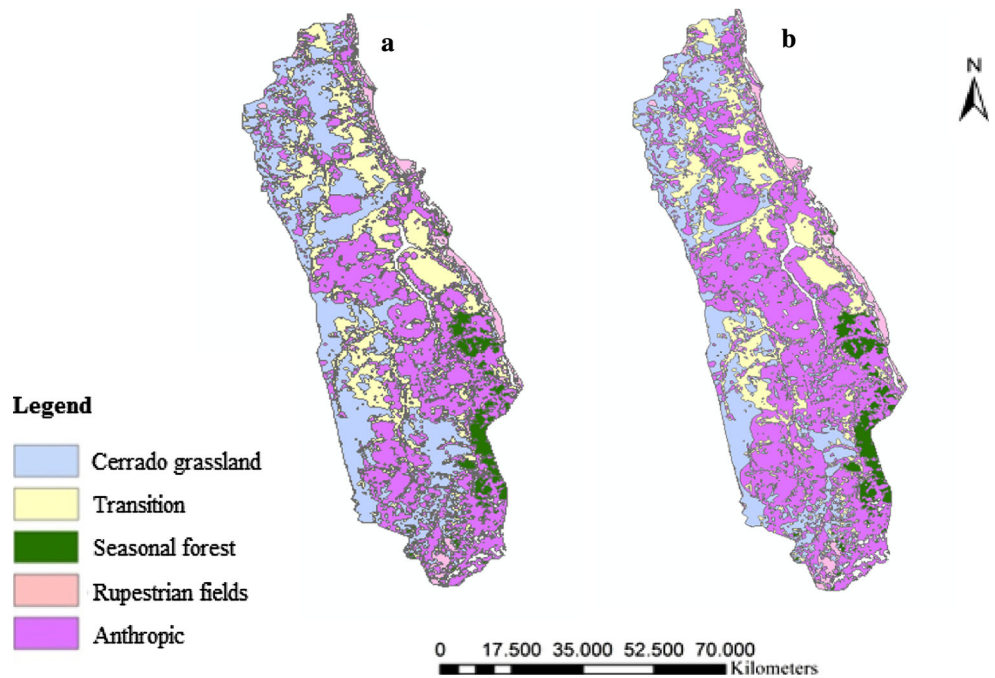
In 2010, the anthropic area corresponded to 39.01 % of the area of the subwatershed, and the prediction for 2050 is that such area will occupy 51.9 % of the watershed. The areas which will mostly lose space to the expansion of the anthropic area are: transition vegetation and Cerrado grassland, which will respectively lose 139.05 and 127.97 km². The other uses (rupestrian fields and seasonal forest) will not suffer that much the modifications, since the soils of the rupestrian fields are shallow and have no potential for irrigated agriculture, whereas the seasonal forest is protected by the “Atlantic Forest Law”. The presence or absence of vegetal cover in a watershed influences the quality and quantity of water, since it interferes in the conservation of the soil and its physical properties. Thus the prediction enables the identification and reduction of areas near water resources, and areas prone to conflicts related to its use.

With the purpose of protecting and maintaining the environmental resources, the zoning is highly recommended. With the application of management techniques, areas considered unsuitable for agriculture can be used, instead of planting in areas of natural vegetation and Cerrado grassland, which can provide a balanced environment and thus mitigate the impacts of such changes.

Table 2 Cramer’s *V* coefficient: association level of the quantitative, explicative variables and the studied land uses

	Anthropic	Seasonal forest	Transition	Rupestrian fields	Cerrado grassland
HCDEM	0.3079	0.228	0.2037	0.0737	0.00
Slope	0.427	0.0565	0.1463	0.0983	0.00
Distance from pivots 2004	0.2357	0.1314	0.1692	0.1176	0.00
Distance from roads 2004	0.2259	0.2644	0.2346	0.1562	0.00
Transition	0.3994	0.56	0.5125	0.478	0.00

Fig. 5 **a** Land use map for 2010; **b** prediction of land use/land cover for 2050, resulting from the analysis performed using the Lange Change Modeler (Idrisi Taiga)



Interaction of land use and rainfall with the hydrological regime

The mean long term flows in the watershed were 18.50 and 15.49 m³/s for the assessed periods of 1980–1989 and 1996–2005, respectively. This is explained by the fact that in both these periods, the mean annual rainfalls were 839 and 727 mm, respectively. Figure 6 shows the monthly mean flow data and rainfall depths for the assessed periods.

As previously mentioned, the land use in the Alto Paraguaçu watershed has undergone intense modifications between 1970 and 2005. The area initially occupied by native vegetation was 263 km², and decreased to 127 km² in 2005. According to Collischonn and Tucci (2001), after deforestation, there is an increase in the mean flow of a watershed. However, in the current scenario, due to the large use of water for irrigation purposes, such fact was not observed. Still according to these authors, when agricultural crops substitute natural vegetation, the impacts can be differentiated. In case of perennial crops such as coffee, the change in runoff is minimized when compared to annual cultures such as vegetables, which are commonly cultivated in the studied watershed. According to Baker and Miller (2013), the land use/land cover changes may affect the rates of interception, infiltration, evapotranspiration and groundwater recharge.

Specifically in the Alto Paraguaçu watershed, with the abandonment of areas open for the production of rainfed grains, the natural vegetation began to restore, which

caused a change in the water balance and consequently in the response of the rainfall x flow model.

The hydrological indicators of land use/land cover in the studied subwatershed are presented in Table 3.

It should be noted that the total precipitation in the subwatershed decreased by 13 % during the studied period, which would cause a decrease in water availability around the same order of magnitude. However, the increase of anthropogenic area of around 192 % in 25 years caused more drastic changes in water availability, reflecting a decrease of 55 % in the minimum mean flow.

The change in the hydrological behavior of the subwatershed is associated with changes in the water balance caused by factors such as the substitution of the natural vegetation of Cerrado grassland, mostly by grass in crop rotation, for the vegetable production system. The exotic grass consumes more water than the Cerrado vegetation, which increases evapotranspiration in the subwatershed, and consequently contributes to the decrease of the flow. Another factor that contributed to such changes was the construction of reservoirs to regulate flow for irrigation purposes, since the resulting reflecting pool increases the evapotranspiration rate in the subwatershed, and contributes to the decrease in flows over time. The increase in the use of water for irrigation plays a significant role in decreasing flows. In this subwatershed, the irrigated area expressively increased over the last few years, estimating an irrigated area around 16,000 hectares nowadays.

Fig. 6 **a** Mean annual flow (m^3/s) for both studied periods; **b** mean annual rainfall (mm) for both studied periods

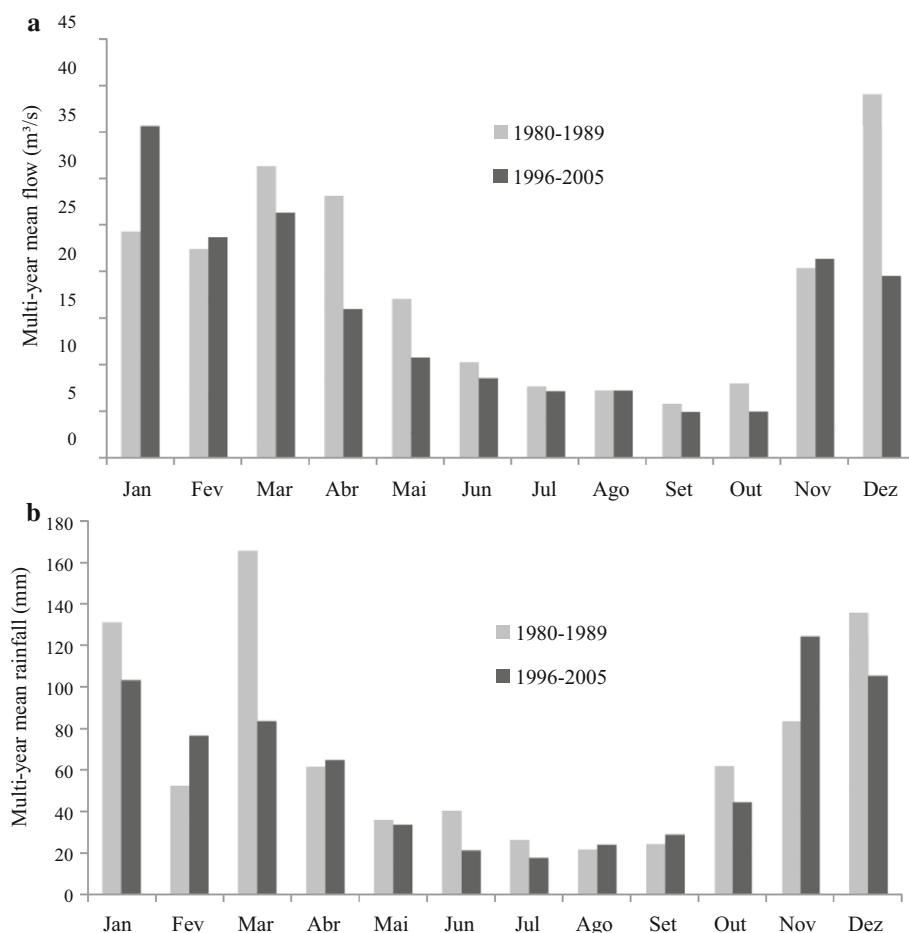


Table 3 Hydrological indicators of land use/land cover in the subwatershed

Indicators	Period		
	1980–1989	1996–2005	Relative difference (%)
Mean anthropic area (km^2)	250	480	192
Minimum mean flow (m^3/s)	4.08	1.85	-54.65
Mean flow (m^3/s)	18.50	15.49	-16.27
Maximum mean flow (m^3/s)	48.71	41.61	-14.58
Q_{95} (m^3/s)	1.94	0.88	-54.64
Q_{90} (m^3/s)	2.53	1.12	-55.73
Total mean annual rainfall (mm)	839	727	-13.35

Interaction between land use/land cover and water quality

A cluster analysis was used to assess the influence of different land uses on the quality of the monitored water bodies. Similarities in water quality were identified at all sampling points. According to Fan et al. (2010), the cluster analysis applied to a future monitoring can optimize the choice of the sampling points, reducing costs.

Figure 7 presents the cluster results for the physical, chemical and microbiological parameters evaluated. The analysis resulted in three main groups.

Group I, which consisted of the points 1, 6 and 9, is characterized by low values of BOD, TN, TP, TSS, reflecting a better preservation of water. These points are located near the headwaters, with low agricultural and/or residential land use, which explains the greater protection of the water resources.

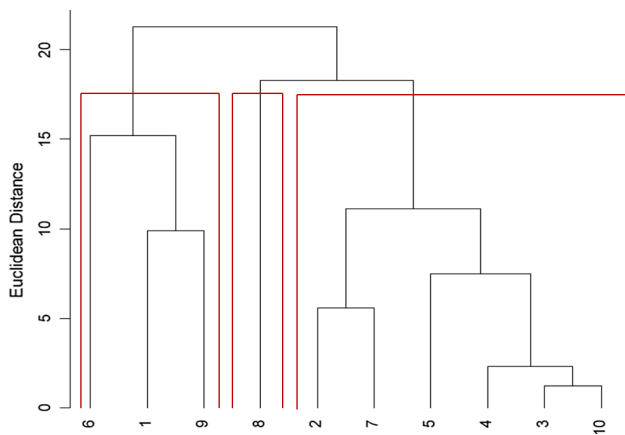


Fig. 7 Dendrogram resulting from the cluster analysis

Group II, represented by the point 8, is located in a lentic environment, given that the area was flooded for the construction of the dam. The high TN level observed at this point can be explained by the accumulation of this nutrient in the lentic environment, since it is located downstream of areas with greater anthropic and agricultural activities.

Group III consisted of the points 2, 3, 4, 5, 7, and 10, and presented water quality deterioration due to the lower levels of DO and higher values of BOD, TSS and TC observed. The DO values were below 5 mg/L in at least one sample. These points are located near urban and agricultural areas, and thus subject to contamination by effluent. The high BOD, TSS and TC concentrations found in such points characterize an anthropic influence due to the contribution of organic matter, that can be represented by the carrying of soil (surface horizon, rich in organic matter), fertilizers and/or pesticides, as well as the discharge of raw sewage into the water bodies.

The low DO concentrations at the sampling points 2 and 7 may be attributed to the discharge of organic matter into the water body, since they are both located in a highly anthropic area. Point 7, specifically, represents the drainage from the district of Cascavel, which does not have sewage collection and treatment. Such fact contributes to increase the organic matter content, which consumes DO during degradation. As for the low DO levels presented at point 4, they can be explained by the advance of the anthropic area in the region (agricultural activities), despite its location near the headwaters.

According to Cunha (2010), the presence of excess suspended solids in a water body directly affects the biodiversity of such environment. The quality of the river is affected, since its reduced transparency decreases the capacity of the aquatic plants to perform photosynthesis. In addition, the suspended solids can obstruct the respiratory system of the fish, damage the eggs and affect the macroinvertebrates population. In the Alto Paraguaçu

watershed, the suspended solids values reflect the intense agricultural activity in the region, with deforestation of forest and Cerrado for the cultivation of crops. Since the farmers in the studied region do not implement conservation practices, the soil is constantly exposed and subject to erosion. The points 2, 3, 4, 5, and 10 present high TSS values; although they are not near big cities, agriculture is the main of land use/land cover in this region. It is important to highlight that the flows were below the Q_{90} during the sampling campaigns, which directly interferes in the concentration of the elements.

It can be noticed that the water availability and water quality in the studied watershed were directly affected by changes in land use. These changes may come from natural causes or human activities. In this case, they were caused by anthropogenic disturbance in the Paraguaçu watershed. Modification of land use, such as waterproofing areas, vegetation removal, disorderly occupation of areas adjacent to water bodies, can produce effects both in quantitative and qualitative aspects of water in a watershed. For example, reduction or increase in the average, maximum and minimum flows, changes in water quality, such as variation in the amount of organic matter and nutrients, increments of pathogenic organism, heavy metals and pesticides in the aquatic environment (Tucci 2002; Bonnet et al. 2008).

Conclusions

The LCM tool was used to obtain information regarding the tendencies and directions toward the increase or decrease of the uses in the Alto Paraguaçu subwatershed, which enables the interference of managers in areas with higher risks of inappropriate occupation.

In addition, we observed that the anthropic area in the subwatershed increased 192 % during the studied period, and the water availability assessed in terms of minimum flows decreased 55 %, which reflect the changes in the water balance due to the opening of areas, planting of agricultural crops, crop rotation using grass, withdrawal of water for irrigation and construction of reservoirs.

The water quality was directly influenced by the anthropization process, and the worst conditions were observed in areas near urban and agricultural occupation, and thus more prone to contamination by effluents.

Therefore, this study showed that the changes in land use/land cover for the development of the current agriculture have significantly impacted the water behavior in the Alto Paraguaçu subwatershed. Also, we highlight the importance of understanding the influence of each factor on such changes during the process of planning the territorial zoning, and recommend that future studies should aim at finding answers to such question. Zonings have the purpose

of protecting and maintaining the environmental resources, as well as mitigating the impacts of transformations through a strict planning toward the use of areas unsuitable for agriculture after implementation of management techniques, which are extremely important in agricultural watersheds.

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