LANDSCAPE ELEMENTS, WATER RESOURCES AND ECOSYSTEM SERVICES: THEIR RELATIONS TO LOSSES AND GAINS IN A PANTANAL REGION

Guilherme T. N. P. de LIMA[1]
Lídia Sanches BERTOLO[2]
Rozely Ferreira dos SANTOS[3]
João dos Santos Vila da SILVA[4]

Abstract

In the last decades, the region of Bonito (Mato Grosso do Sul State – MS) has presented an increase in urban areas, causing impacts on water resources, landscape fragmentation and loss of ecosystem services (ES). Aiming to study the relation chain among land use, water resources and ES, this work determined the influence of the composition from landscape elements and water quality on the offer of three ES (water quality, erosion control and tourism), also defining the critical points between offer of water services and loss of natural resources for urbanization. For this purpose, the following tasks were accomplished: (i) statistical analysis of Pearson correlation and Principal Components Analysis (PCA) to determine the relations between water quality and mapping classes; (ii) elaboration of equations to determine the ES and (iii) analysis of the relation the quality of ESs and the quantity of urbanized areas in several segments of the Formoso river basin (MS). The results showed that at the sub-basin of Bonito stream, the services presented a degradation of around 80% in relation to the Formoso river basin. Besides that, it was verified that one fourth of the urbanized territory caused around 30% of service losses of water quality.

Key words: Ecosystem services. Landscape. Formoso river.

[1] Universidade Estadual de Campinas, Laboratório de Planejamento Ambiental - LAPLA-DRH -FEC/UNICAMP. Associate Researcher. Endereço: Av. Albert Einstein, 951 - Caixa Postal: 6021. 13083-852 - Campinas - SP, Brasil. E-mail: gtnplima@gmail.com

[2] Universidade Estadual de Campinas, Laboratório de Planejamento Ambiental - LAPLA-DRH -FEC/UNICAMP. Doctorate student. Endereço: Av. Albert Einstein, 951 - Caixa Postal: 6021. 13083-852 - Campinas -SP, Brasil. E-mail: bertolo.lidia@gmail.com

[3] Departamento de Ecologia, Laboratório de Ecologia da Paisagem e Conservação. Associate Teacher. Endereço: Rua do Matão, nº321, Trav. 14, Cidade Universitária. 05508-900. São Paulo, SP, Brasil. E-mail: rozefs@uol.com.br

[4] Embrapa Informática Agropecuária – CNPTIA. Researcher. Endereço: Av. André Toselo, 209 - Caixa Postal 6041. 13083-886 - Campinas - SP, Brasil – E-mail: joao.vila@embrapa.br

Resumo

Elementos da paisagem, recursos hídricos e serviços ecossistêmicos: suas relações entre perdas e ganhos em uma região pantaneira

Nas últimas décadas, a região de Bonito (MS/Brasil) vem apresentando um grande aumento de áreas urbanas causando impactos aos recursos hídricos, fragmentação da paisagem e perda de serviços ecossistêmicos (SE). Objetivando estudar a cadeia de relações entre usos, recursos hídricos e SE, o presente trabalho determinou a influência da composição dos elementos da paisagem e da qualidade da água na variação da oferta de três SEs (qualidade de água, controle de erosão e turismo), definindo também os pontos críticos entre a oferta de serviços hídricos e a perda de recursos naturais para a urbanização. Para tanto, foram: (i) realizadas análises estatísticas de correlação Pearson e Análise de Componentes Principais (ACP) para determinar as relações entre qualidade de água e classes de mapeamento; (ii) elaboradas equações para determinação dos SE; e (iii) analisada a relação entre qualidade dos SEs e quantidade de área urbanizada em diversos segmentos da bacia do rio Formoso (MS). Os resultados mostraram que na sub-bacia do córrego Bonito os serviços apresentaram uma degradação de cerca de 80% em relação à bacia do rio Formoso. Além disso, verificou-se que um quarto de território urbanizado causou cerca de 30% de perdas dos serviços de qualidade de água.

Palavras-chave: Serviços ecossistêmicos. Paisagem. Rio Formoso.

INTRODUCTION

In the literature there is an exhaustive repetition that the sustainability of a region depends on the maintenance of the structures and ecosystem functions which guarantee the equilibrium of the biomes and consequently the benefits or nature services for future human generations. If the biome is wide and diverse, it is very probable that there is a large availability of services for the water regulation, water supply, maintenance of climatic conditions, erosion control, recreation or ecotourism (BRAUMAN *et al.*, 2007).

Pantanal is a good example for these considerations, because it presents a great biodiversity with a strong capacity for water regulation and an important critical fraction of the hydrologic cycle from the great La Plata Hydrographic Basin (GOTTGENS *et al.*, 2001).This area, however, is suffering multiple human activities which are hostile to a balanced condition, negatively affecting its habitats, the species diversity and the capacity of hydrologic plugging effect (JUNK & CUNHA, 2005). It is beyond question that its ecological integrity is threatened, despite being a unique center of diversity and ecosystem services (SHRESTHA *et al*., 2002; HARRIS *et al*., 2005; WANTZEN *et al.*, 2008). This fact is remarkable especially when related to the maintenance of a good water condition to guarantee the natural pulse of inundation, fish migration, genetic changes, recharge of aquifers, regularization of water to Paraná river, regulation of evapo-transpiration for a large region within central South America, reduction of suspended sediments in rivers, maintenance of biogeochemical cycles, water purification of cities localized close to Pantanal, among other functions (WANTZEN *et al.*, 2008).

Several studies concerning human impacts on forested areas from hydrographic basins affirm that there is a strong correlation between the reduction and fragmentation of natural vegetation due to human activities and a quality loss of aquatic systems from a region (LIU *et al.*, 2003; LEE *et al.*, 2009; HACKBART, 2012), leading to a reduction on the supply of ecosystem services, such as the water supply and regulation (LIMA, 2011; HACKBART, 2012). This relation also occurs with great probability in the entire Pantanal, due to the multiple composition of elements in this landscape and its peculiar inundation characteristics. It can affect important services such as water reservoir and depuration, climate stabilization and containment of sediments. Seidl & Moraes (2000) verified for instance, in Nhecolândia, Pantanal, that the water supply and regulation of disturbances, represent 2/3 of the total ecosystem services evaluated. Viglizzo & Frank (2006) evidenced that in the *Cerrado* (Savanna) and in the Pantanal of the La Plata river basin, agricultural activities frequently don't pay or justify the loss of ecologic services. In other words, it is important to recognize a critical point between the economic gains obtained from human activities and the degradation of services, i. e. a line of demarcation which reflects the maintenance of ecosystem services so that there is harmony among different land uses. In these cases the common strategy is to identify a threshold between the economic and the ecologic value, which can be deduced from the curves indicating the decrease of the value from the systemic service and the increase of the value from the annual provision of the economic service (GOTTGENS *et al.*, 2001), representing thus a functional complementation.

Based on these theoretic considerations, the objective of this study is to demonstrate the influence of the element composition in a Pantanal landscape and of the water quality in the variation of ecosystem services supplied, looking for critical points between the offer of ecosystem services related to water resources and the loss of natural resources by urbanization.

MATERIAL AND METHODS

The area under study comprehends the hydrographic basin of Formoso river in the municipality of Bonito (Mato Grosso do Sul State), with approximately 135,872 ha (Figure 1). This basin is inserted in the sub-basin of Miranda river, one of the six basins forming the Upper Paraguay River Basin (UPB) (BRASIL, 2002). The Formoso river is part of the *Serra da Bodoquena* complex. Its basin is very important from a conservationist point of view, because it is the connection among several legally protected areas such as the *Serra da Bodoquena* National Park, the National Monument of Formoso River, the Cavern Lago Azul (XAVIER, 2011). On the other hand, these regions have been suffering a strong urbanization process for the last 20 years. In this study, besides the Formoso river, the Bonito stream, its tributary, was considered, once it receives the domestic effluents from the Bonito city, through the Saladero and Restinga streams.

The methodological strategy to evaluate this territory was based on the relation between the area occupied by human uses and the physiognomies of natural vegetation with variations of water quality, expressed in three ecosystem services related to water resources. From these results, the relation between the quality of these services and the percentage of urbanization was obtained. This refers to each one of the sub-basins, presupposing the occurrence of trade-offs, i.e. that there is a probable negative correlation between these landscape factors.

The mapping categories contained in figure 2 originated from a regrouping of the original map (SEMAC/IMASUL, 2010), as presented in Annex 1. This procedure was accomplished with the objective to put together the mapping classes to concentrate the main typologies and to allow the joint analysis with the water quality and calculation of the ecosystem services. On the land use map, from the layover of the hydrographic net and SRTM (Shuttle Radar Topography Mission) images, ten sub-basins of Formoso river were delimited on ArcGIS, in accordance with the localization of water collection points (Figure 2).

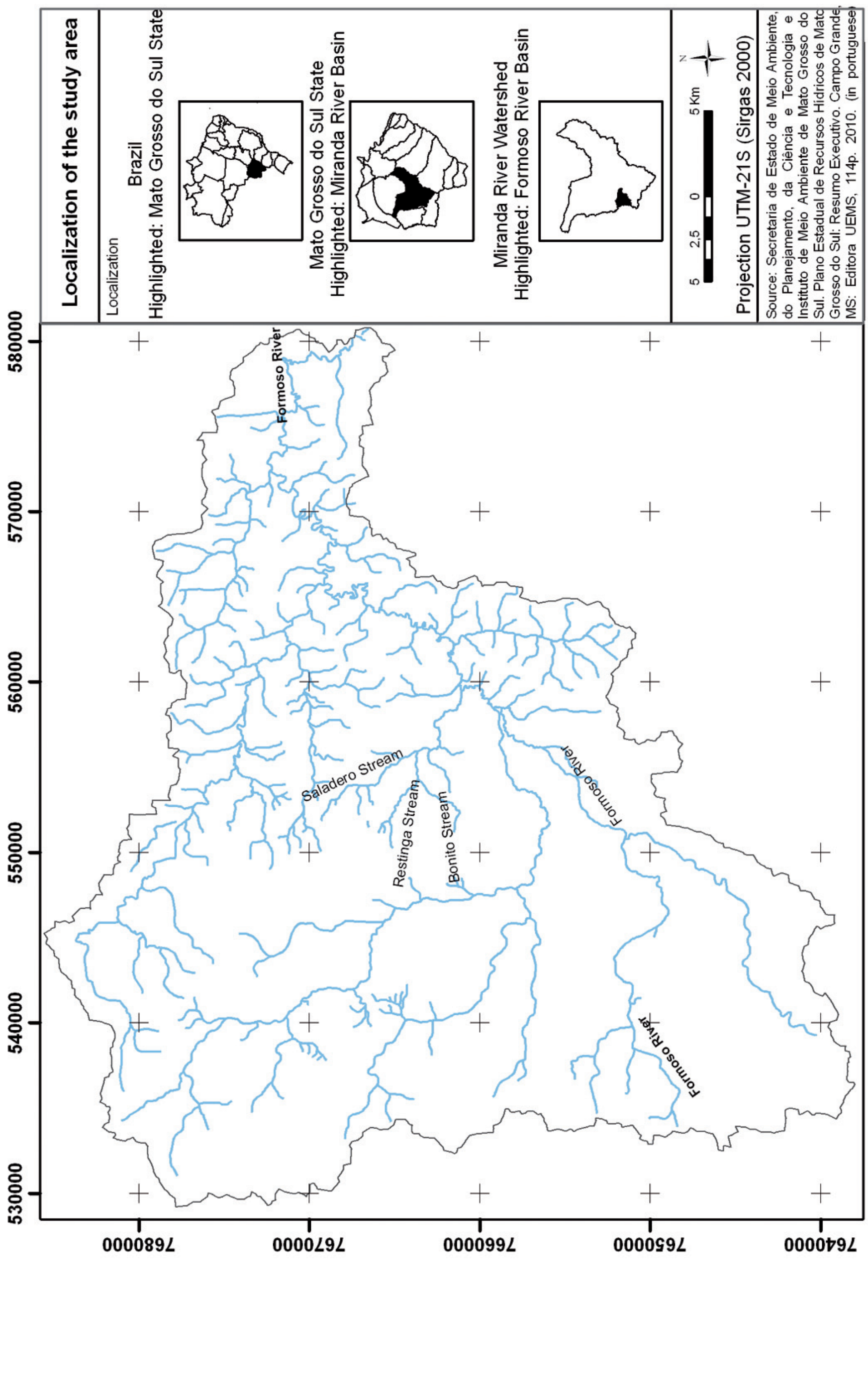


Figure 1 - Localization of the area under study, detaching water courses of the sub-basins selected for this study
Source: SEMAC/IMASUL (2010), data from 2007

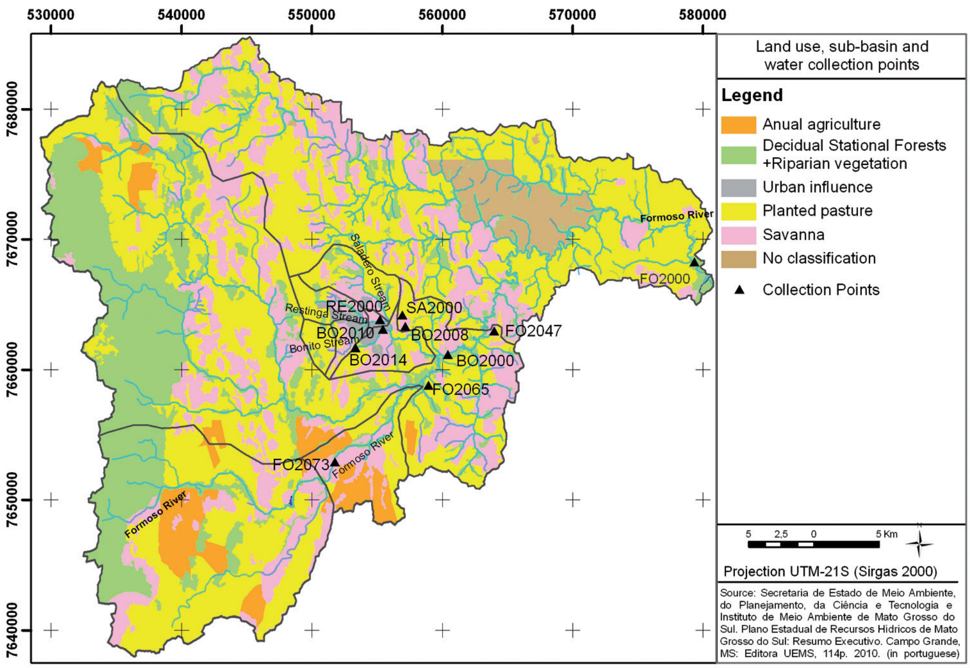


Figure 2 - Land use / land occupation of the Formoso river sub-basins with the division of basins in accordance with the localization of water collection points

Source: SEMAC/IMASUL (2010), data from 2007.

The hydro-chemical data from 2007 were obtained from the monitoring report of surface water quality of Mato Grosso do Sul State. Twenty water quality parameters were analyzed, namely: Temperature (°C), pH, Dissolved Oxygen (OD; mg/L), Biological Oxygen Demand ($BOD_{5,20}$; mg/L), Thermo-tolerant Coliforms (NMP/100mL), Total Nitrogen (mg/L), Total Phosphorus (mg/L), Total Solids (mg/L), Turbidity (NTU), Water Quality Index (WQI, the same as used by the São Paulo State Environmental Agency – CETESB), Conductivity (uS/cm), Chemical Oxygen Demand (COD; mg/L), Ortho-phosphate (mg/L), N-ammoniac (mg/L), N-nitrate (mg/L), N-nitrite (mg/L), Total Nitrogen Kjeldahl (mg/L), Fixed Solids (mg/L), Volatile Solids (mg/L) and Total Dissolved Solids (mg/L). These parameters were evaluated to represent both the humid (October to December) and the dry (June, August) periods, typical of Pantanal. Table 1 characterizes the ten collecting points in the area under study.

The localizations of these collecting points were used to determine segments of the Formoso river, so that the upstream area of a point would include all forms of land use/land occupation contained in the respective section of the sub-basin. Thereby the water quality variation in this sequence of segments determined by the points of water analysis may suggest the influence of variation from forms and intensities of land use/land occupation along these sections.

The water quality parameters were analyzed in terms of their average values, and their relation with the relative areas (%) of the mapping classes were obtained by the analysis of Pearson correlation ($p>0,05$) and Principal components, using the statistical programs Action® and Past®. The results of this statistical analysis were used for the selection of parameters which would best represent the landscape elements and afterwards for the calculus of ecosystem services.

Table 1 - Collection points in the different water bodies and their main uses

Point	river/stream	Main land uses	Area (ha)	Area (%)
FO2073	Formoso	Planted pasture and Decidual Stational Forest	17307,11	71,3
FO2065	Formoso	Annual agriculture, Planted pasture and Savanna	4141,06	90,2
FO2047	Formoso	Planted pasture and Decidual Stational Forest	43168,75	74,4
FO2000	Formoso	Planted pasture and Savanna	42094,01	85,9
BO2014	Bonito	Planted pasture and Decidual Stational Forest	721,66	94,2
BO2010	Bonito	Savanna, Urban influence and Planted pasture	553,81	87,5
BO2008	Bonito	Planted pasture and Urban influence	171,18	89,8
BO2000	Bonito	Planted pasture and Savanna	1497,11	74,2
RE2000	Restinga	Savanna, Urban influence and Planted pasture	1054,01	86,3
SA2000	Saladeiro	Planted pasture and Savanna	1752,35	77,1

The ecosystem services were calculated and analyzed according to procedures described in Lima (2011) and Hackbart (2012). These authors propose a form to calculate the ecosystem services based on the comparison among environments of the same locality, to allow a relative analysis of the degradation from services within the same landscape. This form of calculation reflects the most intrinsically related value to the ecologic and sustainability processes, to detriment of the monetary value which is normally attributed to biomes and ecosystems (LIMA, 2011). The services analyzed, their concept and the water quality parameters selected to represent the respective services, are presented in table 2, based on the description of Hackbart (2012).

Table 2 - Ecosystem services and their definitions (based on HACKBART, 2012)

Ecosystem services	Definition
Water Quality (WQ)	Service related to inland water quality that can be used for human consumption, cleaning, and industrial processes.
Erosion Control (EC)	Refers to the role that vegetation plays in soil retention, landslides prevention, and prevention of water bodies siltation.
Recreation and tourism (RT)	Refers to the importance of a site for the development of leisure practices which is directly based on the site natural landscape quality.

The calculation of services described in table 2, considered the information on the predominant classes in the landscape (over 70%) and the spatial variation of some water quality parameters. In order to allow a comparison among the different water quality parameters (WQP), their values were standardized from 0 to 1, where the worst water quality situation is 0 (zero) and the best condition is shown in Equation 1.

$$VP_{WQP} = (V_{WQP} - V_{min}) / (V_{max} - V_{min}) \qquad \text{Equation 1}$$

Where:

VP_{WQP} = standardized value of the water quality parameter;

V_{WQP} = average value of the water quality parameter;

V_{min} = lowest value of the water quality parameter among all points;

V_{max} = highest value of the water quality parameter among all points.

The standardized values of the selected water quality parameters were added and related to the predominant areas in the segment, according to description in equation 2.

$$V_{SEi} = [(\Sigma VP_{WQP}).\ A_{CAAy}] / A_{CANy} \qquad \text{Equation 2}$$

Where:

V_{SEi} = value of ecosystem *i* service (QA, CE ou RE)

VP_{WQP} = value of standardized water quality parameter

A_{CAAy} = area (ha) of human class/classes (agriculture, pasture and/or urban area) in segment *y*

A_{CANy} = area (ha) of natural class/classes (savanna and/or forest) in the segment *y*

The values obtained by segment and by ecosystem services were corrected by the percentage of the representative segment of the classes used in equation 2, to homogenize the information in areas of different territorial extensions. Finally the value was subtracted from 10 (ten) aiming to interpret the results in the conservation sense. The results were analyzed by graphics which represent the variation offer of three services by their total summation.

The data obtained for the three ecosystem services were related in a graph with the urbanization percentage of each sub-basin, to presuppose the threshold between gains originated from the urban growth and the degradation of water services.

RESULTS AND DISCUSSION

Until the 1990s the municipality of Bonito had a strictly rural structure but with the decadence of agriculture and the increment of touristic activities, the local economy flourished and today the urban occupation predominates (Figure 3A), but concentrated on the margin of the Bonito stream. Until 2010 around 45% of its territory was still occupied by cattle raising in an area of planted pasture (Figure 3B).

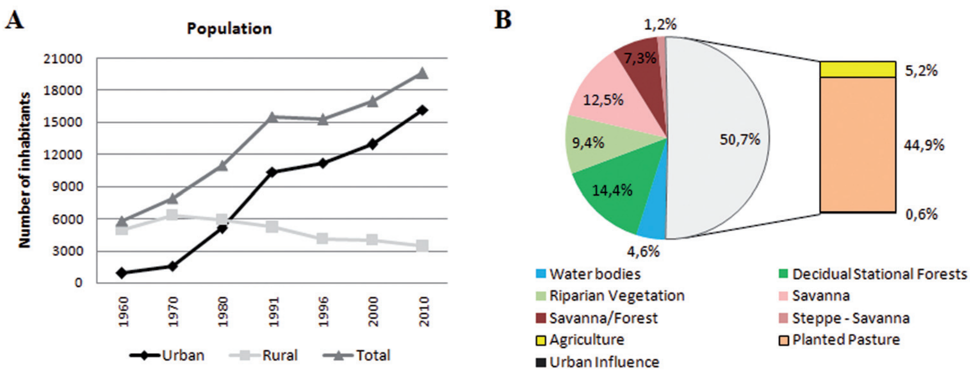
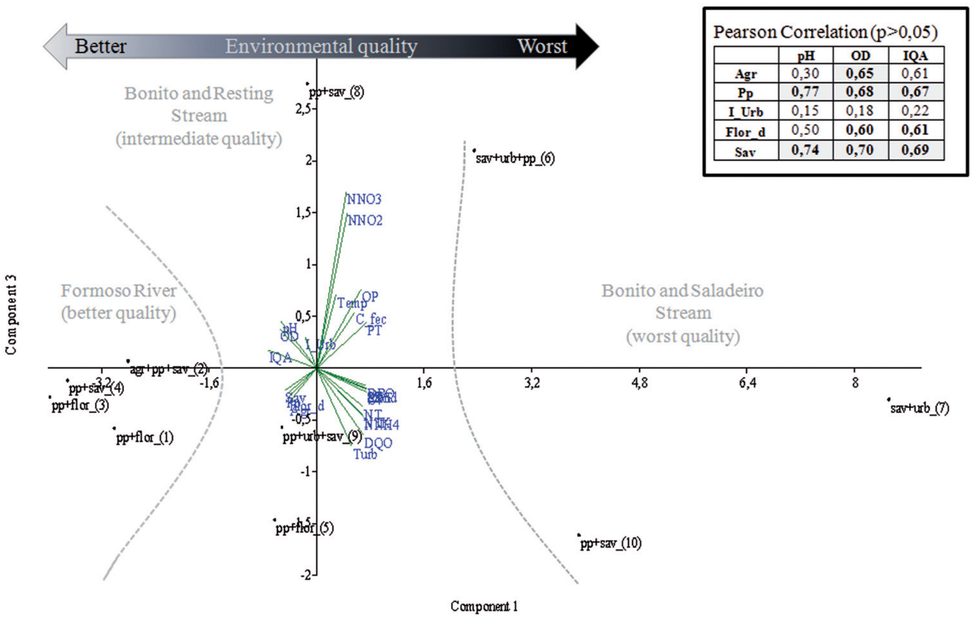


Figure 3 - A) Population of Bonito municipality between years 1960 and 2010; B) Percentage of occupied area in 2007

The changes in the natural landscape due to different types of land use are reflected in the water quality of the water bodies and are largely known and described in the works of Ferreira & Silva (2001), Ferreira (2005), Calheiros (2007) and in the reports and official publications of Mato Grosso do Sul State (BRASIL, 2002; MS, 2005a; MS 2005b; MS, 2009). These studies describe the degradation of the water quality along the Formoso river and especially along the Bonito stream, caused by the release of domestic sewage effluents, from a water treatment plant, and water from rain drainage, dumped directly in this water body.

These releases reflect in the changes of thermo-tolerant coliform parameters $DBO_{5,20}$, OD, P-total and total N (MS, 2009). Besides that, the two streams (Restinga and Seladeiro) which are tributaries to the Bonito stream, are inserted within the urban area of Bonito city and receive underhand a contribution of residual waters of this city (MS, 2005a).

In spite of this knowledge, there is still a very important question not properly evaluated: which landscape elements and how much urbanization are critical for the offer of ecosystem services related to the water resources? The answer can lead to a better understanding of the real influence of changes from land use on water resources, and can also help in decision-making on the adequate conditions for interference in the landscape, to obtain a better environmental quality. From this perspective, the correlation analysis (Pearson; $p>0,05$) and Principal Components were made, to investigate the relation between the water quality and the main landscape elements. For the calculations, the summed up elements occupied an area equivalent or larger than 70% of each segment from the water courses (Table 1) and were pre-weighted. The results can be observed in figure 4.



	pH	OD	IQA
Agr	0,30	**0,65**	0,61
Pp	**0,77**	**0,68**	**0,67**
I_Urb	0,15	0,18	0,22
Flor_d	0,50	**0,60**	**0,61**
Sav	**0,74**	**0,70**	**0,69**

Figure 4 - Analysis of the Principal Components and Pearson Correlation for the evaluation of relations between types and quantity of land uses and values of WQPs

This figure shows that among the 20 parameters evaluated only pH, OD and IQA indicated a significant correlation with the mapping typologies. In spite of the low correlation between water quality parameters and the mapping classes, it was possible to identify patterns of responses among different segments of the water flows. Thus when one observes the hydrographic basin of the Formoso river in its totality, one verifies that the environmental quality is better in relation to Bonito sub-basin. In other words, although the basin presents a mosaic of land uses between natural areas (savannas and forests), the predominance of natural areas in relation to the sub-basin (21% for the Formoso river and 14% for the segment of the Bonito stream) helps to dilute the impact caused by urban areas, including those concentrated on the sub-basin of Bonito.

In the segment related to the Bonito stream, where the savanna was the predominant physiognomy, but with the concentrated presence of urban areas, the environmental quality was worse. This leads to the reflection that the quantity of natural areas present in the segments is not sufficient to dilute the human influence. After this stream crosses the municipality of Bonito, although with a large area of natural vegetation, its presence does not overcome the concentrated pressure of use. In counterpart the data evidence that the segment containing the forest as a predominant element, does not fit among the segments of lower quality of water resources. It is important therefore to pay attention to this evidence and be careful in relation to the maintenance or recovery of forest areas, although in small fragments.

As the results of the statistical analysis were not sufficiently satisfactory in the grouping between water parameters and landscape elements, the calculation of ecosystem services was done using parameters which, although not significant, directly reflect the degradation from the offer of each service by the human action on the landscape (Table 3).

Table 3 - Water Quality Parameters (WQP) used for the calculation of ecosystem services

Ecosystem Services	WQP
Water quality (WQ)	Thermo-tolerant coliforms, BOD, COD, total nitrogen Kjeldahl, total phosphorus, turbidity and total solids
Erosion control (EC)	turbidity and total solids
Recreation and turism (RT)	BOD, NNH_3, turbidity and total phosphorus

The results obtained by the application of equations 1 and 2 presented earlier can be observed in figure 5.

Data related to each one of the services (Figure 5A) clearly show that, when one evaluates the hydrographic basin of the Formoso river as a whole, the offer of ecosystem services is close to the ideal condition, especially for the erosion control service. This result demonstrated that the large amount of natural vegetation still present in the basin, is able to plug the deleterious effect of human actions on the water resources. However, when the evaluation is made in a territorial scale of more detail – sub-basin of the Bonito stream – the variation in the offer of services clearly reflected the human interferences in the water quality and in the landscape.

All points under influence of the Bonito municipality present an accentuated degradation in the offer of the three services, independently of the quantity of natural vegetation still present in the segment. This fact was proven mainly by the negative value found for the service of water quality at the point of Saladeiro stream, indicating not only the degradation but also the total loss of this service. All this information allows stating that the natural vegetation is not able to plug the human impacts concentrated on the water resources within the sub-basin of the Bonito stream, causing impact out of the sub-basin.

In the evaluation as a whole (5B), one observes that inside the Bonito stream sub-basin there is a loss of ecosystem services of around 80% related to the entire hydrographic basin. This result strongly reflects the gravity of the human actions in this region, on the reduction of services offer.

To verify the direct influence of urbanization on the service degradation, a relative quantity of urbanized areas was related to each one of the segments with the values of the three services (Figure 6).

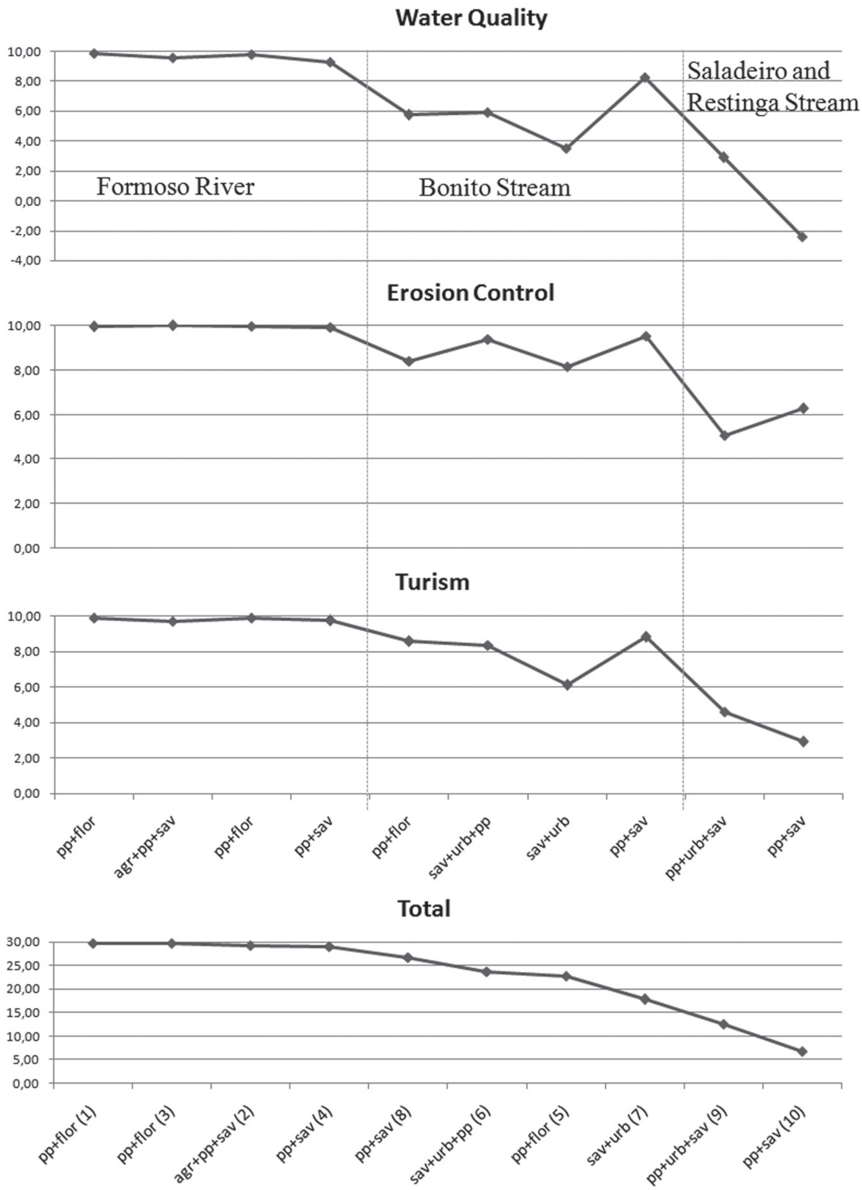


Figure 5 - Values of ecosystem services of (A) **Water quality, Erosion control, recreation, and eco-tourism; and** (B) **the total value of the three services taken together. (1), (2), (3) and (4): water collection points at the Formoso river (respectively 2073, 2065, 2047 and 2000); (5),(6), (7) and (8): water collection points at the Bonito brook (respectively 2014, 2010, 2008 and 2000); (9) water collection point at the Restinga brook (Restinga 2000);(10) water collection point at the Saladeiro brook (2000)**

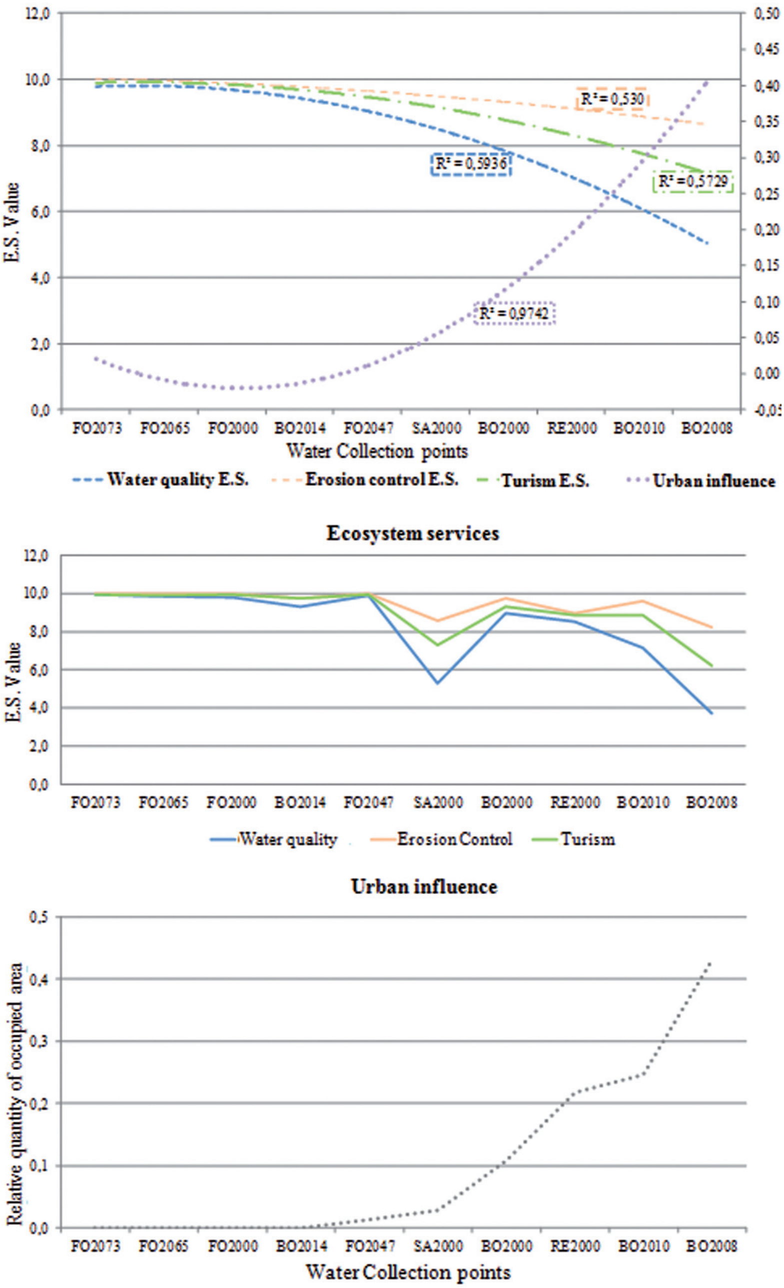


Figure 6 - **(A) Tendency for the degradation of ecosystem services due to the increase of urbanized area (B) values of three ecosystem services and relative quantity of urban area**

Other studies have already evaluated the degradation of water quality by the increase of human occupation, such as Lima (2011) and Hackbart (2012) for the coastal ecotone of Ilhabela (São Paulo State); Araujo & Zeilhofer (2011) for the basins of Cuiabá and São Lourenço rivers (Mato Grosso do Sul State); Zeilhofer *et al.* (2010) for the Upper Paraguay river basin, and by Sobrinho *et al*. (2012) for the Miranda river basin (Mato Grosso do Sul State). The last authors verified that the loss of water quality, especially the increase of Total Nitrogen and Total Phosphorus were related to the release of urban sewage, dairy products, irrigated rice plantation, slaughter houses and sugarcane cultures. Nevertheless the key question is to define the tradeoff which evidences the critical point between losses and gains, between uses and conservation. In this aspect Figure 6A demonstrates that with an urban occupation of 25% of the sub-basins, there is a degradation of 28% for the water quality service, 11% for the ecotourism and 4% for the erosion control.

The better quality of the erosion control service can be explained by the great quantity of native vegetation, still present in the segments analyzed. This vegetation is responsible for the retention of sediments, impeding their transport to the rivers and consequently allowing the occurrence of lower values of turbidity and total solids. However the direct release of effluents in the rivers, reflected in the parameters of water quality used for the calculation of recreation and ecotourism services (especially NNH_3 and Ptotal) and water quality (especially fecal coliforms, Ntotal and Ptotal).

The results obtained by this work would have been more conclusive if significant correlation and grouping values had been found between the landscape and the water quality. For this purpose, an analysis of the historical data series of water quality in parallel with a study on the changes occurred in the landscape along this period, would increase the accuracy on the degradation of the ecosystem services that are important for both the Bonito region and Pantanal.

CONCLUSIONS

The joint evaluation of elements from the landscape and the water quality in the hydrographic basin of the Formoso river, allowed concluding that in general, the presence of large natural vegetation areas dilutes the human actions, which reflects directly in the maintenance – close to the maximum offer of ecosystem services existing in the region, especially for the erosion control service. After an evaluation made in a segmented territorial scale, in sub-basins, the services degradation, especially the water quality, presented values varying between 10 and 77%, independently of the physiognomy type of the natural vegetation cover of the landscape. This is a specific characteristic of the sub-basins surrounding the municipality of Bonito, whose deleterious effects caused mainly by the release of domestic effluents, are exported to the entire basin, propagating its impacts and reducing the availability of services beyond the point of origin. Besides that, it was possible to conclude that the loss of water services due to human occupation presents an exponential tendency. Thus one verifies that one quarter of the territory with urban occupation, is already enough to cause around 30% of service losses of water quality. The erosion control services and ecotourism respond less emphatically to urbanization.

In spite of the limitations pointed out by this study, it is important to emphasize that it demonstrates that: (i) the form of calculation from ecosystem services, based on the comparison among environments of the same location, reflects more faithfully the value related to ecologic processes and to sustainability than the monetary value which is commonly attributed to biomes and ecosystems; (ii) the evaluation of services must be done individually, qualifying and quantifying the indicators which best represent a determined service in a locality; and (iii) it is necessary to identify the critical points between a certain type of land use/land occupation and the loss or degradation of a set of ecosystem services. Within this perspective the calculation of ecosystem services can be very valuable for environmental and urban planning as well as for studies of environmental impact which intend to interfere or not in a certain activity at the offer of ecosystem services.

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