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ECOSYSTEMS

Evaluating the impacts of Payment for Ecosystem Services (water supplies) in an agricultural system of the Brazilian Cerrado

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Abstract: In this study, we investigated the effects of the Payment for Ecosystem Services (PES) in an agrisystem located in the Brazilian Midwest. This PES benefits the owners of rural properties that encompass springs that feed the Abóbora River microbasin which supplies water for consumption in the city of Rio Verde, Goiás. We evaluated the percentage of native vegetation cover around the springs of the watercourses and also estimated its change over time (2005, 2011 and 2017). The vegetation cover of the Areas of Permanent Preservation (APP) increased by 2.24% on average, seven years after the implantation of the PES. There was little difference in the change of vegetation cover maintained over the study years (2005, 2011, and 2017), however, the vegetation cover increased for 17 springs, decreased for 11 springs, and was completely degraded for other two. To improve the performance of this PES, we recommend (1) expanding the program to include the APPs surrounding the springs, together with the legal reserves of each property, (2) implementing measures to ensure that properties are environmentally adequate, (3) including the properties in the Brazilian Rural Environment Register (CAR), and (4) obtaining environmental licensing for the activities undertaken within the Abóbora River basin.

Key words: Central Brazil, hotspot biome, native vegetation cover, springs, Water Production Program.

INTRODUCTION

The increasing shortage of water is a global environmental problem with grave implications for both the natural environment and humanity (Loyola & Bini 2015). This is an important issue given that water is an essential resource for the maintenance of biodiversity, the survival of humanity, and the continuity of many economic activities. In general, the scarcity of water is the result of human-modified landscapes such as the inadequate management of hydrological resources, in addition to factors such as climate change, the pollution of watercourses by domestic, industrial and agricultural effluents, and logging (Latrubesse et al. 2019, Pelicice et al. 2021). These factors may all compromise both the availability and the quality of water in an ecosystem (Dobrovolski & Rattis 2015, Loyola & Bini 2015). Therefore, adequate water conservation and management actions must be urgently implemented to mitigate the negative effects of this crisis (Cosgrove & Loucks 2015, Latrubesse et al. 2019).

The conservation and preservation of springs and their associated riparian vegetation is one alternative solution for the water crisis, given that these concepts can contribute to an improvement in the quality and quantity of the water available for a given region (Jardim & Bursztyn 2015). The adequate maintenance of springs and their riparian vegetation may reduce silting and the level of contamination by pollutants, in addition to increasing the infiltration of water into the ground and, in turn, the water table (Jardim & Bursztyn 2015). On the other hand, the suppression of the native riparian vegetation and the degradation of the stream environment typically lead to a reduction in discharge and loss of water quality, with knock-on effects for the productive sectors that depend on this resource (Ferraz et al. 2014).

The implementation of economic mechanisms for environmental management, such as the Payment for Ecosystem Services (PES) have enormous practical potential for the conservation of biodiversity and maintenance of environmental services (Wunder et al. 2008). These mechanisms are based in the "protector-receiver" principle, because they include the payment of incentives to the individuals that protect specific areas, with the aim of providing or ensuring a specific environmental service (Vilar et al. 2010). Considering that PESs are categorized into distinct modalities (see Pagiola et al. 2013), they may potentially be an excellent mechanism to be adopted as a public policy instrument (at the municipal, state or federal level) for the mediation or resolution of water crises.

Water Production Programs (WPP) are good examples of PESs (Pagiola et al. 2013), since they pay farmers to preserve the springs of the watercourses located on their properties (Chaves et al. 2004) in order to guarantee the quality of the water and its available supply in a given region. In Brazil, approximately 70 WPPs have been identified by Coelho et al. (2021), which are certified and monitored by the National Waters Agency (ANA). These programs are based on the PES scheme, following the protector-receiver principle, which provides the farmers with incentives to invest in the protection of the water sources located on their land. This allows farmers to receive both technical and financial support for the implementation of good conservation practices on their lands (ANA 2021). In addition to the economic contribution, they receive for productivity on their land, these farmers also contribute to the supply of good quality water in their region (ANA 2021).

Despite the clear benefits offered by the WPPs, few studies have evaluated the impacts of this type of initiative in Brazil (e.g., Ruggiero et al. 2019). This means that there is no detailed environmental analysis of the impacts of WPP implementation certified by the ANA, which impedes any systematic evaluation of the target areas prior to and following the existence of this mechanism. In 2011, a WPP was implemented in the municipality of Rio Verde, Brazilian Midwest. This WPP is focused on the springs of watercourses located within the Abóbora River microbasin, which supplies water for both domestic and industrial use in this municipality. Recently, Morais et al. (2022) characterized the landscape composition in the total area of this WPP and also provided a species list of fauna (amphibians, birds, fish and medium and large terrestrial mammals) and woody flora that occur in this location.

However, no previous study has evaluated the impacts of this PES program on the native vegetation around the springs located in this microbasin. In our study. we fill this knowledge gap by calculating the percentage of native vegetation cover around the springs of the watercourses and also estimating the change over time (2005, 2011 and 2017). Specifically, we tested the hypothesis that the establishment of PES has had a positive effect on the conservation of the springs in the program, based on the assumption that the springs should increase the percentage of native vegetation cover over time.

MATERIALS AND METHODS

Study area

The present study was conducted in the municipality of Rio Verde (17°47’7.81” S, 50°54’29.28” W) which is located in the southwest of the state of Goiás in the Brazilian Midwest. Rio Verde has become one of the key grain-producing regions in Brazil in recent decades. It has an estimated population of 236,000 inhabitants (IBGE 2019) and covers an area of approximately 8,000 km², of which, around 75% is farmland (e.g., plantations of maize and soybean) and cattle ranches (Siqueira & Faria 2019). The rest of this municipality, located entirely within the Cerrado hotspot, encompasses remnants of the original native vegetation, such as forest formations, which are often associated with the watercourses in the region needing to be conserved (Siqueira & Faria 2019).

The present study focused specifically on 55 natural springs distributed in 26 rural properties located within the hydrographic microbasin of the Abóbora River (Figure 1). This microbasin is located entirely within the municipality of Rio Verde and covers an area of 4,992 hectares. This area is the target of an important PES program, known as the Water Production Program (WPP). In 2011, the WPP was implemented by the municipal law 6,033/2011 (Rio Verde 2011), which was consolidated in 2013 by municipal

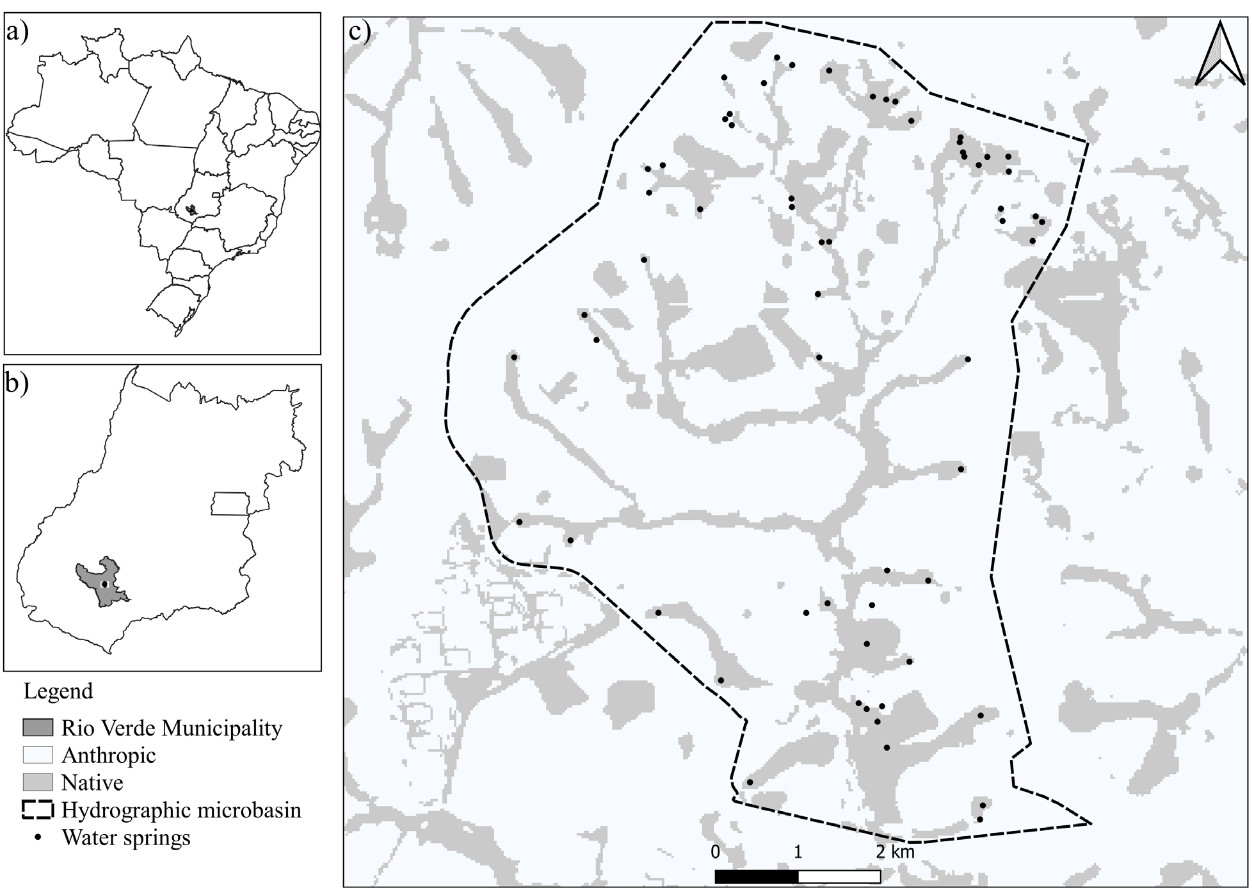

Figure 1. Location of the state of Goiás (a), municipality of Rio Verde (b), and Abóbora River microbasin (c), upstream from the municipal water supply acquisition point.

law 6,290/2013 (Rio Verde 2013). These legal instruments were used to identify and catalog the springs of the watercourses that feed the Abóbora River system, which is the principal water supply of Rio Verde.

This program has been certified by ANA and aims to promote the recuperation and conservation of the springs that supply water to Rio Verde through the financial compensation of local farmers for the provision of environmental services. In addition to the financial benefits, the Rio Verde Municipal Secretary of the Environment provides these local farmers with technical support for the implementation of good conservation practices. This initiative aims to guarantee the medium to long-term implementation of Areas of Permanent Preservation (APPs) that surround the springs, as well as the restoration of the streams that have undergone an extreme level of degradation (Benincá & Clemente 2021). These initiatives include (1) fencing-off the APPs of the springs, (2) constructing terraces to prevent erosion, (3) planting seedlings of native tree species to restore the APPs of the springs, and (4) promoting events that contribute to the environmental awareness of the local population.

Recently, Morais et al. (2022) characterized the landscape in the WPP area and found that remaining native vegetation represented only 21.32% (1,064.73 ha) of the total mapped area. These authors also found that the remaining native vegetation was distributed in 80 fragments, with sizes varying between 0.05 and 224.23 ha. In addition, this study identified that the WPP area had 300 registered species: 20 anurans, 100 birds, 10 fish, 16 terrestrial mammals (medium and large-sized), and 154 woody plants. The species list provided by Morais et al. (2022) includes species considered endemic to the Cerrado (e.g., Anuran – *Barycholos terntezi* and Mammal – *Callithrix penicillata*) and also threatened species (e.g., Mammals – *Herpailurus yagouaroundi*, *Myrmecophaga tridactyla* and *Tapirus terrestris*).

Analysis of land-use and cover

Information on vegetation cover and land-use within the Cerrado biome was obtained from the *mapbiomas* database (Projeto Mapbiomas 2019), available at: http://mapbiomas.org/. The analyses presented here were based on the native vegetation cover and land-use data for 2005, 2011, and 2017. The images of the target areas – 55 springs located within the Abóbora River microbasin (Figure 2) – were then cropped for analysis. A buffer with a radius of 50 meters was established around each of the 55 springs. The analyses were run in the R program (R Core Team 2020) using the *raster* (Raster 2019) and *rgdal* packages (Bivand et al. 2022). The data were assigned to one of two categories: (i) natural cover – areas covered with forest formations (e.g., gallery forest), natural grassland (e.g., humid scrub grassland) or vereda (buriti palm swamp); and (ii) anthropogenic habitats – areas covered by forestry plantations, farmland or cattle pasture. A detailed description of each category can be found at http://mapbiomas.org/pages/database/mapbiomas_collection. Following this classification, the percentage of native vegetation present at each spring was calculated for 2005, 2011 and 2017.

Data analysis

To evaluate the impacts of the WPP on the target springs, the following dependent variables were considered: (1) percentage of native vegetation for each year (2005, 2011, 2017) and (2) change in native vegetation cover between years (2011-2005 and 2017– 2011). So, prior to the statistical analyses, the data were tested for the assumptions of normality and the homogeneity of variances using Levene's test. As the data

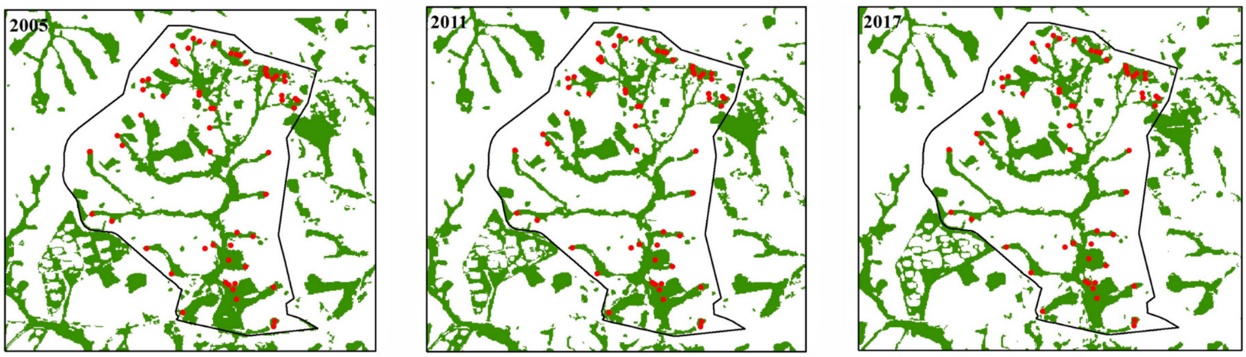

Figure 2. **Spatial distribution of the native vegetation cover (in green) within the hydrographic microbasin of the Abóbora River among the study years (2005, 2011, and 2017).**

satisfied these assumptions, it was possible to use a repeated-measures Analysis of Variance (ANOVA) to test the hypothesis that the WPP had a positive effect on the percentage of native vegetation associated with the springs of the watercourses located in the Abóbora River microbasin. We considered 2011 as the reference point for this analysis, given that this was when the WPP was implemented in the Abóbora basin. For each spring, the percentage of native vegetation cover (%VC) was calculated for 2005 ($\%VC_{2005}$), 2011 ($\%VC_{2011}$), and 2017 ($\%VC_{2017}$). The change in native vegetation cover was also calculated for two periods: (i) 2011–2005 (= $\%VC_{2011}$ - $\%VC_{2005}$) and (ii) 2017–2011 (= $\%VC_{2017}$ - $\%VC_{2011}$). A paired *t* test was used to evaluate the hypothesis that the WPP had a positive effect on the native vegetation cover surrounding the springs of the study streams. The principal prediction was that the implementation of the WPP in the Abóbora basin in 2011 resulted in a significant increase in the native vegetation cover associated with the springs in comparison with the previous years. The analyses were run in the R program (R Core Team 2020).

RESULTS

The number of springs with 75% or more native vegetation within the buffer increased between 2005 and 2017 (Figure 3). In this period, the native vegetation cover surrounding 27 of the study's springs (49.1% of the total) remained unchanged, of which 20 had 100% of the area of the respective buffers covered by native vegetation. By contrast, in two cases, the native vegetation cover was practically 0% in both years. In 17 springs (30.91% of the total), the native vegetation cover expanded by 24.22% on average (SD = 22.89%, range = 1.79–71.9%; n = 17 springs), whereas 11 (16.36%) springs lost an average of 10.51% of their native vegetation (SD = 9.41%, range = 0.9–33.03%; n = 11 springs) between 2005 and 2017.

In 2005, the mean native vegetation cover represented 76.13% of the area within the buffer established around each of the study's springs (Figure 4; Table SI – Supplementary Material). This cover increased to 79.3% in 2011 and then to 81.53% in 2017 (Figure 4; Table SI). Despite this progressive increase in the percentage of native vegetation cover around the study's springs, the variation was not significant ($F_{(2,162)}$ = 0.41; p = 0.665). Similarly, native vegetation cover increased 3.15% on average between 2005 and 2011, and 2.24% between 2011 and 2017, but there were no significant differences in the change of the native vegetation cover between the two periods (*t* = 0.36; df = 54; p = 0.719).

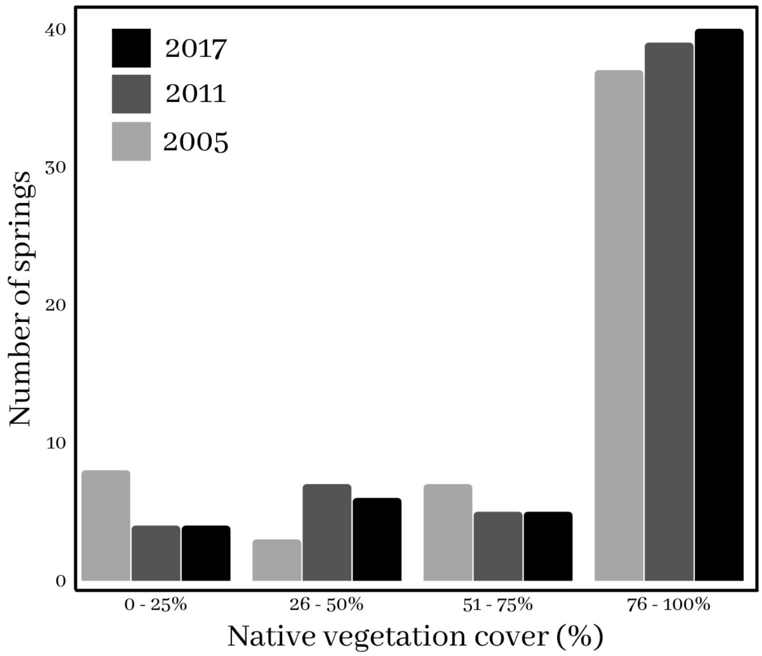

Figure 3. **Number of springs in each class of native vegetation cover between 2005, 2011 and 2017.**

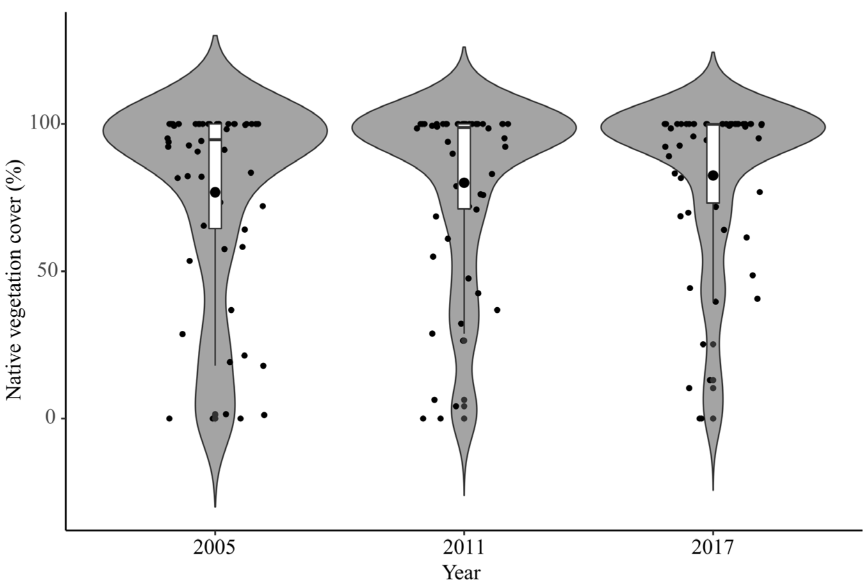

Figure 4. **Violin plots demonstrating the mean, median and variation of native vegetation cover around the springs over the years (200, 2011 and 2017).**

DISCUSSION

Our present study describes the dynamics of the native vegetation cover over a 12-year period in the Areas of Permanent Preservation (APPs) surrounding 55 target springs of a Payment for Ecosystem Services (PES) program in the Cerrado Biome. The initial prediction of this study was that the implementation of the Water Production Program (WPP) in the microbasin would have had a positive impact on the native vegetation cover surrounding of these springs and as a consequence, on the provision of these environmental services (i.e., the supply of water). We observed that 76% of the studied springs maintained or increased their native vegetation cover within their APPs over time. Despite this result, we did not find any significant differences in the native vegetation cover between 2005, 2011 and 2017. Therefore, we did not corroborate our initial hypothesis.

Despite the lack of significant findings, we can highlight that this WPP has contributed to the maintenance of native vegetation around springs that are located in an area of intense agricultural activity. This is important, because despite Brazilian environmental legislation which specifically protects the native vegetation associated to areas of permanent preservation (Brancalion et al. 2016), the provision of critical environmental services may be compromised by the lack of incentives or inadequate management of natural resources (Pagiola & Platais 2002). In addition, the lack of environmental awareness on the part of rural landowners is also preoccupying, given that the existing legislation (federal law 12,651/2012 - the Native Vegetation Protection Law) does not obligate landowners to recuperate native vegetation in plots within the APPs that are considered to have been consolidated as part of their rural property (Brasil 2012). In this context, empirical field data have shown that the plant species composition and richness of these consolidated areas may be significantly different from those of undisturbed APPs (Siqueira et al. 2016).

This scenario may be further aggravated by the fact that the owners of these areas may often not recognize the importance of maintaining or restoring the native vegetation on their properties, given that they are not compensated financially for the ecosystem services generated by any such measures (Pagiola & Platais 2002). On the other hand, the rural landowners that recognize the importance of ecosystem services are more likely to implement management measures that have positive impacts on the environment (Lima & Bastos 2020). This is likely to be the case in the present study area of the Abóbora River microbasin, given that while it is part of a major farming region, the local landowners' opinions appear to be favorable to the measures covered by the WPP.

In addition, we observed that the percentage of vegetation cover associated with the study's springs did tend to maintain over time (2005 – 2017). This result is important, considering the contribution of the Rio Verde municipality to the Brazilian production of grain (soybean and maize), which has transformed much of the region's natural habitats into anthropogenic landscapes over the past few decades (Siqueira & Faria 2019). In particular, the latter authors found that by 2016, only 23% of the municipality was covered with native vegetation (e.g., grassland, forest, and savanna formations). This pattern has been repeated within the Abóbora basin on a smaller scale, where Morais et al. (2022) found in 2018 that approximately 21% of the total area of this basin was covered with native vegetation.

In contrast with previous studies (Siqueira & Faria 2019, Morais et al. 2022), the present analysis focused on an even more restricted scale, that is the 50 m buffer around the springs of the study's streams. In 2017, the springs that feed into the Abóbora River had a mean native vegetation cover of approximately 80%. The springs of watercourses are considered to be environmentally, economically, and socially important, given that they provide conditions for the survival of a region's native fauna and flora, as well as protecting the most valuable resource – water – needed for many economic activities (Falkenmark & Molden 2008). Therefore, the approach adopted in the present study permitted the description of processes on a fine spatial scale, along with the variation over time, providing an accurate depiction of the study landscape. It is important to provide fine-scale spatial data to better characterize the environments within agroecosystems (Santos et al. 2021), thus making the information presented in this study essential in the planning of future conservation actions for biodiversity and ecosystem services.

As the WPP is a long-term initiative, future management actions may guarantee more positive results, in terms of the both the conservation of biodiversity and the long-term guarantee of water supplies. Such actions can consider (i) expanding the program to formally include the APPs surrounding the springs together with the legal reserves of each property (e.g., Metzger et al. 2019), (ii) the implementation of measures to ensure that the properties become environmentally adequate (e.g., to implement the agroforest system and/or reduce the use of pesticides), (iii) the inclusion of the properties in the Brazilian Rural Environment Register (CAR), and (iv) obtaining environmental licensing for the activities undertaken within the Abóbora River basin.

Ultimately, the PESs (e.g. WWP) may represent a complementary mechanism of environmental management, which can contribute to the effective protection of natural resources, such as the native vegetation, and the provision of important ecological services (Pagiola et al. 2013). In this sense, the Water Production Program (WPP) of Rio Verde has contributed to the maintenance of native vegetation around the springs located in an area that has historically suffered intense anthropic impacts (e.g., Siqueira & Faria 2019). Therefore, we recommend that municipalities that also suffer from anthropogenic changes similar to observed in Rio Verde should adopt WWPs as an environmental management mechanism for a more effective preservation of Cerrado water resources. This is particularly important, because this tool may represent a viable alternative for the balancing of economic growth and environmental preservation in a given region.

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SUPPLEMENTARY MATERIAL

Table SI.

How to cite

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Author contributions

FKO, CES and HSP: Contribution to data collection, data analysis and interpretation, manuscript preparation and critical revision. MNS: Contribution to data collection, data analysis and interpretation, manuscript preparation, critical revision, and adding intellectual content. ARM: Substantial contribution in the concept and design of the study, contribution to data collection, data analysis and interpretation, manuscript preparation, critical revision, and adding intellectual content.