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Water production in a Brazilian montane rainforest: Implications for water resources management

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ABSTRACT

The objective of this study was to evaluate water production within a national park in order to characterize quantity and quality when associated with preserved landscapes in rainforests. After acquiring the necessary quali-quantitative information, a second objective was defined, aiming to propose a new approach for water valuation in preserved forest areas within a scenario of integrated water resources management. Field campaigns were conducted in subwatersheds within the Serra das Lontras National Park in order to collect hydrological and hydrochemical data. Results showed that the effluent streams presented perennial water production of 4,000 l ha^{-1} day^{-1} in the most conservative scenario. Regardless of flow rate regimes, waters were well-oxygenated and presented low salinity and low concentration of total suspended solids. These results prove the effectiveness of a montane rainforest in providing protection to water bodies and in delivering important ecosystem services. Thus, we propose the inclusion payments policies for watershed services (PWS) by water resources management from an alternative approach. In conclusion, these policies could be reviewed with the objective of adding water valuation, making programs more robust and attractive to rural producers and other stakeholders. Water catchment and treatment agencies could also be part of this process, including PWS in their revenue budgets, and using their prices to stimulate the ecosystem service market.

1. Introduction

Water is one of the main natural resources that living beings depend on, regarding both quantity and quality. Climatic changes and oscillations, population growth, and complex economic activities promote increases in pressure on water resources, compromising runoffs and the quality of the world's large freshwater ecosystems (Grafton et al., 2013). In this context, according to Tundisi and Barbosa et al. (1995), knowledge on environmental processes, water uses, and the socioeconomic aspects of watersheds is paramount for formulating water resource management strategies.

The volume and hydrochemical characteristics of water produced by areas with preserved vegetation cover reflect the interactions of factors such as climate, soil, relief, geology, and vegetation of a watershed (Neary et al., 2009; Souza et al., 2013; Van Lear et al., 1985). According to Sopper (1975) and Neary and Leonard (1978), watersheds that present dense forest cover provide protection against soil erosion and excessive inorganic matter lixiviation into river waters. Areas with these characteristics are in better condition to produce high-quality water (Bateni et al., 2013; Fiquepron et al., 2013; Jayawardana et al., 2017).

Investing in the protection and conservation of forest areas in watersheds may be the most prudent and lucrative path, as shown by Chichilnisky and Heal (1998). This investment is able to reduce the cost of water treatments, as indicated in the studies conducted by Ernst et al. (2004) and Abildtrup et al. (2013). Thus, promoting mechanisms that alter agricultural land uses into forest land uses in zones that are strategic for fluvial and underground recharge is paramount to allow significant volumes of water with high environmental quality and low economic cost.

In Brazil, initiatives at the federal level (ANA - Agência Nacional de Águas, 2011) and also by state water supply agencies support maintenance and regeneration actions towards native vegetation in areas often as far as a hundred kilometers upstream, in order to guarantee the runoffs and to reduce the load of inorganic matter drained. These initiatives are structured within the principle of Payment for Ecosystem Services (PES). Regarding water resources, approximately 129 initiatives of Payment for Watershed Services (PWS) have been mapped

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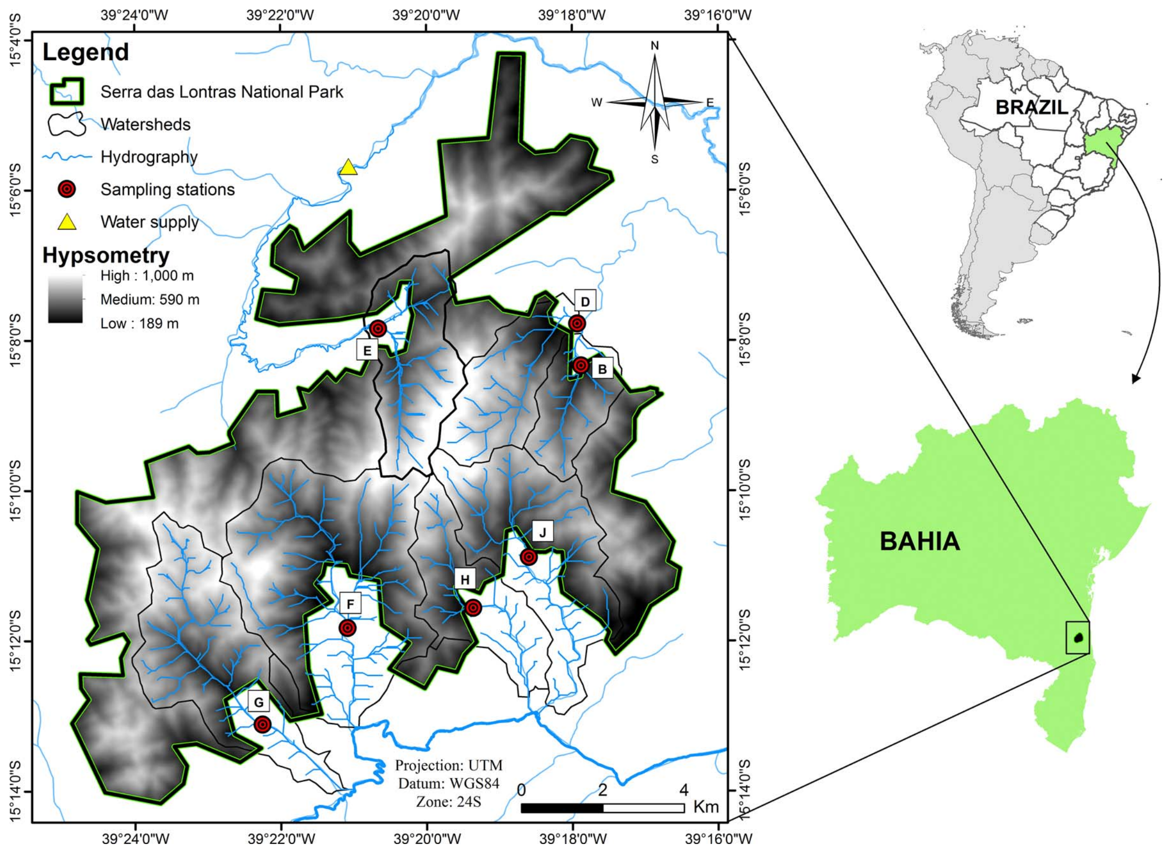

Fig. 1. Location of sampling stations in watersheds within the SLNP.

in Brazil (http://www.brazil.forest-trends.org/). According to Guedes and Seehusen et al., 2011, the effectiveness of most programs is assessed through monitoring activities regarding the preservation of a pre-determined area. However, according to Forest Trends (2015), the implementation of monitoring activities regarding water volumes produced and the quality of these waters is low.

Several aspects should be taken into account when executing PES-PWS in Brazil. Research studies should be especially encouraged in order to implement this type of program, be them of either a physical/environmental nature or from a political or socioeconomic standpoint. Studies are indispensable tools to measure the productive ability of a natural system and to identify the needs of a certain region in face of socioeconomic objectives. Liu et al. (2013) and Pereira et al. (2015) conducted participatory action research projects considering natural drivers in watersheds and the environmental perception of water users. According to Quintero et al. (2009), experiments such as these serve as tools for the decision-making process, diagnosing the implementation of a PWS program in a given region as either viable or not.

Araújo et al. (2015) reiterated that investments in research and development of water resource management plans are ineffective if monitoring and inspection actions are not implemented. Monitoring should aim to evaluate the effectiveness of the program regarding not only water production but also water quality, as indicated by He et al. (2015), who detected gradual and sharp changes in water quality after the implementation of a PWS program in essentially agricultural areas. In order to understand the processes related to PES programs, Grimma et al. (2016) analyzed 40 PES programs in Latin America since 1990. These authors identified that an essential characteristic of successful programs was the use of data from local-regional studies, incorporated into cultural and political contexts.

The use of this type of data in order to guarantee the success of a program should be based on the execution of correct policies, encompassing innovative public incentive and subsidy mechanisms, as well as awareness and transparency. These policies should necessarily follow these recommendations because environmental services become commodified and, therefore, promote complex relationships of power, which can cause value subjectivities and imbalances from one region to the other, causing dissatisfaction among those participating in the program. Thus, Guerra (2016) considers PES an important tool, but also one that requires careful analysis before implementation in order for it to be more coherent (optimization between theory and practice) and flexible, and to guarantee that the social and cultural aspects of the region are taken into consideration. According to Muradian et al. (2010), the effective policies of PES initiatives can be grouped according to three criteria: i) importance of economic incentive; ii) transparency in transactions between suppliers, intermediates and buyers of an environmental service; and iii) degree of commodification of these services.

A systemic approach was taken towards the relationship between a montane rainforest and water production and water resource management based on data obtained from subwatersheds located within a National Park in the southern portion of the State of Bahia (northeastern Brazil). The objective of the present study was to evaluate the quantity and quality of water produced within a preserved area in order to characterize these measures when associated with preserved rainforest landscapes. After acquiring the necessary quali-quantitative information, a second objective was defined, aiming to propose a new approach to water valuation in PWS policies of preserved forest areas in a scenario of integrated water resources management.

2. Material and methods

2.1. Study area

The present study was conducted in the Serra das Lontras National Park - SLNP (ID No. 555,576,352 in the World Database on Protected

Areas: http://www.wdpa.org/parque-nacional-da-serra-das-lontras-park). The SLNP covers an area of approximately 114 km^2 located in the southern region of the State of Bahia, northeastern Brazil, between geodesic coordinates 15°4′ and 15°14′S and 39°16′ and 39°25′W (Fig. 1).

The climate in the region, according to the international classification proposed by Koppen (1948), is type Af, which represents a warm and humid tropical climate, without a defined dry season and with annual rainfall of approximately 1500 mm equally distributed over the year. Temperature varies only slightly throughout the year, with mean values of approximately 23 °C, and minimum temperatures never below 18 °C (BRASIL - Ministério das Cidades, 2016). This climate typology promotes exuberant vegetation cover, classified as montane rainforest, which is in an excellent state of preservation (Pardini et al., 2009). The preservation status of the region is attributed to its designation as a National Park, which according to Brazilian legislation is classified as one of the most restrictive types of Conservation Units regarding the state of the ecosystems found within its limits. The main land use in the area is characterized by century-old cacao cultivation shadowed by the canopies of emerging trees and common subsistence agriculture.

The geology of the study area is dominated by orthogneissic rocks of the Buerarema Complex, with fissure aquifer systems that belong to the Hydrogeological Province of the Eastern Shield of the Crystalline Domains (CPRM - Serviço Geológico do Brasil, 2004). Soils of the lowest portions of SLNP are predominantly represented by deep, porous, and well-drained latosols, while litholic soils are found in the areas of steeper relief (Nacif et al., 2009). The relief of the Serra das Lontras is quite wavy, with an approximate altitude of 1,000 m at its highest point, presenting steep slopes and occasional scarps.

2.2. Methodology

After analyzing and interpreting the area using Geographic Information System (GIS) tools and field surveys, a total of seven subwatersheds were included in the present study. These subwatersheds were chosen because they represent water courses with springs within the area of the SLNP. Sampling stations were located as close as possible to the borders of the Park (Fig. 1). These locations were systematically visited during 16 field campaigns, between April 2012 and January 2013. Table 1 presents a summary of these subwatersheds, all of which are typical of headwater regions, with encased valleys and mean slope values within the lower limit of a strong wavy relief classification. Subwatershed E (Rio Una) was particularly important to include in the present analysis considering that it represents the water source used to supply two small municipalities (Buerarema and São José da Vitória), which together add up 25,300 inhabitants (IBGE - Instituto Brasileiro de Geografia e Estatística, Cidades, 2016).

Flow rate measurements were conducted using the area *versus* velocity method. To do so, measuring tapes, rulers and a flow meter were used. In these measurements the lower speed accuracy limit ($\pm$ 0.1 ft s^{-1}) calculated by the flowmeter was always used: (http://www.globalw.com/downloads/flowprobe/FP111.pdf). Portable electrodes of an YSI® 556 MPS multiparameter probe were used in order to determine temperature, pH, electric conductivity, and dissolved oxygen. Water samples were collected in duplicates using wide mouth flasks, transferring their contents into previously decontaminated flasks that were stored in polystyrene boxes with ice and transported to the Limnology Laboratory of the Universidade Estadual de Santa Cruz. Concentration of total suspended solids (TSS) was determined in the laboratory by gravimetric analysis after filtration through a 47-mm GF-F membrane, previously tared (Strickland and Parsons, 1972). The variation coefficient between duplicates was always below 10%.

Fixed (FS) and volatile solids (*vs*) of the SPM were separated through the calcination method, performed at 450 °C for four hours (Heiri et al., 2001). Duplicates and “analytical blanks” were used to evaluate the quality of the data obtained. All values above 100% were discarded, being considered beyond the detection ability of the method used. The variation coefficient between duplicate pairs ranged between 0 and 9%, with a mean value of 2%.

3. Results and discussion

3.1. Water production

Fig. 2 presents the flow rates recorded throughout the sampling period. Two different moments are distinguishable in the hydrograph of the streams sampled. The first represents a period with higher flow rates, which was concentrated over the months spanning the middle of the year. The second was a drier period, observed during the first and last field campaigns. Despite the reduced number of field campaigns, sampling was considered to have contemplated all the varying phases of the hydrograph and the hydrochemical characteristics associated with seasonal variations in the area. In fact, some of the streams sampled varied as much as one order of magnitude throughout the sampling period (Fig. 3). These values were within the intervals recorded in watersheds with preserved forest cover in Brazil (Forti et al., 2007), which are characterized by perennial regimes and high water productivity.

Table 2 also presents daily water production per hectare of the subwatersheds studied. If on one hand there were significant differences between median values of flow rates recorded due to the obvious influence of the different areas of each watershed, on the other hand water production presented values within a more restricted interval of values. The differences found among production values were due to either the presence or absence of shallow soils, rock outcrops, and even watershed slope variations, which can either favor or not surface runoff over infiltration.

Therefore, results demonstrated that in the most conservative scenario each hectare of montane rainforest provides at least, during 95% of time, approximately 4,000 L of water per day. These results offer the first characterization of runoffs found in preserved montane forest areas of southern Bahia and represents implications for water resource management, as discussed below in topic 3.2.

Fig. 3 presents the values of physicochemical parameters obtained over the various phases of the hydrograph. The low regression value found is particularly interesting because, although variations as high as one order of magnitude were recorded for the flow rates, the measured parameters occurred within a narrow interval of values. Waters were

Table 1
Characteristics of the watersheds sampled in the SLNP.

Watersheds	Area (ha)	Forest (%)	Sampling stations altitude	Slope average (%)	Stream order	Drainage density	Compactness factor
B	326	97	280	20	3rd	2.31	1.25
D	714	99	200	23	3rd	2.32	1.36
E	924	91	300	27	3rd	2.31	1.39
F	1,746	93	180	25	4th	2.44	1.27
G	1,184	96	240	24	3rd	2.41	1.57
H	403	99	300	24	3rd	2.26	1.64
J	706	97	300	23	3rd	2.37	1.52

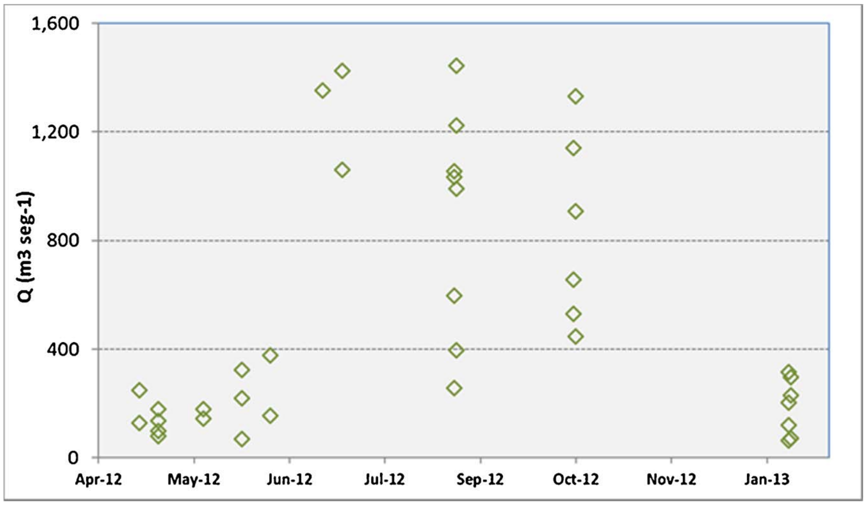

Fig. 2. Flow rates recorded in all studied watersheds in SLNP, throughout the sampling period.

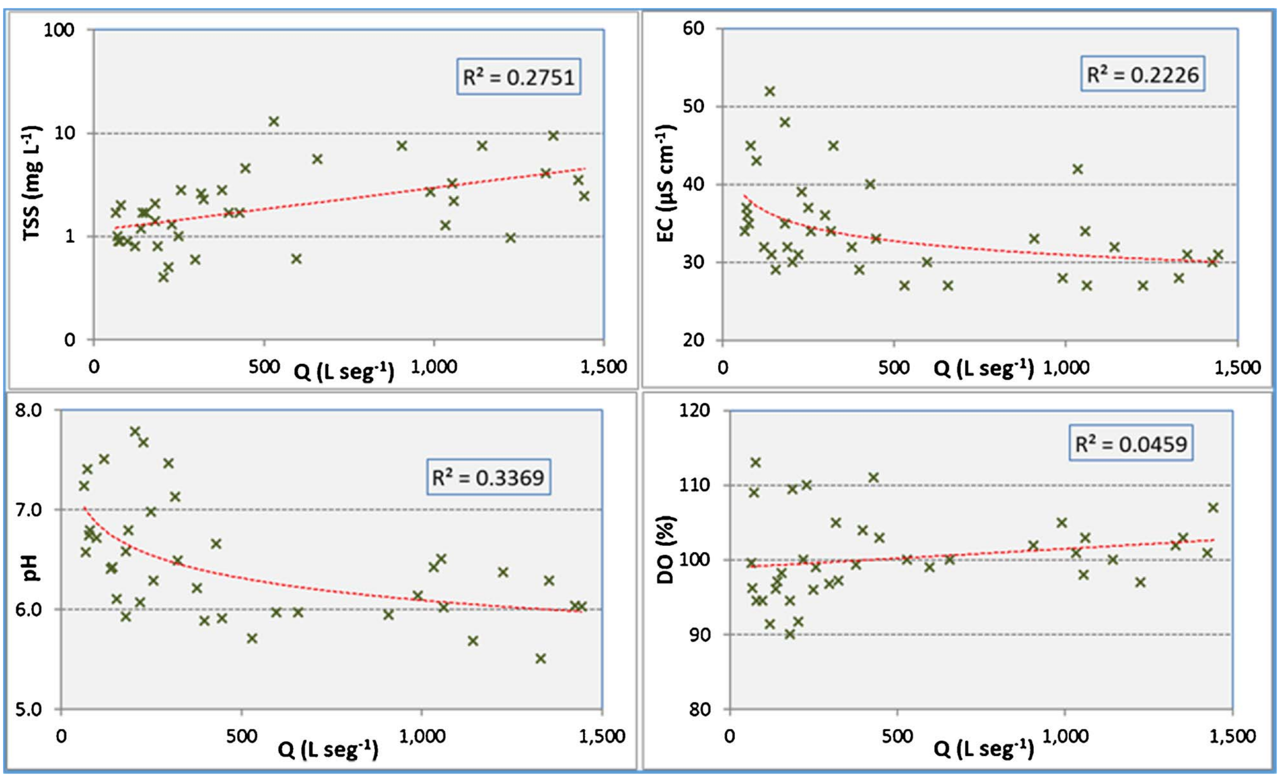

Fig. 3. Physicochemical parameters (TSS = total suspended solids; EC = electrical conductivity; pH; DO = dissolved oxygen saturation) and flow rates, recorded in all studied watersheds in SLNP throughout the sampling period.

Table 2
Flow rates and water production in watersheds sampled in SLNP.

	B	D	E	F	G	H	J
n	6	5	6	5	5	4	3
Discharge (l sec $^{-1}$)							
Min	68	188	80	64	180	120	137
Max	447	1,330	1,353	1,060	1,443	529	1,225
Median	88	298	669	657	1,142	276	204
Water production (l ha $^{-1}$ day^{-1})							
Min	18,022	22,750	7,481	3,167	13,135	25,727	15,542
Max	118,469	160,941	126,514	52,454	105,300	113,413	149,915
Median	23,190	36,061	62,509	32,511	83,335	59,065	24,965
5 Percentile	18,287	23,524	10,964	3,949	15,120	26,820	16,485

clear, presented low salinity, and were well-oxygenated and slightly acidic. This fluvial typology is characteristic of well-preserved watersheds found in rainforest areas (Andrade et al., 2011; Souza and Paula, 2013; Stallard and Murphy, 2014; Paula and Mozeto, 2001).

The vegetation cover within SLNP reduces the erosive effect of rain, preventing the direct carrying of sediments into the aquatic environment, resulting in the extremely low SPM values found even during periods of higher rainfall rates. Low salinity, represented by the electric conductivity, was influenced by two factors: climate typology, with constant water surplus throughout the year, and local lithology composed of granulites, which usually present low electrolyte contents. The steep relief of the Park is favorable for the occurrence of waterfalls and rapids, therefore promoting the oxygenation of these waters. Moreover, since there are no significant sources of organic pollution in the area, oxygen saturation always oscillated around 100%. Values of pH revealed neutral to slightly acidic waters, resulting from the presence of weak organic acids.

Speciation of total suspended solids (TSS) (Fig. 4) shows the predominance of the organic fraction (*vs*), equally reflecting the excellent preservation status of the vegetation cover within the studied subwatersheds. This reduces inorganic substrate denudation processes and favors only the drag of organic matter provided by the litter.

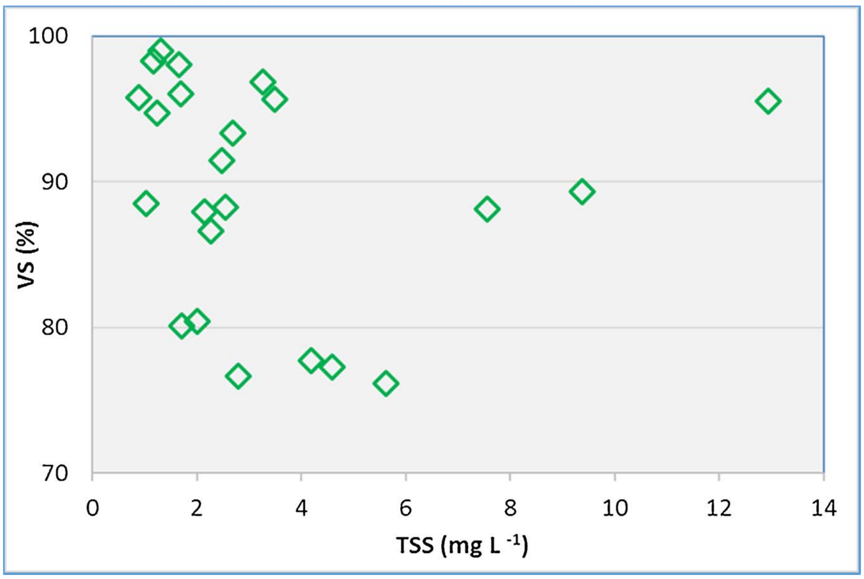

Fig. 4. Total suspended solids and volatile solids percent, in selected samples from studied watersheds in SLNP.

3.2. Implications for water resources management

In face of the scenario depicted by the water production results, SLNP was proven to contribute a significant net water production with high environmental quality to its subwatersheds. Levels of water productivity are high in preserved rainforest areas, therefore comprising an instrument of high environmental and economic potential. Conservation units are important not only for the environmental conservation actions they promote, but also due to the ability to illustrate scenarios of high natural resource productivity in areas with no human interference. This ability should serve as a subsidy for the management of these resources not only in the Atlantic Rainforest but also in other biomes around the world.

The water production observed in the subwatersheds of SLNP is one piece of data among several others that reinforces the buffering function of preserved forest areas over water bodies, guaranteeing their quality and quantity. Currently, this important environmental function promoted by the conservation area provides economic value and, therefore, may be exploited through legal mechanisms (judicial, political, and economic). Thus, ecosystem services, as stated by Guswa et al. (2014), become strategic factors for decision makers, since the valuation of natural processes may create conditions that benefit the economy, and human health and well-being.

The proposal for creating SLNP was not directly motivated by water production, but rather by the need for local biodiversity conservation. By identifying the hydric potential of the area, the present study allows proposing the creation of preservation areas not only through conventional mechanisms (decrees and expropriations). Proposals for creating preserved areas for water production may stimulate the dialogue among water users intermediated by an ecosystem service valuation policy, such as the Payment for Environmental Services Program (PES).

The PES program for watersheds (PWS) consists of an internationally disseminated management element, where each country has a specific way of managing their water and environmental resources, defined according to the characteristics and needs of their society, and their political and economic ability. According to Vogl et al. (2017), PWS programs are expanding, but their full potential has not yet been reached. In Brazil, the implementation of PES-PWS programs occurred quite recently through experiments and pilot plans in a few watersheds. According Garcia et al. (2013), given the context of Brazil's new Forest Code, these policies for economic incentives will be paramount in order to safeguard Brazilian natural ecosystems.

Although PES in Brazil is in accordance with international trends and that some advances can already be detected at a local scale, in most of the country the execution of PWS is still in its infancy (ElabrasVeiga and Magrini et al., 2013). The reasons for this low level of implementation of PWS in Brazil, according to Forest Trends (2015), Richards et al. (2017), and Zanella et al. (2014), are problems such as bureaucracy, economic barriers, lack of governmental transparency, lack of information, and the absence of mechanisms that facilitate the implementation and execution of programs. Deficiencies were also detected in Costa Rica, which was one of the pioneering countries to implement PES-PWS, and corrections to the program needed to be made (Pagiola, 2008). Similar problems associated with some market failures are observed in other regions of the world (Vogl et al., 2017), highlighting the need for adjustments and improvements in PWS policy and mechanisms.

For a country such as Brazil, which is abundant in water resources, an emerging economy and large population, perhaps a bolder plan would need to be elaborated and put into practice in order to execute PWS across the country's whole territory. PWS mechanisms can be reviewed in order to make the program more accessible and attractive to rural producers. In the current scenario, these mechanisms need to be incorporated into feasible economic assets for forest restoration conception and implementation, as shown by Brancalion et al. (2012). According to these authors, considering a balanced economic proposal, within approximately ten years, rainforest restoration could become more profitable than current land use by extensive cattle breeding.

Taking European practices as a reference, De Groot and Hermans et al. (2009) present the results of an experiment in the Netherlands on the negotiation of PWS schemes seeking to identify and structure factors that boost the execution of programs from an interdisciplinary point of view, with analyses that involve especially economics, hydrology, and institutional relationships. Setting these programs into motion and, consequently, expanding them may represent mid- to long-term guarantees and incentives for the maintenance of preserved areas, and also consequently the availability of water resources in excellent conditions for various uses (Vogl et al., 2017).

Water production within SLNP illustrates this reality. According to the data surveyed, each hectare of montane rainforest can currently meet the water demand of at least 40 people per day, and up to 268 people during high rainfall periods, based on recommendations of the World Health Organization (WHO - World Health Organization, 2013), which determines net daily water consumption as at least 100 l per individual. Within SLNP, soil loss due to surface runoff tends to be reduced, even during high rainfall and flow rate periods, since approximately over 75% of the suspended load in waters consist of forest-borne organic matter. These results are corroborated by the studies of Alvarenga et al. (2016) and Girardi et al.,(2016), conducted in watersheds located within (Atlantic) rainforests in Brazil. These authors demonstrated the ability of vegetation cover to control soil loss and surface runoff. Notably, this protection is important for water resources under various climatic contexts and regions of the world, preserving soil stability and water quality within watersheds (Erol and Randhir, 2013, Mohammad and Adam, 2010; Yan et al., 2015; Zokaib and Naser, 2011).

The quality of the water produced in SLNP is another point that illustrates the effect of forests on water resources. This should be of particular concern to water managers since the water quality of a spring is strongly correlated with the costs of treatment processes. Tundisi and Tundisi (2010) compared water treatment values between waters from protected areas and from degraded areas, identifying a one hundredfold cost difference. Biao et al. (2010) and Fiquepron et al. (2013) developed water treatment cost quantification models considering various land uses, and also found low-cost scenarios for the water treatment in forest areas, generating a significant money-saving situation for water users.

Fig. 5. illustrates the proposed mechanism for the implications of water production for water resources management from a systematic organization that approaches PWS adjustments, water valuation, and associated benefits. The Brazilian National Water Agency (ANA) has a PWS project called Water Producer Program, which currently pays up to R$ 125 (approximately US$ 38, according 1.0 US$ = R$ 3.30 rate) per hectare. Correlating these values to the water production values surveyed in SLNP during the low-rainfall period would mean that, in southern Bahia or in an equivalent region (rainforest), each hectare of preserved areas hired by ANA would receive up to US$ 38 to produce 1,460 m^3 of quality water per year. In order to treat this volume of water produced in these preserved areas, treatment and supply agencies would spend just over US$ 20. Agencies such as the Water and Sanitation Company of the state of Bahia (EMBASA) currently receive from water users approximately R$ 4467.00 (US$ 1350), representing a mean cost of R$ 3.06 (US$ 0.92) per m^3 in order to supply the same volume of treated water (BRASIL - Ministério das Cidades, 2016).

The profit margin between what is collected and what is spent in water treatment is significant, even in a scenario where waters flow through degraded areas and need more complex and costly treatments. These simulations are useful in order to show that water catchment and treatment agencies need to organize their management actions aiming for the inclusion of PES-PWS programs in their budget revenues. Considering the funds currently available, there is margin for enough economic resource application to cover the costs of PWS in Brazilian (Atlantic) rainforests, and with attractive market conditions for water producers. In addition, the implementation of PES schemes has been shown to improve and recover ecosystem services at relatively low costs to the Brazilian GDP, as shown by Banks-Leite et al. (2014), when simulating a scenario in which an investment < 10% of agriculture subsidies in Brazil would be enough to support strategic areas for forest restorations. Obviously, other issues should be taken into account, such as sociocultural aspects. However, regarding economic funds, there is operational compatibility.

In southern Bahia, where SLNP is located, there are already significant disturbances in watersheds to the point of triggering water crises in a considerable amount of neighboring municipalities. The increase in demand and deterioration of priority areas within watersheds have been indicated as the main causes of water crisis in the region. Itabuna, a medium-sized town from southern Bahia, for instance, presents over 220,000 inhabitants according to estimates from IBGE - Instituto Brasileiro de Geografia e Estatística, Cidades (2016) and has an intense regional market and service dynamics. The town suffered during 2015 and 2016 a severe water crisis, which was caused by the effects of the El Niño phenomenon associated with the inadequate management of priority areas within the watershed. In this region, the implementation and spreading of PES-PWS may certainly turn out to be a solution to guarantee water security.

There are a few cases in Brazil that can serve as an example, such as the municipality of Extrema, in the state of Minas Gerais, which was a pioneer in conducting a municipal PES program. This municipality of 33,000 inhabitants is located within an area of predominantly Atlantic rainforest. It is also part of a hydrographic system that provides waters to reservoirs (Cantareira System) used by millions of people in the state of São Paulo. A study conducted by Jardim and Bursztyn (2015) describes a panorama on the payment for environmental services in water resource management in Extrema, demonstrating the effectiveness of the program.

The success of the initiative in Extrema relied on strong political articulation between the city hall, the watershed committee, governmental agencies, and non-governmental organizations in order to define a solid structure that provided the program with guarantees. Barbosa et al. (2016) shows that this kind of interaction is essential for advancing the implementation of policies for water, however, the authors emphasize that in order to improve it better coordination is needed, because political, institutional and governance challenges are often more important in decision-making processes. In the case of Extrema, Richards et al. (2015) stated that the impact of municipal leadership is evident, but in order to attract investments to other areas the hydrological benefits obtained by forest restoration in these ongoing projects should be better understood.

The results described in the present study suggest the possibility of adopting economic mechanisms that include water valuation in PES programs. For instance, an ongoing study of synoptic surveys in the sampling station of subwatershed E and in the water catchment point (11 km downstream, Fig. 1), has shown that 60% of the water volume that reaches the catchment point originated from the 924 ha of this subwatershed. This means that this subwatershed alone would be enough to supply more than twice the population already assisted. Thus, the annual water production per hectare of this subwatershed would be worth approximately R$ 12,300 (US$ 3723). This value estimate refers to prices charged by water catchment and treatment agencies, and could be the basis for the policy of economic incentive to water producers associated with PWS program.

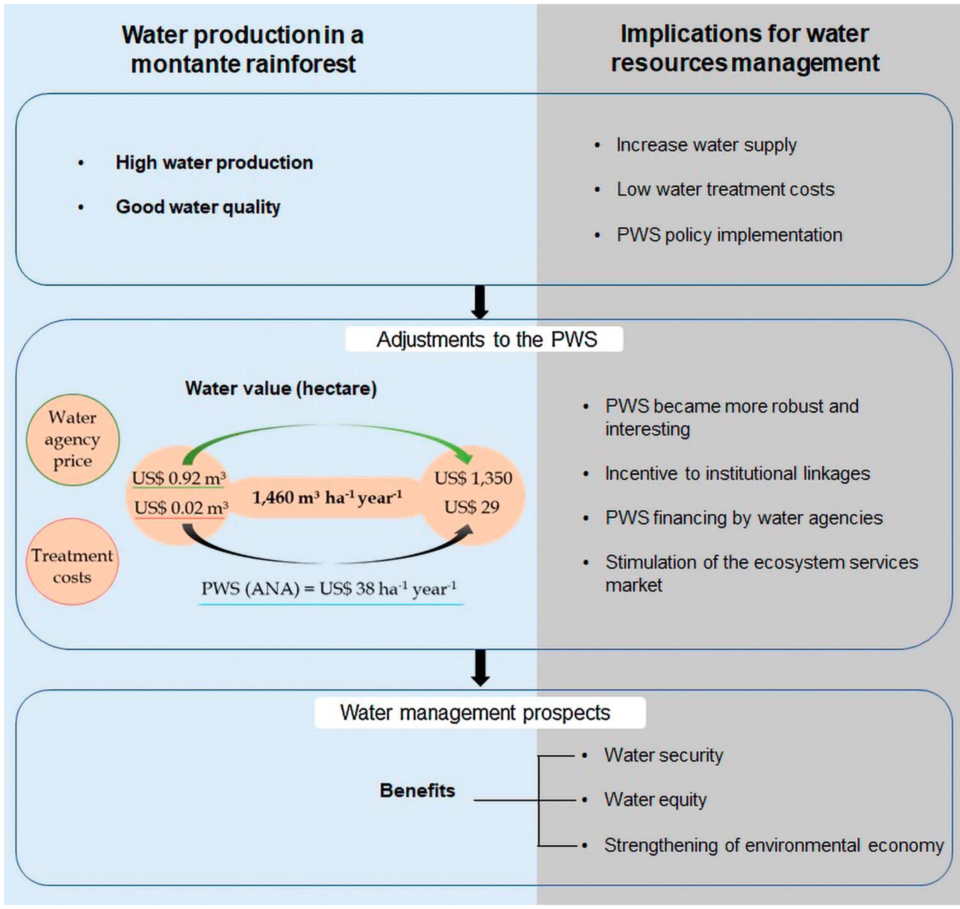

Fig. 5. An overview of the proposed mechanism for water production and the implications for water resources management.

4. Conclusions

The results found in the present study showed that the effluent streams of the area of SLNP presented water production in a perennial regime of at least 4,000 l ha^{-1} day^{-1}, with excellent quality. A preserved rainforest area may provide important ecosystem services with operational conditions and accessible economic costs to Brazil. Water in quantity and quality is a product of these ecosystem services in SLNP, and may certainly be explored by an integrated water resources management framework that seeks to guarantee significant water production in watersheds using policies such as PES-PWS.

In face of the water production scenario detected in SLNP and PES-PWS policy in Brazil, the authors propose a review of the current mechanisms of these programs, with the objective of market strengthening, increasing robustness and attractiveness to rural producers. This review could include, in addition to payments for the maintenance of preserved areas, payments also for the water that is effectively produced by this same area, based on values charged by water catchment and treatment agencies from water users. We show that there is operational and financial compatibility for adhesion of PWS programs by these agencies, being this a potential mechanism to reach a higher stimulation of the ecosystem service market. The watersheds should not be managed from an empty green discourse but rather respected as a business partners, with PWS as part of infrastructure strategies that can ensure water security.

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References

Abildtrup, J., Garcia, S., Stenger, A., 2013. The effect of forest land use on the cost of drinking water supply: a spatial econometric analysis. Ecol. Econ. 92, 126–136. http://dx.doi.org/10.1016/j.ecolecon.2013.01.004.

Alvarenga, L.A., De Mello, C.R., Colombo, A., Cuartas, L.A., Bowling, L.C., 2016. Assessment of land cover change on the hydrology of a Brazilian headwater watershed using the distributed hydrology-soil-vegetation model. Catena 143, 7–17. http://dx.doi.org/10.1016/j.catena.2016.04.001. 2016.

ANA - Agência Nacional de Águas, 2011. Programa produtor de Água. Brasília. Available in: http://www.ana.gov.br/produagua (Acessed 15 August 2012).

Andrade, T.M., Camargo, P.B., Silva, D.M.L., Piccolo, M.C., Vieira, S.A., Alves, L.F., Martinelli, L.A., 2011. Dynamics of dissolved forms of carbon and inorganic nitrogen in small watersheds of the Coastal Atlantic Forest in Southeast Brazil. Water Air Soil Poll. 214 (1-4), 393–408. http://dx.doi.org/10.1007/s11270-010-0431-z.

Araújo, R.S., Alves, M.G., Melo, M.T.C., Chrispim, Z.M.P., Mendes, M.P., Silva Júnior, G.C., 2015. Water resource management: a comparative evaluation of Brazil, Rio deJaneiro, the European Union, and Portugal. Sci. Total Environ. 511, 815–828. http://dx.doi.org/10.1016/j.scitotenv.2014.11.098.

Banks-Leite, C., Pardini, R., Tambosi, L.R., Pearse, W.D., Bueno, A.A., Bruscagin, R.T., Condez, T.H., Dixo, M., Igari, A.T., Martensen, A.C., Metzger, J.P., 2014. Using ecological thresholds to evaluate the costs and benefits of set-asides in a biodiversity hotspot. Science 345, 1041–1045. http://dx.doi.org/10.1126/science.1255768.

Barbosa, M.C., Alam, K., Mushtaq, S., 2016. Water policy implementation in the state of São Paulo, Brazil: key challenges and opportunities. Environ. Sci. Policy 60, 11–18. http://dx.doi.org/10.1016/j.envsci.2016.02.017.

Bateni, F., Fakheran, S., Soffianian, A., 2013. Assessment of land cover changes & water quality changes in the Zayandehroud River Basin between 1997–2008. Environ. Monit. Assess. 185, 10511–10519. http://dx.doi.org/10.1007/s10661-017-5863-0.

Biao, Z., Wenhua, L., Gaodi, X., Yu, X., 2010. Water conservation of forest ecosystem in Beijing and its value. Ecol. Econ. 69, 1416–1426. http://dx.doi.org/10.1016/j.ecolecon.2008.09.004.

Brancalion, P.H.S., Viani, R.A.G., Strassburg, B.B.N., Rodrigues, R.R., 2012. Finding the

money for tropical forest restoration. Unasylva 63, 41–50.
BRASIL - Ministério das Cidades, 2016. Diagnóstico dos serviços de água e esgoto 2015. Available in:. http://www.snis.gov.br/diagnostico-agua-e-esgotos-diagnostico-ae-2015.
Chichilnisky, G., Heal, G., 1998. Economic returns from the biosphere. Nature 391, 629–630. http://dx.doi.org/10.1038/35481.
CPRM - Serviço Geológico do Brasil, 2004. Mapa de Domínios e Subdomínios Hidrogeológicos do Brasil, escala 1:2.500.000. Available in: http://www.cprm.gov.br/publique/cgi/ (Acessed 25 August 2013).
De Groot, R.B.A., Hermans, L.M., 2009. Broadening the picture: negotiating payment schemes for water-related environmental services in the Netherlands. Ecol. Econ. 68, 2760–2767. http://dx.doi.org/10.1016/j.ecolecon.2009.06.008. 2009.
Elabras Veiga, L.B., Magrini, A., 2013. The Brazilian water resources management policy: fifteen years of success and challenges. Water Resour. Manage. 27, 2287–2302. http://dx.doi.org/10.1007/s11269-013-0288-1.
Ernst, C., Gullick, R., Nixon, K., 2004. Protecting the source — conserving forests to protect water. Am. Water Works Assoc. 30 (5), 3–7.
Erol, A., Randhir, T.O., 2013. Watershed ecosystem modeling of land-use impacts on water quality. Ecol. Modell 270, 54–63. http://dx.doi.org/10.1016/j.ecolmodel.2013.09.005.
Fiquepron, J., Garcia, S., Stenger, A., 2013. Land use impact on water quality: valuing forest services in terms of the water supply sector. J. Environ. Manage. 126, 113–121. http://dx.doi.org/10.1016/j.jenvman.2013.04.002.
Forest Trends, 2015. Incentivos econômicos para serviços ecossistêmicos no Brasil. Matriz Global de Serviços Ecossistêmicos. Org. por Forest Trends. 122 p. Available in: http://brazil.forest-trends.org/documentos/.
Forti, M.C., Bourotte, C., Cicco, V., Arcova, F.C.S., Ranzini, M., 2007. Fluxes of solute in two catchments with contrasting deposition loads in Atlantic Forest (Serra do Mar/SP-Brazil). Appl. Geochem. 22, 1149–1156. http://dx.doi.org/10.1016/j.apgeochem.2007.03.006.
Garcia, L.C., Santos, J.S., Matsumoto, M., Silva, T.S.F., Padovezi, A., Sparovek, G., Hobbs, R.J., 2013. Restoration challenges and opportunities for increasing landscape connectivity under the New Brazilian Forest Act. Natureza Conservação 11 (2), 181–185. http://dx.doi.org/10.4322/natcon.2013.028.
Girardi, R., Pinheiro, A., Garbossa, L.H.P., Torres, E., 2016. Water quality change of rivers during rainy events in a watershed with different land uses in Southern Brazil. Braz. J. Water Res. 21 (3), 514–524. http://dx.doi.org/10.1590/2318-0331.011615179.
Grafton, R.Q., Pittock, J., Davis, R., Williams, J., Fu, G., Warburton, M., Udall, B., McKenzie, R., Yu, X., Che, Nhu, ConnelL, D., Jiang, Q., Kompas, T., Lynch, A., Norris, R., Possingham, H., Quiggin, J., 2013. Global insights into water resources, climate change and governance. Nat. Clim.Change 3, 315–321. http://dx.doi.org/10.1038/nclimate1746.
Grimma, N., Singh, S.J., Smetschka, B., Ringhofer, L., 2016. Payment for ecosystem services (PES) in Latin America: analysing the performance of 40 case studies. Ecosyst. Serv. 17, 24–32. http://dx.doi.org/10.1016/j.ecoser.2015.11.010.
Guedes, F.B., Seehusen, E., 2011. O PSA na Mata Atlântica – Situação Atual, Desafios e Recomendações. In: Org. por Guedes, F.B., Seehusen, E. (Eds.), Pagamentos por Serviços Ambientais na Mata Atlântica: lições aprendidas e desafios. Ministério do Meio Ambiente, Brazil, pp. 225–249.
Guerra, R., 2016. Assessing preconditions for implementing a payment for environmental services initiative in cotriguaçu (Mato Grosso, Brazil). Ecosyst. Serv. 21, 31–38. http://dx.doi.org/10.1016/j.ecoser.2016.07.009.
Guswa, A.J., Brauman, K.A., Brown, C., Hamel, P., Keeler, B.L., Sayre, S.S., 2014. Ecosystem services: challenges and opportunities for hydrologic modeling to support decision making. Water Resour. Res. 50, 4535–4544. http://dx.doi.org/10.1002/2014WR015497.
He, T., Lu, Y., Cui, Y., Luo, Y., Wang, M., Meng, W., Zhang, K., Zhao, F., 2015. Detecting gradual and abrupt changes in water quality time series in response to regional payment programs for watershed services in an agricultural area. J. Hydrol. 525, 457–471. http://dx.doi.org/10.1016/j.jhydrol.2015.04.005.
Heiri, O., Lotter, A.F., Lemcke, G., 2001. Loss on ignition as a method for estimating organic and carbonate content in sediments: reproducibility and comparability of results. J. Paleolimnol. 25 (1), 101–110. http://dx.doi.org/10.1023/A:1008119611481.
IBGE – Instituto Brasileiro de Geografia e Estatística, Cidades, 2016. Available in: http://cidades.ibge.gov.br (Acessed 10 February 2017).
Jardim, M.H., Bursztyn, M.A., 2015. Payment for environmental services in water resources management: the case of extrema (MG). Brazil Engenharia Sanitária e Ambiental 20 (3), 353–360. http://dx.doi.org/10.1590/S1413-41522015020000106299.
Jayawardana, J.M.C.K., Gunawardana, W.D.T.M., Udayakumara, E.P.N., Westbrooke, M., 2017. Land use impacts on river health of Uma Oya, Sri Lanka: implications of spatial scales. Environ. Monit. Assess. 189 (192), 1–23. http://dx.doi.org/10.1007/s10661-017-5863-0.
Koppen, W., 1948. Climatologia con un estudio de los climas de la tierra (transl. P. R. H. Peres). Fondo de Cultura E Economica, Mexico City, Mexico.
Liu, S., Crossman, N.D., Nolan, M., Ghirmay, H., 2013. Bringing ecosystem services into integrated water resources management. J. Environ. Manage. 129, 92–102. http://dx.doi.org/10.1016/j.jenvman.2013.06.047.
Mohammad, A.G., Adam, M.A., 2010. The impact of vegetative cover type on runoff and soil erosion under different land uses. Catena 81 (2), 97–103. http://dx.doi.org/10.1016/j.catena.2010.01.008.
Muradian, R., Corbera, E., Pascual, U., Kosoy, N., May, P.H., 2010. Reconciling theory and practice: an alternative conceptual framework for understanding payments for environmental services. Ecol. Econ. 69, 1202–1208. http://dx.doi.org/10.1016/j.ecolecon.2009.11.006.
Nacif, P.G.S., Costa, O.V., Araújo, M., e Santos, P.S., 2009. Geomorfodinâmica da região do complexo de serras das lontras, 9–14. SAVE Brasil, IESB E BirdLife International. Complexo de Serras Das Lontras E Una, Bahia: Elementos Naturais E Aspectos de Sua Conservação. SAVE Brasil, São Paulo.
Neary, D.G., Leonard, J.H., 1978. Effects of forest fertilization on water quality. N. Z. J. For. Sci. 8, 189–205.
Neary, D.G., Ice, G.G., Jackson, R., 2009. Linkages between forest soils and water quality and quantity. For. Ecol. Manage. 258, 2269–2281. http://dx.doi.org/10.1016/j.foreco.2009.05.027.
Pagiola, S., 2008. Payments for environmental services in costa rica. Ecol. Econ 65, 712–724. http://dx.doi.org/10.1016/j.ecolecon.2007.07.033. n.
Pardini, R., Faria, D., Accacio, G.M., Laps, R.R., Mariano-Neto, E., Paciencia, M.L., Dixo, M., Baumgarten, J., 2009. The challenge of maintaining Atlantic forest biodiversity: a multi-taxa conservation assessment of specialist and generalist species in an agro-forestry mosaic in southern Bahia. Biol. Conserv. 142 (6), 1178–1190. http://dx.doi.org/10.1016/j.biocon.2009.02.010.
Paula, F.C.F., Mozeto, A.A., 2001. Biogeochemical evolution of trace elements in a pristine watershed in the Brazilian southeastern coastal region. Appl. Geochem. 16, 1139–1151. http://dx.doi.org/10.1016/S0883-2927(00)00084-6.
Pereira, B.C., De Paula, F.C.F., Gomes, A.R., Fandi, A.C., Falcão Filho, C.A.T., Mattos, J.B., Santos, D.A., Rancura, S.A.O., 2015. Aliança das Águas: uma iniciativa para conhecer o papel do Parque Nacional da Serra das Lontras no fornecimento de água para municípios do sul da Bahia. Biodiversidade Brasileira 5 (1), 59–73.
Quintero, M., Wunder, S., Estrada, R.D., 2009. For services rendered? modeling hydrology and livelihoods in Andean payments for environmental services schemes. For. Ecol. Manag. 258, 1871–1880. http://dx.doi.org/10.1016/j.foreco.2009.04.032.
Richards, R.C., Rerolle, J., Aronson, J., Pereira, P.H., Gonçalves, H., Brancalion, P.H.S., 2015. Governing a pioneer program on payment for watershed services: stakeholder involvement, legal frameworks and early lessons from the Atlantic forest of Brazil. Ecosyst. Serv. 16, 23–32. http://dx.doi.org/10.1016/j.ecoser.2015.09.002.
Richards, R.C., Kennedy, C.J., Lovejoy, T.E., Brancalion, P.H.S., 2017. Considering farmer land use decisions in efforts to 'scale up' payments for watershed services. Ecosyst. Services 23, 238–247. http://dx.doi.org/10.1016/j.ecoser.2016.12.016.
Sopper, W.E., 1975. Effects of timber harvesting and related management practices on water quality in forested watersheds. J. Environ. Qual. 4, 24–29.
Souza, A.L.T., Fonseca, D.G., Libório, R.A., Tanaka, M.O., 2013. Influence of riparian vegetation and forest structure on the water quality of rural low-order streams in SE Brazil. For. Ecol. Manag. 298, 12–18. http://dx.doi.org/10.1016/j.foreco.2013.02.02.
Souza, E.R., Paula, F.C.F., 2013. Spatial and temporal hydrochemical variation of a third order River network in a Quasi Pristine Coastal watershed, at southern Bahia, Brazil. Anais Da Academia Brasileira de Ciências 85 (4), 1357–1370. http://dx.doi.org/10.1590/0001-3765201364111.
Stallard, R.F., Murphy, S.F.A., 2014. Unified assessment of hydrologic and biogeochemical responses in research watersheds in eastern Puerto Rico using runoff–concentration relations. Aquat. Geochem. 20 (2–3), 115–139. http://dx.doi.org/10.1007/s10498-013-9216-5.
Strickland, J.D.H., Parsons, T.R., 1972. A practical handbook of seawater analysis. Ottawa: Fish. Res. Board Can. Bull 167 p.
Tundisi, J.G., Barbosa, F.A.R., 1995. Conservation of aquatic ecosystems: present status and perspectives. In: Tundisi, J.G., Bicudo, C.E.M., Matsumara Tundisi, T. (Eds.), Limnology in Brazil. 1995. Brazilian Limnological Society.
Tundisi, J.G., Tundisi, T.M., 2010. Potencial impacts of changes in the forest law in relation to water resources. Biota Neotrópica 10 (4), 67–76. http://dx.doi.org/10.1590/S1676-06032010000400010.
Van Lear, D.H., Douglas, J.E., Cox, S.K., Augspurger, M.K., 1985. Sediment and nutrient export in runoff from burned and harvested pine watersheds in the South Carolina Piedmont. J. Environ. Qual. 14, 169–174.
Vogl, A.L., Goldstein, J.H., Daily, G.C., Vira, B., Bremer, L., McDonald, R.I., Shemie, D., Tellman, B., Cassin, J., 2017. Mainstreaming investments in watershed services to enhance water security: barriers and opportunities. Environ. Sci. Policy 75, 19–27. http://dx.doi.org/10.1016/j.envsci.2017.05.007.
WHO - World Health Organization, 2013. Technical Notes on Drinking-Water, Sanitation and Hygiene in Emergencies. Geneva. .
Yan, Q., Lei, T., Yuan, C., Lei, Q., Yang, X., Zhang, M., Su, G., An, L., 2015. Effects of watershed management practices on the relationships among rainfall, runoff, and sediment delivery in the hilly-gully region of the loess plateau in China. Geomorphology 228, 735–745. http://dx.doi.org/10.1016/j.geomorph.2014.10.015.
Zanella, M.A., Schleyer, C., Speelman, S., 2014. Why do farmers join payments for ecosystem services (PES) schemes? An assessment of PES water scheme participation in Brazil. Ecol. Econ. 105, 166–176. http://dx.doi.org/10.1016/j.ecolecon.2014.06.004.
Zokaib, S., Naser, Gh., 2011. Impacts of land uses on runoff and soil erosion: A case study in hilkot watershed Pakistan. Int. J. Sediment Res. 26 (3), 343–352. http://dx.doi.org/10.1016/S1001-6279(11)60098-X.