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Financial compensation in hydropower generation: a tool for social and environmental development

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Abstract

In the current scenario of Brazilian low water availability, the financial compensation funded by hydroelectric power plants (HPPs) represents an important tool for water management and conservation of the hydrographic basin. This payment could be applied to mitigate HPP's greatest problems such as water scarcity and reservoir silting. We propose an apportionment proportional to the average water flow provided by each municipality within the HPP's catchment area and the size of the flooded area by its reservoir. The water flow was obtained through the balance between precipitation and evapotranspiration for all municipalities in the study area with only 3% difference from the observed water flow in the HPP. As a result of the proposed methodology, the number of benefiting municipalities increased from 41 to 167 in the drainage area of Furnas' HPP, providing financial resources to the upstream municipalities and enabling them to invest in conservation techniques to ensure the maintenance of water resources, promoting social and environmental development, and mitigation of HPP's greatest problems such as water scarcity and reservoir silting.

Keywords: Brazilian water policy; Environmental services; Geographic information systems; Hydroelectric royalties; Territory-based compensation; Watershed management

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1. Introduction

Brazil has an extensive hydrographic network and large water resources, but the current situation of water availability is fragile (Gutiérrez *et al*., 2014; Awange *et al*., 2016). The increasing population's demand for food and energy and the unsuitable use of water resources have led to a deep reflection on the current water management systems (Gaudard & Romerio, 2014; WWAP, 2014; Araújo *et al*., 2015; Dobrovolski & Ratis, 2015). In 2015, the Brazilian government imposed a water and power rationing program due to low water availability in the hydroelectric system which impaired the country's economy. As the electricity consumption is projected to grow by 3.9% per year, the Brazilian strategy to meet the electrical demand is the creation of alternative energy sources as well as the maintenance and increase of those already in use (EPE, 2017).

The main source of electric energy in Brazil comes from hydroelectric power plants (HPPs), and although considered as a sustainable source of energy, the construction and operation of HPPs produce social and environmental impacts (Silva, 2007; Faria *et al*., 2017; Hess & Fenrich, 2017). The impact caused by the HPP installation interferes in hydrological and social interactions within the hydrographic basin observed in several countries around the world: the United States (Martínez & Castillo, 2016), Europe (Wagner *et al*., 2015; Majone *et al*., 2016; Ferrario & Castiglioni, 2017), Asia (Dukpa *et al*., 2018; Zhang *et al*., 2018), Africa (Abdelsalam *et al*., 2014; Spalding-Fecher *et al*., 2017), and Oceania (Sekac *et al*., 2017).

Facing this issue, Brazilian public policies in the electrical sector try to integrate instruments that are able to minimize the negative externalities and maximize the positive ones such as the financial compensation for energy generation (Lima, 2015; Pineu *et al*., 2017). To compensate the states and municipalities affected by HPP projects, Federal law no. 7,990 from the year 1989 established financial compensation for electrical power generation based on HPP's power generation. Thus, the financial compensation received from HPP's water use is a resource applied in social and environmental development in HPP areas (Silva, 2007).

Currently, the National Agency of Electrical Energy (Agência Nacional de Energia Elétrica (ANEEL)) manages both the tax charges and the royalty's distribution among the beneficiaries. The tax is adjusted every year by the ANEEL and is charged on the amount of energy produced. In accordance with Federal law no. 8,001 of 1990, there are two criteria for royalty distribution to municipalities: (1) the percentage of the flooded area of the municipality directly affected by the reservoir construction and (2) the percentage of the flooded area directly affected by upstream reservoirs. The second criterion exists because the water flow regulation controlled by upstream reservoirs affects the energy generation of downstream plants. In the HPP of Furnas, for instance, the greatest share of the apportionment is distributed among the municipalities in the vicinity of Furnas, Camargos, and Itutinga (ANEEL, 2005).

As the power generated by a specific HPP depends, among other factors, on the water flow originated in the entire drainage area, it is reasonable that every municipality within this basin should also receive a share of the money (Lorenzon *et al*., 2016). In addition, once the state grants the rights of water use for HPP's energy generation, the municipalities situated upstream of the plant must ensure that the granted water flow arrives at the HPP to generate power. This regulation can render other upstream uses of water infeasible (Kadigi *et al*., 2008; Premalatha *et al*., 2014; Fanaian *et al*., 2015).

Historically, the hydroelectric companies in Brazil are controlled by the state, but currently, there is a bill underway at the congress that allows the privatization of the largest state-owned electric power company responsible for 30.7% of the country's installed capacity (MPDG, 2018). Nowadays, the private sector already has 60% of installed capacity in the energy sector. Regarding improvements to power production, the benefits provided by landowners that apply sustainable practices to reduce soil erosion and to increase water infiltration in the HPP's catchment area are of great interest because it mitigates the HPP's greatest problems such as water scarcity and reservoir silting. In this way, royalties from power generation could be used for both the social and environmental development and improvement in the HPP power production capacity in a win-win game for public and private sectors provided by the proposed methodology.

Therefore, the financial compensation to regions along the HPP's catchment area is an important tool that accounts for these issues and benefits the energy production through water management and social development (Diduck *et al*., 2013). Thus, the aim of this study is to apply and evaluate the methodological proposal (Lorenzon *et al*., 2016) of payment for environmental services for Furnas' HPP.

2. Materials and methods

2.1. Study area

The HPP of Furnas is located at Rio Grande, a tributary of the Paraná River. The power plant has a waterfall height of 94.06 m, a working volume of 17.22 hm^3, and a total storage volume of 22.95 hm^3, with 5.73 hm^3 being the minimum operational volume. The total installed power is 1,312.0 MW, and the flooded area due to the plant's reservoir construction affects 31 municipalities in the Minas Gerais state and floods an area of 1,440 km^2 (Figure 1) (ANA, 2013).

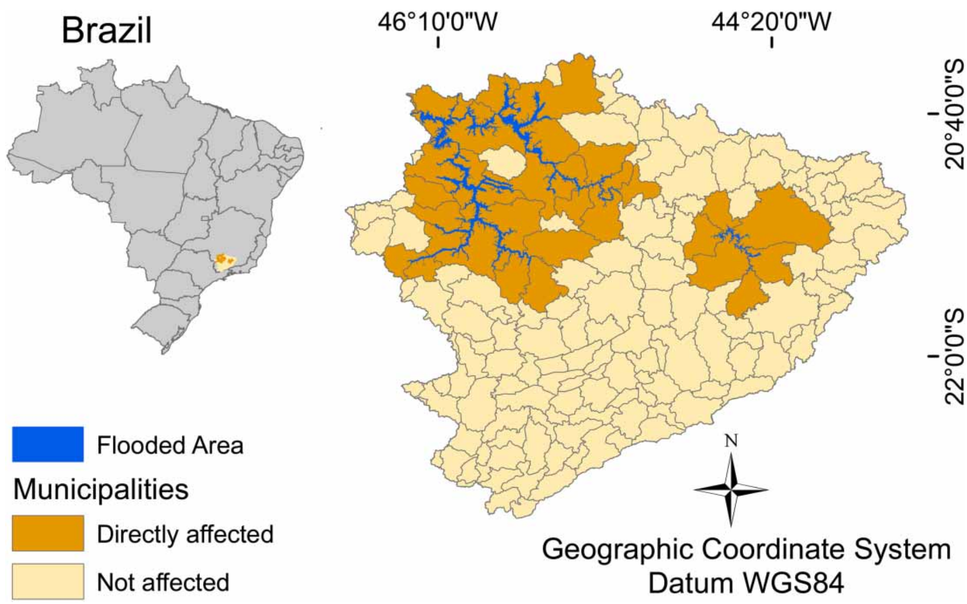

Fig. 1. Catchment area of the Furnas reservoir and its affected municipalities.

The population covered by the Furnas' catchment area was 2,885,620 people, and the GDP per capita among the municipalities ranged from R$8,820.93 to 76,908.93 in the Brazilian currency. Agriculture and livestock are important economic activities in this region.

The catchment area of the Furnas' HPP reservoir is 51,900 km^2, which corresponds to approximately 30% of the Rio Grande Basin. This basin has high energetic importance for the country, with 7,722 MW of installed power, which corresponds to 11.7% of the total hydroelectric power capacity of Brazil (ANEEL, 2005). Moreover, within this drainage area lies Camargos' HPP reservoir, which floods areas in 10 municipalities (Figure 1).

2.2. Data collection and processing

Lorenzon *et al.* (2016) suggested that the financial distribution should be based on two different percentages: one related to the regularized water flow and another related to the waterfall height.

The power generated in a group of turbine generators of a power plant can be calculated as shown by the following equation (Yoo, 2009; Gaudard & Romerio, 2014):

$$P = \eta \times g \times Q \times h \tag{1}$$

where P is the power generated (in watts), η is the efficiency of the turbine generator set, g is the gravitational constant (m s^{-2}), Q is the regularized water flow (m^3 s^{-1}), and h is the waterfall height (m).

Based on Equation (1), it is possible to establish the following equations (Lorenzon *et al.*, 2016):

$$P_Q = \frac{100 \times Q}{Q + h} \tag{2}$$

$$P_h = \frac{100 \times h}{Q + h} \tag{3}$$

where P_Q is the relative contribution of the water flow in the generation of electrical energy (%), P_h is the relative contribution of the waterfall height in the generation of electrical energy (%), Q is the regularized water flow (m^3 s^{-1}), h is the waterfall height (m), and 100 denotes 100% of the power generated.

Thus, the municipalities affected by the reservoir share an amount of financial compensation regarding the waterfall height (P_h), which is related to the flooded area in each municipality, and a percentage related to the water flow (P_Q). The P_Q, in turn, was divided among all the municipalities located in the drainage area of the hydroelectric plant, including the municipalities affected by its reservoir.

In 2000, the amount of 1,040,053.72 US dollars was charged from the Furnas' HPP for financial compensation (ANEEL, 2005). The proposed methodology shares the amount of royalties between each municipality by the following equation:

$$\text{FC}_i(\$) = \text{Royalty}(\$) * \left(\frac{P_h * \text{Flooded Area}_i}{\sum \text{Flooded Area}} + \frac{P_Q * \text{Water Flow}_i}{\sum \text{Water Flow}} \right) \tag{4}$$

where $\text{FC}_i(\$)$ is the financial compensation received by ith municipality in dollars, Royalty($) is the total value for financial compensation, Flooded Area_i is the flooded area within the ith municipality, and Water Flow_i is the water flow contribution by the ith municipality.

According to Oliveira (2009) and Menezes (2011), the municipality contribution to the water flow is proportional to its area (in relation to the total drainage area). These authors considered a constant water flow for the entire basin (the rate/total drainage area). However, for that to be considered true, it is necessary that the whole basin has a similar hydrologic behavior. In that case, a detailed hydrological study must be conducted beforehand (Euclydes *et al*., 1999).

Lorenzon *et al*. (2016) proposed that the water flow contribution of each municipality is defined as the difference between the input and output of water regarding the hydrological cycle. Thus, the average long-term water flow of a stream can be obtained as the difference between its precipitation and evapotranspiration annual values (Coe *et al*., 2009; Stickler *et al*., 2013).

The precipitation data utilized were obtained from rainfall stations distributed across the basin plus to the ones inside an 18 km buffer zone (Figure 2). The available data between the years of 1970–2000 were extracted from the Hidroweb portal of the National Water Agency. Next, the Kriging method was applied to interpolate the precipitation point data for the entire study area.

The evapotranspiration data were obtained from the global survey of the Moderate Resolution Imaging Spectroradiometer (MODIS) where it was estimated by the improved algorithm of Mu *et al.* (2011) using the Penman–Monteith equation (Monteith, 1965). The data have a spatial resolution of 1 km^2 and is available since the year 2000. The MODIS products are not suitable for evaporation estimates across liquid surfaces such as lakes and reservoirs. Therefore, these surfaces have discrepant values in MODIS data and were removed from the calculations (black pixels in Figure 4).

In the present study, 2000 was utilized as the baseline year because it was the only year with available evapotranspiration data coincident with the rainfall historical series.

The data processing and analysis were done in the ArcGIS® 10.3.1 software. To simplify the problem, municipalities with an area less than or equal to 2 km^2 within the drainage area were removed from the analysis.

A methodological flowchart consisting of the steps necessary to the development of royalties' apportionment is shown in Figure 3. The first eight steps are the geoprocessing tools used to

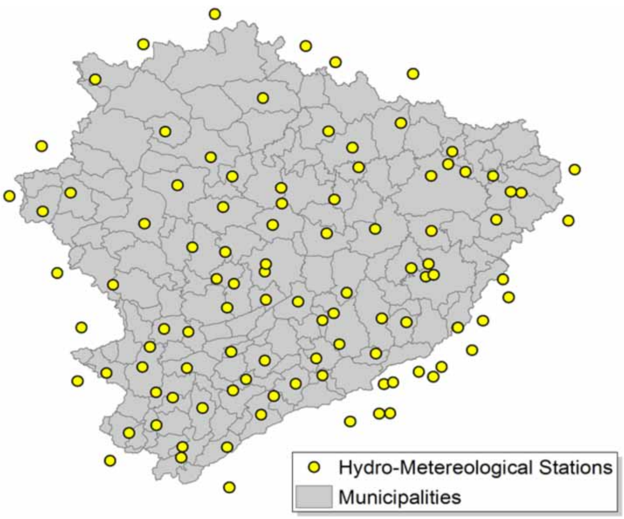

Fig. 2. Catchment area of the Furnas HPP and the distribution of the rainfall stations.

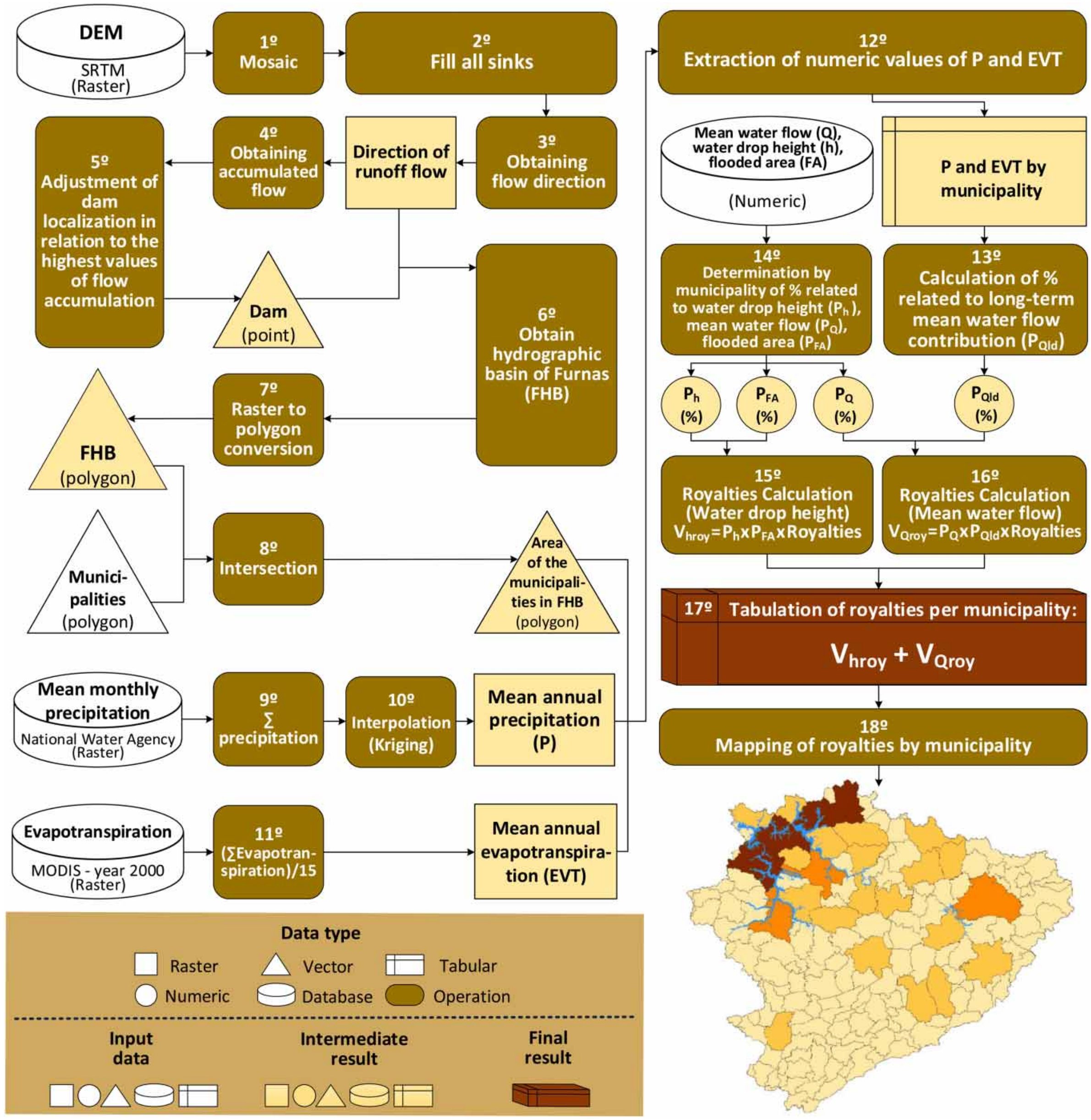

Fig. 3. Methodological flowchart consisting of the steps necessary to the development of royalties' apportionment.

obtain the area of each municipality within the Furnas' catchment area. Next, from steps 9 to 12, the balance between precipitation and evapotranspiration was performed. Finally, Equations (3) and (4) were applied to compute the amount of financial compensation each municipality should receive.

3. Results and discussion

There is an extensive variation of precipitation across the drainage area of the Furnas' HPP, which suggests that water management should be different among the municipalities (Figure 4).

The sum of all water flow contribution of all municipalities was 966 $m^3 s^{-1}$, representing an estimation of the total water flow that arrives at the HPP. This water flow estimation obtained from the difference between precipitation and evapotranspiration disregards other uses variations such as irrigation, human consumption, and lake evaporation. The historical natural water flow data measured between the periods of 1931–2000 at the Furnas' HPP have an average value of 938 $m^3 s^{-1}$ (ONS, 2014), which is a difference of only 3% from the water flow estimation in this study. The term 'natural water flow' used in the electrical sector indicates the water flow that would be observed in a specific stream section if there were no human interventions in its drainage area. Human interventions include water flow regulation by reservoirs, stream diversions, evaporation from reservoirs, and consumptive uses (ONS, 2014).

The calculated water flow contribution of each municipality is presented in Figure 5. The municipalities with major contributions to the total water flow were Formiga, Carmo do Rio Claro, Guapé, and São João Del Rei. Among them, only São João Del Rei does not have an area directly flooded by the Furnas reservoir, despite the fact that it has a small area flooded by the Camargos reservoir.

The contribution of the regularized water flow to power generation (P_Q) was 91.1%, whereas the waterfall height (P_h) was only 8.9%. Thus, in the proposed apportionment calculation, the amount of financial compensation due to P_h was divided among the municipalities proportionally to their flooded area, and the amount due to P_Q was divided among all municipalities within the drainage area proportionally to the contribution of each municipality to the total water flow. Therefore, the apportionment of each municipality is proportional to its contribution for P_Q and P_h (Equation (4)). Figure 6 presents the share of each municipality in the total compensation amount paid by the HPP.

According to the Financial Compensation Report of the ANEEL, in 2001, US$ 1,040,053.72 were distributed among only 41 municipalities in the vicinity of the Furnas' HPP (ANEEL, 2005). Pineu *et al.* (2017) evaluated the financial compensation systems of the largest hydroelectric suppliers in the world (the United States, Canada, China, and Brazil) and observed important differences in the way their distribution is performed; in China, as guidelines are set by the central government; in

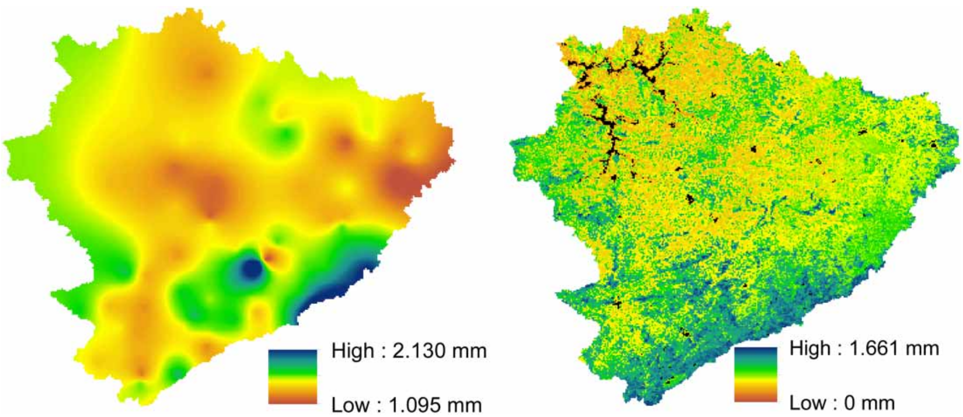

Fig. 4. Precipitation (left) and evapotranspiration (right) in the catchment area of the Furnas HPP.

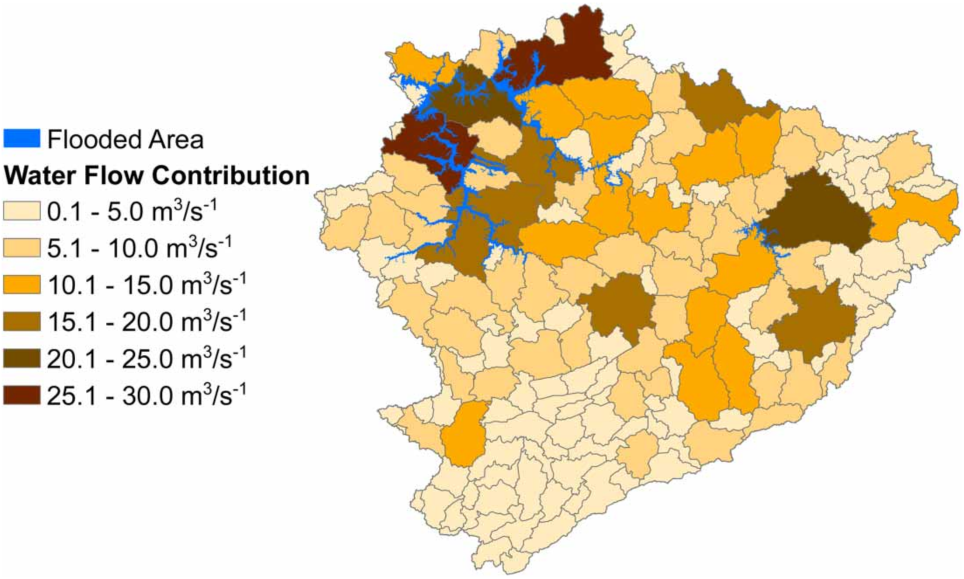

Fig. 5. Water flow contribution of each municipality.

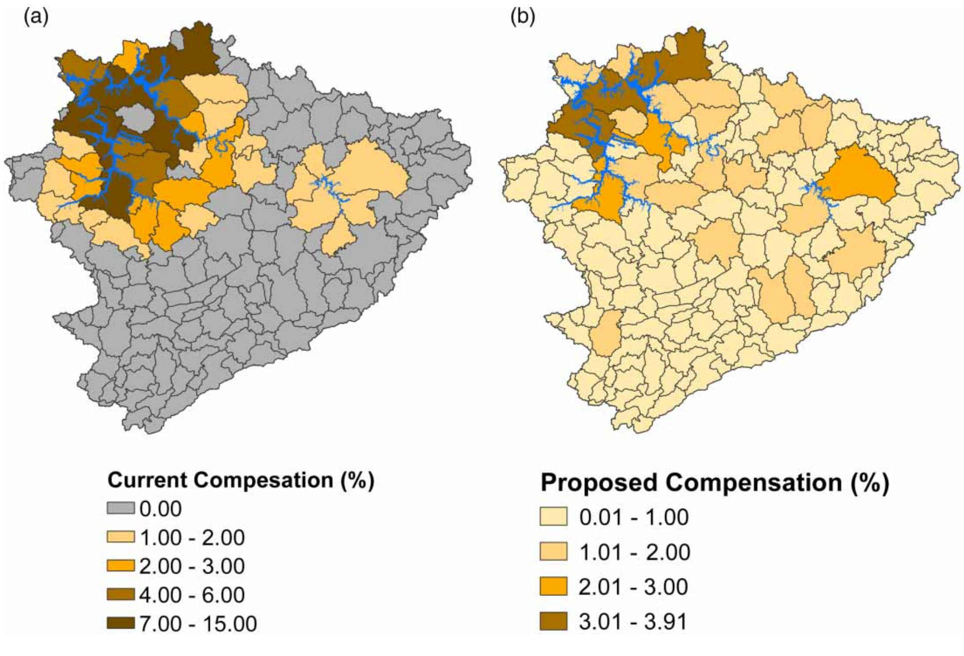

Fig. 6. Financial compensation paid to the municipalities according to (a) the current methodology and (b) the proposed methodology.

Canada, each province determines the form of collection and, in Brazil and the United States, maintains most of the rules at the federal level, but, in the United States, allows each state to create its rule, which does not happen in Brazil.

Despite the fact that São João Del Rei is one of the major contributors in terms of water flow, it only receives approximately 10% of the financial compensation offered to other municipalities by the current methodology, which means a missed opportunity of investment in priority areas for water management and conservation. The municipalities that received more money based on the current and the proposed methodology are presented in Table 1 (see the entire table in Supplementary Material).

The proposed methodology was able to better address cases like São João Del Rei and raised the number of benefited municipalities from 41 to 167 (Figure 6). Hence, the payment for the environmental services can support landowners located in priority areas within the basin to improve their land management aiming for more sustainable ways of production and to achieve the goal of water quality and availability demanded by the hydroelectric sector.

The apportionment of the financial compensation to the municipalities directly and indirectly affected by the Furnas reservoir is summarized in Table 2. The directly affected municipalities are those in the vicinity of the reservoir and the indirectly affected are those that have no flooded area but are inside the contribution basin of the reservoir.

The fact that 56.4% of the water flow that arrives at the Furnas reservoir originates in municipalities that do not receive the financial compensation indicates the need for a review of the tax mechanism, as the resources must be applied where it can impact most, especially in times of water scarcity. Besides, the municipalities directly affected by the Furnas reservoir are still being supported, which represent 24% of the municipalities within the drainage area and 48.5% of the compensation.

In Brazil, there are payment programs for environmental services to rural landowners who promote good conservation practices and keep their spring, and the financial compensation could supply these programs with more resources. Thus, rural landowners are encouraged to adopt good practices in their property, promoting the reduction of soil erosion and infiltration, what supplies the litter and promotes satisfactory flow in the water courses during the dry season (Young & Bakker, 2014; Zanella *et al*., 2014; Richards *et al*., 2017).

Table 1. Financial compensation according to (1) the current methodology and (2) the proposed methodology.

Municipality	Water flow contribution (%)	Current methodology* (US$)	Proposed methodology (US$)		
			Water flow	Waterfall height	Total
Formiga	3.30	112,448.65	31,281.55	9,895.48	41,177.04
Carmo do Rio Claro	2.73	152,639.95	25,899.43	13,432.32	39,331.75
Guapé	2.57	137,685.58	24,376.68	12,116.33	36,493.02
São João Del Rei	2.54	1,400.32	24,068.81	123.23	24,192.04

**Source*: ANEEL, 2005.

Table 2. Apportionment of municipalities directly and indirectly affected by the Furnas reservoir.

	Number of municipalities	Contribution to the water flow (%)	Current (US$)	Proposed (US$)	Proposed (%)
Directly affected	41	43.6	1,040,053.72	504,838.54	48.5
Indirectly affected	126	56.4	–	535,381.00	51.5
Total	–	100	1,040,053.72	1,040,053.72	100

A new legislation is required in which the financial compensation from the HPP could be applied for social development and water conservation across the entire watershed since upstream municipalities need to limit water use to ensure the granted water flow for energy production (PDRH, 2013; Galvão & Bermann, 2015). Moreover, the benefits extend toward the HPP's energy production in terms of water flow volume and regularization and reduced soil erosion across the watershed.

4. Conclusions

The proposed methodology allows a distribution of the financial compensation for all municipalities within the hydrographic basin, prioritizing those that have a larger drainage area and a greater contribution to the water flow. It also allows temporal adaptation due to water balance.

The municipal collection could be applied in payment for environmental services to rural landowners who maintain good conservation practices in their properties, encouraging the protection of springs and the infiltration of water along the basin.

In a win-win game, the HPPs also benefit from minimized erosion and improvement of the water flow provided by conservationists' practices. This condition is important for stakeholders to discuss the proper modifications in law.

The balance between precipitation and evapotranspiration provided proper estimates of water flow contribution to support the apportionment of royalties from energy sales along a watershed.

Finally, this methodology can be applied to any other system of financial compensation from water use in the world to support water conservation and rural development.

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Supplementary material

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