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Payment for Water-Related Ecosystem Services as a Strategic Watershed Management Approach

Mariana Beraldi Rigonato*, Kaline de Mello, Roberta Averna Valente, Luiz Carlos Faria

Department of Environmental Science, Federal University of Sao Carlos, Sorocaba, Brazil
Email: *marianaberaldi@estudante.ufscar.br

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Abstract

Payments for ecosystem services (PES) have been created worldwide to assist watershed management and improve or maintain water quality. Considering their importance, we conducted a holistic review of payment for water-related ecosystem services to understand how this instrument has been applied in watershed management worldwide. First, we identified the watershed management actions considered by the PES programs and the challenges of implementing water-related PES. After we identified the methods and criteria used to define priority areas for water-related PES. Our review considered articles published on the Web of Science from 2011 to 2022. We found 236 articles relating PES to water resources, highlighting the main water conservation strategies: native vegetation conservation, native vegetation restoration, and implementing best agricultural practices. The method most frequent was interview, followed by the use of technologies, document analysis, and hydrological models. Another significant result was that priority areas for receiving PES are mainly riparian zones, areas near or with native vegetation cover, areas with higher erosion potential, steep areas, and areas with socially vulnerable communities. This review was crucial to identify efficient water resource conservation strategies and potential challenges in the implementation and development of PES programs.

Keywords

Payment for Ecosystem Services, Water Resources, Conservation Strategies, Watershed Management, Landscape Planning

1. Introduction

Water is the most fundamental natural resource, essential for environmental control and for maintaining and promoting sustainable socioeconomic development [1]. The concern about its degradation has become a global issue since many regions worldwide have already faced drinking water scarcity [2].

Most continents experienced drought in 2021 [3], and 40% of water bodies worldwide in 2020 presented poor water quality [4]. On the other hand, there is an estimated increase in water demand by 20% - 30% in 2050, when the world population will be 9.7 billion [5]. We can reduce water availability due to water degradation from land-use land cover and climate changes [6]. The leading global challenge for the current and next decades is managing trade-offs between immediate human needs and maintaining the capacity of the ecosystems to maintain freshwater in the long term [7].

Natural-based solutions such as native vegetation conservation and restoration have been adopted as watershed management strategies to provide freshwater ecosystem services [7]. Forested watersheds worldwide are related to better water quality than watersheds with other land uses [8] [9] [10] [11]. Keeping forest areas in agricultural or urban watersheds can control biogeochemical cycles, protect against erosion, reduce pollutant loading, decrease nutrient runoff, and lower water temperature [12] [13]. Thus, native vegetation in watersheds can provide many water-related ecosystem services, including drinking water, regulating water streamflow and flood events, climate regulation, fish production, and creating opportunities for water-based recreation and culture [14] [15]. For example, forest cover in watersheds is essential to minimize the impacts of droughts, keeping minimum streamflow in dry periods [12] [16].

Command and control instruments can be applied in watershed management to obligate landowners to keep water ecosystem services provision by protecting or restoring essential forest areas in the watershed. In Brazil, the Native Vegetation Protection Law [17] requires a minimum riparian buffer covered by native vegetation along water bodies to protect water resources. However, these policies cannot protect freshwater effectively once a narrow strip of vegetation (30 m or less) along rivers can be insufficient to retain non-point source pollution and regulate the water cycle [8]. In addition, economic and political issues may affect compliance with such obligations [18].

Thus, the implementation of incentive instruments such as Payments for Ecosystem Services (PES) has emerged as a potential tool to guarantee the protection of water resources and control of the hydrological systems, financially compensating the providers of these ecosystem services [19]. The PES programs have proven to be a possible alternative to promote the protection of water resources and reverse the degradation of ecosystem services related to inadequate land-use planning by the adoption of conservation practices by the landowners [20] [21] [22] [23].

PES supports landowners in promoting sustainable practices, including conservation of existing native vegetation, forest restoration, implementation of agroforestry systems, or other good management practices such as ecological enrichment [24] [25]. The Atlantic Forest in Brazil has one of the most effective PES programs, the "Programa Conservador das Águas" of Extrema—Minas Gerais, which has focused on restoration activities aiming the increasing native forest cover by 60% in selected watersheds to improve water supply [24]. Also, watershed management practices in the Atlantic Forest region could improve water-related ecosystem services cost-effectively by implementing PES programs, as simulated by [25].

Therefore, studies identifying priority areas for PES programs implementation are fundamental to defining criteria that allow efficient economic distribution of financial resources directed to PES and minimize the risk of public investments exacerbating social inequality [22]. Thus, it is essential to focus on priority areas for PES implementation to improve the cost-effectiveness of program actions [26], maximize environmental and socioeconomic benefits, also to guarantee the success of programs for the restoration and conservation of native vegetation [27]. However, many studies did not use an approach based on water-related ecosystem services, and there are significant gaps in the criteria identification for prioritization areas for PES [26].

In this context, this paper provides a holistic review of payment for water-related ecosystem services to understand how this instrument has been applied in watershed management. First, we identified the watershed management actions considered by the PES programs and the challenges of implementing water-related PES. After we identified the methodological approaches and criteria used to define priority areas for water-related PES. We expect that this study can support decision-makers in water resources management, which involves the implementation of PES. Have PES programs been effective? What actions to adopt to improve its effectiveness? What criteria to use for defining priority areas for water-related PES? What are the most suitable methodologies for implementing PES? What are the main challenges and how to overcome them? This article provides important information regarding these questions that can be applied to new research proposals.

2. Methods

We structured the present systematic review to identify scientific articles about methodological approaches to prioritize areas for receiving PES (Payments for Ecosystem Services) related to water resources since the prioritization is crucial to ensure the best financial resources and promote socio-environmental gains.

The Web of Science database supported our review since it is an available worldwide platform that supports literature analysis and scientific search in several areas of knowledge. We searched terms in English in the titles and/or abstracts and/or keywords in peer-reviewed scientific articles published from January 2011 to June 2021. As a first selection, the keywords used were—"payment*" AND "ecosystem services*" OR "environmental services" OR "environmental benefit."

The Boolean "AND" operator aims to search for articles that consider all the dimensions mentioned, and the "OR" operator was used as different authors use different terms to refer to the subject of this study. The (*) symbol includes any possible variation of the word. Subsequently, the terms "water" OR "water resources" were used to search for articles related to payment for water ecosystem services.

Third step of the analysis, the keywords "priority areas" OR "conservation areas" were used to select the studies that address methodologies to define priority areas for payments for water ecosystem services. The search data for the articles was July 1, 2021, using the mentioned terms in **Figure 1**. To eliminate unrelated publications, we read the articles' titles, keywords, and abstracts to identify and exclude studies that did not consider payment for ecosystem services or were not related to water resources (**Figure 1**).

We read the selected articles, identifying the main journals that published these articles. Based on this material, we analyzed the evolution of publications and citations over the period. We identified and grouped the main strategies for water conservation listed in the articles: native vegetation conservation (or avoiding deforestation), native vegetation restoration, and best agricultural practices. We also identified the main challenges to implementing water-related PES. Furthermore, we listed the methods and criteria used to identify priority areas for water-related PES.

3. Results

3.1. Water-Related Payments for Ecosystem Services

The systematic review showed 1.548 articles that approached PES and 236 articles about water-related PES specifically. Among them, only 9 articles addressed the definition of priority areas for PES. The main journals that published the 236 articles, them were "Ecosystem Services" (about 9.7% of publications), "Ecological Economics" (5.4%), "Journal of Environmental Management" (3.8%), "Land Use Policy" (both with 3.4%), "Water International" (with 3%)" and "Science of the Total Environment" (about 2.5%).

The number of citations referring to "payments for ecosystem services" related to water resources has increased over the years (**Figure 2**), with the maximum reached in 2020 with 663 citations. We emphasize that the drop in citations in 2021 was because the survey not completing the entire year. The number of publications, despite the frequency varying over the years, was also growing.

The PES in freshwater ecosystems had different focuses and strategies to promote the conservation of water resources. Some of the main identified strategies to improve water quality are native vegetation conservation (avoiding deforestation (4.6% of articles) [28] [29] [30], native vegetation restoration (4.6% of articles) [30]-[36] and best agricultural practices implementation (5% of articles), such as land conversion and sustainable land management practices including agroforestry and reforestation [37]-[42].

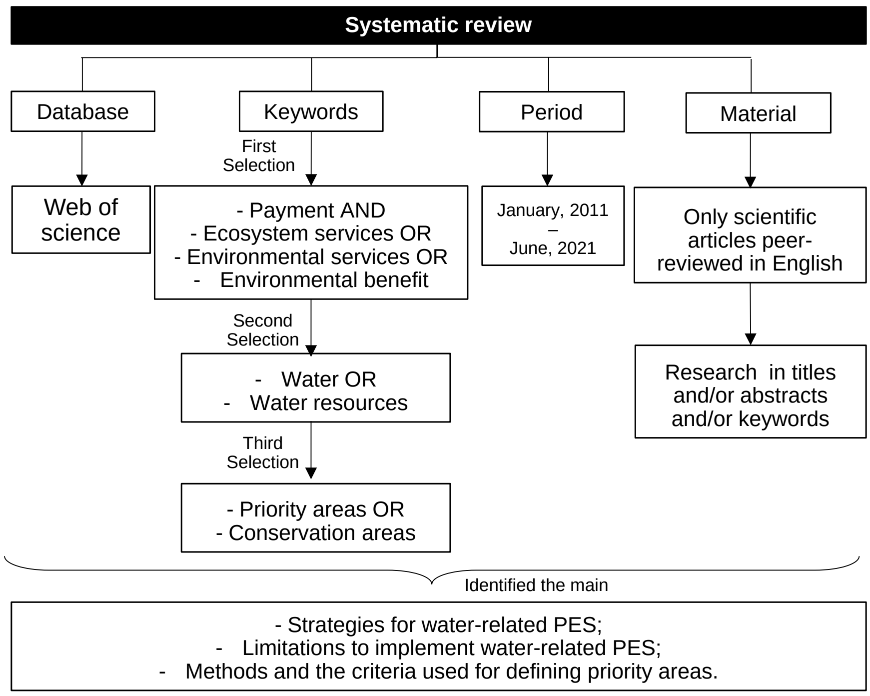

Figure 1. The conceptual framework with the criteria selected in this Systematic review.

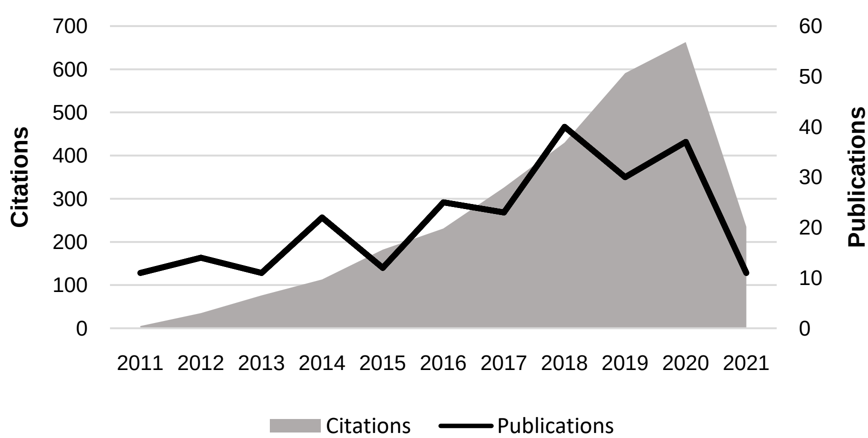

Figure 2. The evolution of publications and citations on the theme "payment for ecosystem services" related to water resources by year of publication.

In general, PES that includes native vegetation conservation aims to avoid changes in water quality and quantity, keeping water provision for population and economic activities [43] [44] and providing a better resilience to endure extreme events such as drought [20]. PES for restoration aims to improve both water quality and quantity [31] [45] [46], also increasing forest connectivity and local biodiversity [47] [48]. PES that includes best agricultural practices aims to reduce superficial displacement of pollutants and sediments to water bodies [40] [49] [50], regulating mechanisms of aquifer recharge and discharge [38] [51] and optimizing the use of freshwater flows [52] (**Figure 3**). We will discuss each strategy in more detail in the following topics.

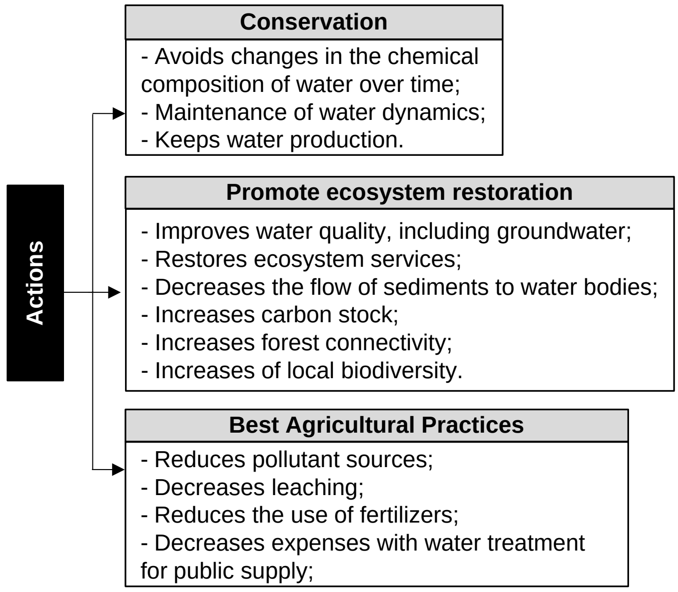

Figure 3. Main actions for payments for ecosystem services related to water resources and their premises.

3.2. Strategies for Water-Related Payments for Ecosystem Services

3.2.1. Conservation

The conservation of forest cover or other native vegetation types contributes to the production of water and to the quality of water resources, in addition to reducing the erosive effect of rainfall, as it limits the transport of sediment to water bodies. Mattos *et al.* (2018) affirm, based on their studies on Atlantic Forest (Brazil), that a preserved rainforest area can provide important ecosystem services with operational conditions and economically feasible to Brazil [21]. Their studies concluded that in the most conservative forest scenario, the water was well-oxygenated and presented low salinity and low concentration of total suspended solids. This finding proved the effectiveness of a montane rainforest in providing protection to water bodies and delivering important ecosystem services.

Pagiola, Platais, and Sossai (2019) presented a PES program for preserving native vegetation in a watershed contributing to avoid sediments runoff to the rivers, which benefits downstream water users with lower water treatment costs and upstream landowners with increased revenues from agricultural activities and payments for conservation [34]. In Mexico, a PES for native vegetation conservation aiming to maintain the water supply quality was responsible for avoiding chemical composition changes in water over 30 years [28].

Vegetation cover is also related to the improvement of groundwater quality and is associated with lower water treatment costs, especially for the public water supply coming from groundwater. This last is filtered and purified in the soil by the plant root system, which reduces the concentration of phosphorus and nitrates, improving water quality. For companies that extract water from under-ground in Portugal, forest cover generated treatment cost savings of 0.056% [30].

In Mexico, Monarch Butterfly Biosphere Reserve PES programs that aimed the forest cover conservation helped to avoid deforestation and contributed to the maintenance of water dynamics and trout production, which is an important activity to improve the socioeconomic level of the local communities. In addition to these benefits, the flow of tourists to the reserve has led to forest recovery in the areas, considering forest cover is crucial for maintaining the hibernation cycle of the butterfly, a significant achievement in a region where forest degradation is the norm [29]. These factors represent how important is native vegetation conservation PES for the environmental awareness of local communities and the improvement of their quality of life [29].

3.2.2. Restoration

Native vegetation restoration is an alternative to improve water quality and recover ecosystem services [31] [32]. The simulation of scenarios predicted that an increase of 7% in primary forests combined with 56% in the total forest in 30 years led to an increase in carbon stock and providence of ecosystem services, such as water regulation, agroforestry products, and non-timber forest products for local communities [33].

Townsend *et al.* (2012) proposed, based on their studies in Australia, that the conversion of more than 70% of pasture areas to forestry would result in water quality improvement, which would return it to potability standards [31]. Additionally, Sun *et al.* (2013) concluded that the conversion of crops into forest and grassland has a better capacity for water conservation because it reduces sediment runoff into water bodies and decreases soil erosion [44]. In Brazil, the first successful water-related PES project was the "Conservador das Águas" (Water Conservationist Project) based on forest restoration focused on water production. The program has already been responsible for the restoration of 3,000 ha of Atlantic Forest in Extrema, Minas Gerais, Brazil [24].

Viani *et al.* (2018) observed an increase in forest cover due to the Conservador das Águas program [48]. In Minas Gerais, Brazil, the forest cover increased from 42.5 ha to 86.1 ha after the project implementation, and the largest area remaining before the program was 5 ha and increased to 36 ha. Therefore, forest restoration in a watershed to improve water supply also increased the structure and functional connection between the landscape's forest patches. An increased forest connectivity was reported by Fiorini *et al.* (2019) with this PES program, even with only 1.5% increase in forest cover in 7 years [53]. These benefits represent a great potential for incorporating biodiversity conservation goals in water-related PES programs. De Melo *et al.* (2016) also pointed out the biodiversity conservation as a consequence of water-related PES programs [35]. They pointed out an increase in the biodiversity of native forest species and a significant improvement in water quality because of PES program "Protetor das Águas" (Protector of the Waters) in Vera Cruz, Rio Grande do Sul, Brazil.

Restoration in these areas has also formed ecological corridors for the gene flow of fauna and flora [48]. In addition, PES program for the restoration of springs and riparian areas has led the regions of Vera Cruz to a gradual process of ecological succession. Thus, other benefits from forest restoration with a focus on water such as biodiversity conservation, must be incorporated into the planning and implementation of PES programs that have ecological restoration as an eligible action for PES [48].

However, in Minas Gerais, Brazil, a PES program aimed at forest recovery has made a limited contribution to water quality due to polluting sources like agricultural waste and domestic sewage input. The authors recommend that PES schemes could also consider controlling point sources of pollution to fulfill their purpose [54]. Thus, it is highlighted that PES schemes are complex, and their financing only does not guarantee success in forest restoration projects [32]. Also, native vegetation conservation and restoration PES depending on the region, such as in Brazil, must be concomitant with best agricultural practices.

3.2.3. Best Agricultural Practices

Diffuse pollution from agricultural areas is one of the main causes of water quality degradation, and therefore, changes in agricultural practices by landowners are another important strategy to contribute to water quality [13]. Branca *et al.* (2011) state that PES programs help to encourage the adoption of best agricultural practices that are less aggressive to the environment because they reduce soil erosion and overall land degradation, thus improving downstream water quality and avoiding future worsening conditions [55]. These changes in water catchment, combined with water quality improvement, can reduce treatment costs [56].

PES programs based on the adoption of best agricultural practices contribute to leaching and fertilizer usage reduction, which improves water quantity and quality [37] [42]. For example, Liang *et al.* (2018) state that the conversion of rice to corn crops was successful in terms of its main goal, with 47% less water consumption [57]. The replacement of corn crops with switchgrass, a perennial grass, to meet the target levels of nitrogen flowing into the Chesapeake Bay, U.S.A., reduced nitrogen loading by 18 kg/ha/year, reaching 31% of the target [40]. Cover crops were identified by Benisiewicz *et al.* (2021) as the practice that most reduced both production and export of sediment, decreasing 13.4% and 14.1%, respectively [41].

In Brazil, in addition to forest restoration, the Conservador das Águas program also encourages the installation of water sanitation systems for the treatment of wastewater from rural properties, the maintenance of native vegetation in riparian zones, and registration of the Legal Reserve (a percentage of the rural property that must be covered by native vegetation by law – BRAZIL, 2012). Many agricultural areas in Brazil do not have sewage collection and treatment, and the adoption of sanitary practices is essential for the conservation of water resources, in addition to restoration and conservation [13].

Sustainable land management practices such as agroforestry, reforestation in environmental fragile areas, and terracing can improve the quality and quantity of water for downstream users [39]. Interventions in forestry, such as the preference of landowners for pine forests of the species Pinus halepensis Mill in the Mediterranean Basin, Spain, could produce an important increase in groundwater recharge, benefiting both users and forest owners, clearly exceeding operational costs [38]. In fact, an opportunity cost assessment is essential for the decision-making by landowners to change their agricultural practices. Designing process and implementing PES schemes as well as the manager-user relationship are crucial to successfully engage farmers in programs to achieve better levels of environmental performance [58].

3.3. Challenges for Implementing Water-Related Payment for Ecosystem Services Programs

In the vast majority of articles, PES programs are a significant strategy to promote water resource conservation. However, some PES programs may present challenges in their implementation (**Figure 4**). The relationship between upstream land management and downstream benefits has been pointed out as causes of conflict in the implementation of PES programs [55] [59] [60] [61] [62]. For example, upstream communities in Pimampiro, Ecuador, disagreed with the PES payment program. They argue that the payment is insufficient, and the local government is controlling the use of their land [59].

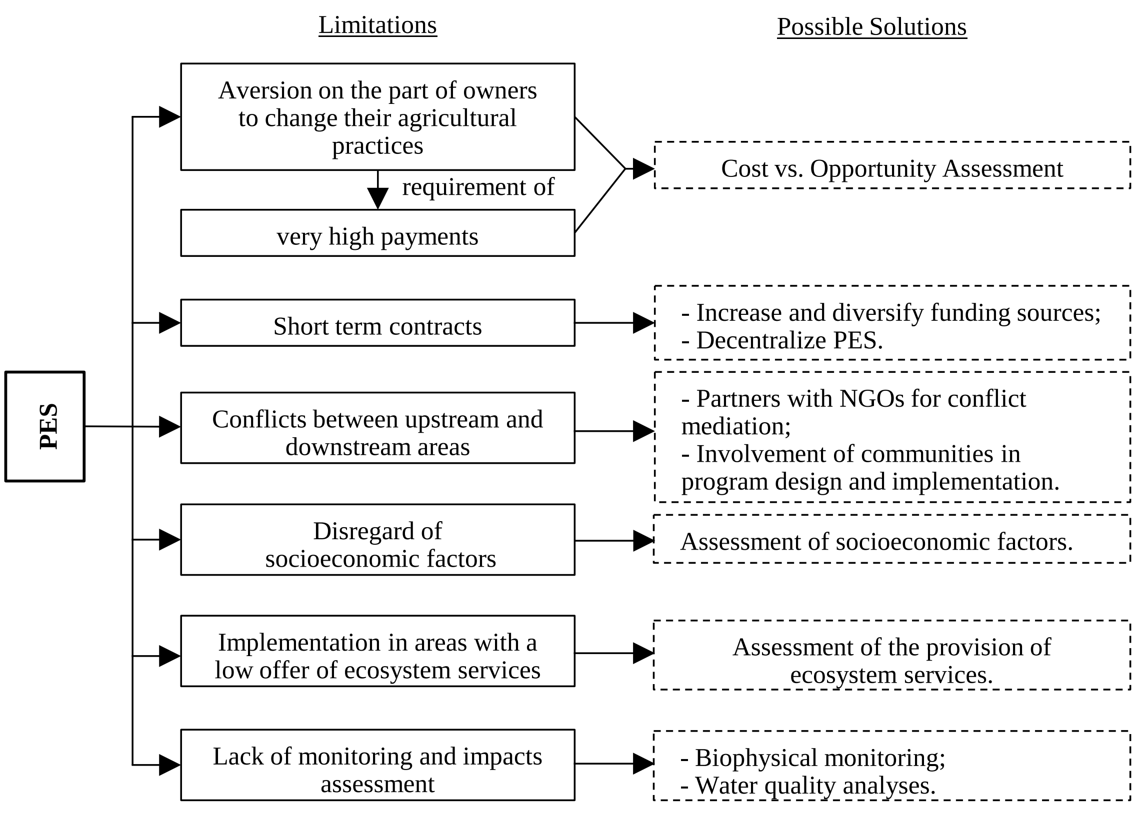

Figure 4. Challenges of PES programs and possible solutions.

In this context, Branca *et al.* (2011) report that the involvement of NGOs during the implementation of the PES scheme helps to build a strong partnership within civil society and a bridge between upstream farmers and downstream users that can help to clarify the potential costs and benefits borne by the PES related parties. The authors also point out that without this type of support, whether from the public sector or civil society, PES schemes would probably not be viable [55].

The effectiveness of PES programs may not be achieved in some regions. Some factors that lead to this failure are programs installed in areas of low risk of deforestation, where there are no buyers for the ecosystem services provided by producers, and where access to information is limited to politicians and decision-makers [60]. Another prominent problem is the lack of empirical monitoring data over a period long enough to demonstrate impacts of PES [63], key strategies to attract new investment, fill fundamental knowledge gaps and benefit program managers, participants, and communities [61].

The short term of PES contracts is also a determining factor for the success of the programs, being necessary for the establishment of opportunities for long-term contracts or renewal contracts to avoid the possible negative consequences of the loss of funding for the participants [24] [64]. In the Cantareira system, Brazil, supplying 9 million inhabitants, a study suggests that the current PES contracts are unlikely to encourage the adhesion of small landowners with high dependence on agricultural income. This group is unlikely to reforest without compensation, and the authors identified that they would need a much higher payout than the current payout structures provided. In-kind incentives that increase agricultural productivity would encourage the participation of these landowners [62].

Other authors criticize the depoliticization of some programs, the private appropriation of property guided by exchange value, and the disregard that socio-natural transformations and hydro-social territories can broaden and deepen asymmetries of power, poverty, and inequality [59]. For Libanio (2015), the main challenge regarding the implementation of both the "Conservador das Águas" and the Depollution of Hydrographic Basins (Prodes) programs, developed by ANA (National Agency for Water and Basic Sanitation), is to convince the political world of the need for a paradigm shift in addressing water security issues, transitioning from a narrow view of water crisis management to a broader perspective of risk reduction, ensuring a robust foundation of water governance and investing not only in water infrastructure but also in water conservation initiatives [65].

3.4. Methods for Water-Related Payment for Ecosystem Services

The use of interviews is the most frequent method in the 236 articles to set priority areas for water-related PES and was present in approximately 28% of the studies, especially the "willingness to pay" (Willingness to Pay—W.T.P.) evaluations. This W.T.P. represents how many farmers and consumers are willing to pay for water quality (**Figure 5**). Respondents varied among articles, including farmers, experts, individuals from the community, companies purchasing the ecosystem service, and NGOs involved in the implementation of the PES program.

The authors concluded that the results of a survey of the interested parts, such as users and beneficiaries of ecosystem services, sellers (the providers of the ecosystem services - forest owners and/or forest managers), intermediaries, NGOs, and knowledge providers (like forest management experts, regulators, legal advisors, or researchers), can act as a starting point when designing PES schemes. The preferences, opinions, and perceptions of different users provide information in order to reduce conflicts between interest groups and increase the acceptance of decisions related to the management of natural resources [66] [67].

Interview results can encourage those implementing PES programs to carefully consider local motivations and capitalize on opportunities to promote potential environmental benefits [68]. WTP-type interviews provide valuable insights for designing and starting a potential PES scheme that can improve current forest management practices as well as support landowners, creating opportunities for conservation of water resources [67].

Notably, the shared value of an ecosystem service is strictly connected to local knowledge and feelings and, therefore, should be integrated into the design of PES schemes. Thus, these programs implementation must be a participatory process that incorporates the multilevel governance of the management and delivery of ecosystems services at different levels [66]. How the local community and beneficiaries perceive the environment and its ecological benefits are critical to integrate local perceptions and science, policy and management [69].

The use of geotechnologies, such as analysis of satellite images, geoprocessing programs and their combination with hydrological models, were applied in 17.37% of the studies (**Figure 5**), especially to analyze changes in land use and land cover and identify areas with the greatest offer of water-related ecosystem services [48] [70] [71] [72]. The use of these tools has served as a foundation and generated fundamental information in the definition of priority areas that should receive PES programs [26] [66].

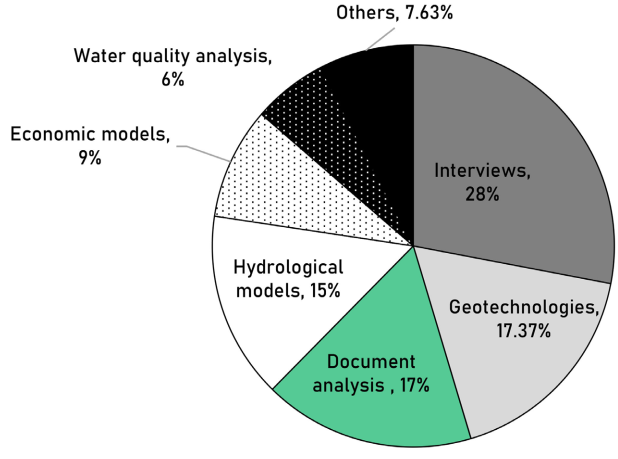

Figure 5. Methods employed in articles on payments for ecosystem services related to water resources.

Analyses of PES programs by document assessment were performed in approximately 17% of the articles (**Figure 5**). PES studies are critical in providing background information describing factors that led to program implementation and its results. These analyses were important to identify: financing mechanisms, the parts involved in the process, the difficulties of implementing PES schemes [73], the impacts of the schemes on the community [74], the importance of NGOs in territorializing watersheds [75], the satisfaction of farmers with the programs and their preferences regarding environmental conservation strategies [76], the conceptions of potentially paying companies [77], and how many consumers are willing to pay for water conservation [78]. In short, the analyses highlight the comprehension of the complex management of water resources.

The assessment and quantification of ecosystem services related to water resources is still challenging, therefore, were the focus of many articles [67] [79] [80]. Because of that, studies used hydrological models to predict or simulate water-related ecosystem services. Hydrological models were used for about 15% of the articles (**Figure 5**).

The main hydrological models were SWAT [81] and InVEST [82]. Liu *et al.* (2019) were successful in using InVEST to estimate and map the cost of pollution treatment [83]; Saad *et al.* (2018) and Saad *et al.* (2021) used it to simulate the transport of sediments from a small watershed [46] [84]; Wang *et al.* (2020) applied it to quantify the supply of fresh water [85]; Mokondoko *et al.* (2018) to quantify ecosystem services [79]. Concerning the SWAT model, Lopes *et al.* (2020) provided a good fit between the observed and simulated data, thus, enabling its use in the management of water resources and PES programs supporting [23]. Song *et al.* (2020) applied the model to simulate water ecosystem services; [80] and Palm-Forster *et al.* (2016) could predict reductions in exported phosphorus due to the type of conservation practice and location of the farm [86]. Modeling integrated with the dynamics of land use and cover in watersheds can successfully predict various impacts resulting from policy decisions and also allow the efficiency evaluation of conservation instruments [33] [87].

Despite the efficiency of hydrological models, several authors cite the need for further improvements and refinements, as well as more details of input data to increase the quality of modeling systems [87] [88]. Saad *et al.* (2018) advise studies that compare models for a better estimation of uncertainties [46], and Palm-Forster (2016) pointed out the need for biophysical research to understand the movement of nutrients in the natural environment for a higher reliability of SWAT-related models [86].

The analysis of water quality in the field was applied by only 6% of the articles (**Figure 5**). Water chemistry is an important indicator of changes in water resources and therefore a useful reference for assessing pollution trends and monitoring the impacts of water management instruments. The low frequency of this method indicates the lack of results monitoring regarding the water quality of PES programs, a fact pointed out by some authors [50] [89] [90].

The articles also used economic modeling to determine water pricing and evaluate the cost-benefit and market assessment (about 9% of the studies) (**Figure 5**). Additional applied methods were: literature review, multi-criteria analysis, and biodiversity survey. The variety of methods identified in this review demonstrates the diversity in the approaches given to PES programs and the complexity of water resources management, ranging from evaluations of the environment's biophysical characteristics to socioeconomic factors and market analysis.

3.5. Criteria for Defining Priority Areas for Water-Related Payment for Ecosystem Services Implementation

A key challenge for PES programs is identifying the most relevant areas for delivering ecosystem services in the watershed. This prioritization ensures that funds are spent more efficiently. However, several subsidy programs do not condition payments on the capacity of ecosystem services, either due to transaction costs or concern overachieving a dual goal of poverty decreasing [91]. Pynegar *et al.* (2018) also argue that not all lands registered in PES schemes represent additional water quality conservation [50]. Aiming solve these difficulties and enhance the effects of PES schemes, nine articles tried to elaborate specific criteria for defining priority areas for water resources conversation (**Table 1**).

Table 1. Criteria to define priority areas for payments for ecosystem services related to water resources, their premises, and respective authors.

Criteria	Premise	Authors
Marginal areas of agricultural land with a high probability of natural regeneration	- Lower requirements implementation costs.	- VIANI, BRACALE, TAFFARELLO, 2019 [32];
Steeper areas	- Increases sediment runoff that can affect water quality; - Provides soil stability reducing the risk of landslides and maintaining agricultural productivity.	- JONES *et al.*, 2017 [92]; - SAAD *et al.*, 2018 [46]; - VALENTE *et al.*, 2021[26];
Areas with high forest cover	- Provides water purification service; - Related to soil erosion; - Improves water quality.	-MOKONDOKO; MANSON; PÉREZ-MAQUEO, 2016 [93]; - MOKONDOKO *et al.*, 2018 [79]; - LI *et al.*, 2020 [94];
Riparian zones and close to rivers	- Provides water purification service; - Promotes biodiversity conservation; - Large water storage capacity.	- LEI *et al.*, 2011 [95]; - FREMIER *et al.*, 2013 [47]; - JOHNSON *et al.*, 2016 [96]; - VALENTE *et al.*, 2021 [26];
Socioeconomic criteria	- Reduces social inequality.	- WILLAARTS, VOLK, AGUILERA, 2012 [52]; - ASBJORNSEN *et al.*, 2015 [97]; - ASBJORNSEN *et al.*, 2017 [98];
Soils with high erosion potential	- Increases sediment runoff that can affect water quality.	- SAAD *et al.*, 2018 [46]; - JONES *et al.*, 2017 [92]; - VALENTE *et al.*, 2021 [26].

Viani, Bracale and Taffarello (2019) suggest that PES projects should focus on marginal areas of agricultural land with a high probability of natural regeneration and, alternatively, future projects could focus on lands with a remaining forest cover of high conservation value [32]. Li *et al.* (2020) considered socioeconomic and biophysical criteria in the reservoir in Beijing, China [94]. However, the biophysical criteria were pointed out as being of greater importance. The most relevant criterium was related to catchment conservation (e.g., land use, water quantity, forest water conservation capacity). Mokondoko *et al.* (2018) argue that spatial heterogeneity of ecosystem services must be considered when targeting PES [79]. The criteria set that most influenced the provision of ecosystem services related to water resources and water production in their studies were forest cover, followed by carbon storage, and soil retention. Program payment zones occupied only 11.3% of eligible for PES areas [79].

According to Valente *et al.* (2021), the high priority areas for forest restoration and PES receiving was pasture and agricultural lands, even in a watershed predominantly covered by forest, and areas close to rivers, in steep areas of the watershed, with soils with high erosion potential [26].

Asbjornsen *et al.* (2017) assessed the impact of a PES program in Mexico on hydrological services and people's behavior and knowledge related to forest and water conservation. The program benefits landowners who have their areas within eligible watersheds based on the presence of priority ecosystems, proximity to parks, downstream cities, degree of aquifers overexploitation, and poverty reduction. The program assumes as a premise that there is a positive relationship between forest cover (especially cloud forests) and the provision of hydrological services. Hence, this payment has a positive impact on landowners' decisions regarding forest conservation. However, cloud forests have variable hydrological characteristics among them. Thus, the researchers claim that protecting cloud forests at the expense of other types of vegetation, such as pasture, will probably not increase the total annual water production and may even intensify the dry seasons, as cloud forests intercepted the water in their study area rain at a rate of only 2% and in the dry seasons only 8% per year [98].

The authors suggest a more complex relationship between forests and hydrological services, with cloud forests having an annual water production lower than pasture, even though they play a crucial role in other hydrological services, such as flow regulation, groundwater recharge and improvement in water quality. Furthermore, these functions may be associated with the topographic and geological characteristics of the basins that contribute for promoting infiltration. The authors suggest that further researches are needed to identify water recharge zones with high precipitation in relation to land cover type and geology to develop policies and tools that prioritize areas with intense production of hydrological services [98].

Mokondoko, Manson and Pérez-Maqueo (2016) also argue that the effectiveness of PES programs in Mexico can be reduced by an overemphasis on water supply compared to other services, such as water quality. Thus, the authors explored in their studies the relationships among land use, water quality and public health, via an assessment of the frequency of cholera (associated to Escherichia coli) in stream water. A positive relationship was found between forest cover and surface water quality measured by the concentration of E. Coli, especially in riparian zones (100 meters of riparian buffer), that represents an important link between hydrological services and public health. Therefore, the riparian zones represent an important benefit that should be evaluated and compensated in PES programs to enhance their effectiveness [93].

Riparian zones are also the focus of PES in a program in China established in 2008 that aims to improve water quality in the Lake Nansi basin in Shadong province. The authors performed a cost-benefit analysis of the program and concluded that riparian zones have a large water storage capacity, and the economic value of these areas is greater compared to productive and low productive agricultural areas [95] [96]. Notably riparian areas provide a set of important water ecosystem services and also promote biodiversity conservation at multiple scales, including habitat protection and functional connectivity [47]. Also, the riparian areas as well as areas close to rivers were the most important criterium for Valente *et al.* (2021) to receive PES [26]. For forest restoration, presenting 34.80% of importance in their decision-making support model. Thus, riparian zones should be included in efforts to identify priority zones in which forest cover conservation or restoration would maximize the provision of services related to water resources [93].

In a study carried out by Brazilian researchers compared restoration strategies for riparian areas and steeper areas. The restoration of 25% (percentage reached by PES program) of steeper areas promoted the highest decrease in soil loss (21%) in contrast to the restoration of riparian areas, which presented a rate of 16%. Regarding the export of sediments, the restoration of riparian areas reduced 78% and 27% in steep areas. Despite the clear superiority of riparian forest restoration compared to steep areas in protecting water quality and preventing siltation, the authors argue that forests may have a limited capacity to trap sediment due to the possibility of saturating in rainy periods [46].

Thus, both types of restoration are advisable, as they are complementary strategies to prevent sediments from reaching water bodies and protect them at their source. Restoring riparian areas improves water quality and decreases the risk of siltation. Slope restoration provides soil stability reducing the risk of landslides and maintains agricultural productivity and, therefore, should also be treated as a priority to avoid sediments arrival to rivers [46]. Still about steep areas, Valente *et al.* (2021) highlight that the forest cover restoration in these areas, especially in the agricultural watershed, is essential for water quality improvement [26].

Besides riparian zones, Watanabe and Ortega (2011) suggest that PES areas prioritization should focus on issues related to aquifer recharge, leaching, and carbon and nitrogen runoff, since these processes are highly affected by changes in the use of soil. Agricultural and urban expansion increases runoff and reduces infiltration, which provides severe consequences for human well-being by decreasing groundwater flow and slowing aquifer recharge [99].

Some watershed PES programs focus on reducing the risk of wildfires on lands that produce potable water sources, such as a program in Colorado, USA. This program is premised on the fact that fire affects water quality, aiming the reduction of water supply costs after a fire. According to the authors, it is essential to reduce erosion and sediment runoff to maintain post-fire water quality. Thus, PES programs in areas where there is little ground cover, with erodible soil and high sediment delivery (e.g. slopes steep areas and areas with large volumes of rain) are more susceptible to fire and, therefore, should be prioritized for the production of ecosystem services [92].

In this review, the focus of researchers on biophysical criteria in prioritizing areas for PES and also for monitoring programs is evident. However, socioeconomic criteria are also considered, especially about the sustainability of hydrographic basins and the integration between socioeconomic and biophysical aspects can influence the decision-making and the elaboration of more effective public policies. Asbjornsen *et al.* (2015) in their review cite the main socioeconomic criteria used by researchers: 1) Knowledge and participation (how much users know about the PES program); 2) Demand and access to water; 3) Practices and Land Management; 4) Human Health (prevalence of water-related diseases); 5) Demographic data; 6) Livelihoods (dependence on agriculture for family survival); 7) Social conflicts; 8) Poverty; 9) Work (percentage of families who do not work with agriculture and who work with agriculture); 10) Equity and Justice (refers to the distribution of program costs and benefits) [97]. However, Mokondoko *et al.* (2018) suggest that the inclusion of socioeconomic criteria in the payment program analyzed by them resulted in a decreasing influence of biophysical factors, which tend to move away from ecological objectives and possible loss of program effectiveness [79].

In this context, the socioeconomic criteria, addition to the biophysical ones, were evaluated by Willaarts, Volk and Aguilera (2012) in Sierra Norte de Sevilla, Spain [52]. The authors considered the performance of different types of land use and also social preferences related to types of ecosystem services. Multifunctional agroecosystems, where agricultural activities such as agroforestry and forestry coexist, optimize the flow of freshwater and provide the greatest ecosystem services and, therefore, are priority areas for PES [52]. Thus, it is clear that we still face off barriers regarding the prioritization of criteria for defining areas for PES, especially regarding the balance of biophysical and socioeconomic criteria. This represents a gap in the articles on the subject and demonstrates the need for further studies with this approach.

In another approach, with the prioritization of human needs, authors related the forecast of ecosystem services with the supply of electricity by hydroelectric plants. In this context, the authors argue that water conservation services are a priority for compensation and then soil conservation functions. Compensation must include, in the first place, the protection of wetlands that are crucial for the retention of water in ecosystems [100].

Wetland protection was the focus of a PES in Florida and researchers looked at possible synergies with other ecosystem services. It was identified that wetlands of intermediate to low retention harbor most of the biodiversity, especially of amphibians, fish, and macroinvertebrates. Higher retention levels can reduce the richness of native plants and fish. Non-native plants are more abundant in shallow or deep water. These non-linear relationships between water retention and biodiversity suggest that there is a range of intermediate levels of retention that also maintain biodiversity. Thus, different strategies are needed, especially in this study site, where the quantity and quality of downstream water are important environmental and social issues and wetlands with less biodiversity could be managed to retain and remove nutrients [101].

4. Conclusions

Our review identified the PES programs have been a tool for the watershed conservation, contributing to the water quality maintenance or improvement, improving agricultural practices and reducing social inequalities in rural areas. In this context, the most frequent practices to improve the supply of water-related ecosystem services were conservation, restoration and adoption of best agricultural practices.

The most used methodologies by the authors were interviews with rural landowners and other parties involved in the Payment for Ecosystem Services (PES) development process, such as buyers and intermediaries, followed by the use of geotechnologies, documentary analyses, and hydrological models. The diversity of methodologies reflects the complexity of PES implementation, which should involve both biophysical and socioeconomic factors.

Researchers' efforts are evident in the articles raised to establish a relationship between forest coverage and water-related ecosystem services, identify priority areas for receiving this payment in order to maximize investments and analyze the effects of PES programs in the natural environment and context socioeconomic. Defining priority areas to receive water-related PES is critical to ensuring the provision of ecosystem services that improve water quality. In this review, the Riparian areas, steep areas, areas with erodible soil, and areas with high forest cover were the most eligible for PES.

However, there is still a lack of information between the valuation of water and the impacts on the quality of this resource and this lack of data indicates that there is a long way to go so that PES can effectively contribute to the sustainable use of water, especially in developing countries, where resources for conservation are limited.

The scarcity of data on the effectiveness of PES programs in promoting water quality was evident in this review. Understanding the factors that affect water quality is specific to each ecosystem, depending on a series of variables, such as climatic conditions, land use and occupation, and potential polluting sources. Thus, the collection of this information is essential, whether through physical-chemical analysis of water, analysis of changes in the structure of the landscape, modeling to predict ecosystem services, or through the assessment of socioeconomic indicators.

The implementation and development of payment programs for ecosystem services related to water resources involves a complex watershed management process and requires the involvement of a wide range of stakeholders. A body of research on socioeconomic, social and environmental factors is needed to aid the decision-making by water managers.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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