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Participatory assessment to define indicators for monitoring water-based payment of ecosystem services programs in Brazil

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ABSTRACT

The cascade model is a commonly applied framework to evaluate ecosystem services provision, highlighting their benefits to society and assigning non-monetary and monetary values to these services. Adapting this model, we present a methodology to establish the most suitable indicators for monitoring Payment for Ecosystem Services (PES) programs related to water resources in Brazil. Through a participatory process, a set of ecosystem functions indicators were assigned for each ecosystem service (ES) considered in the study. The indicators were then classified following these criteria: clarity, viability, sensitivity, and relevance. The indicators were organized by their final score according to each evaluated criterion. The results demonstrated that "clarity" and "relevance" criteria were those most important for the experts to choose an indicator. In general, we could also observe a preference for analytical and well-established indicators in the literature for all ES evaluated. The indicators list presented can support the PES program monitoring in Brazil. Additionally, the methodology developed can be easily applied in other areas and provide the definition of the most suitable indicators to monitor water-based PES in different Brazilian contexts.

Keywords: cascade model, ecosystem functions, ecosystem service indicators, tropical areas.

Avaliação participativa para definição de indicadores para monitoramento de programas de pagamento de serviços ecossistêmicos hídricos no Brasil

RESUMO

O modelo em cascata é uma estrutura comumente utilizada para avaliar a provisão de serviços ecossistêmicos, destacando seus benefícios para a sociedade e atribuindo valores não monetários e monetários a esses serviços. Adaptando este modelo, apresentamos uma metodologia para estabelecer os indicadores mais adequados para monitorar programas de Pagamento por Serviços Ecossistêmicos (PSA) hídricos no Brasil. Por meio de um processo participativo, um conjunto de indicadores para as funções ecossistêmicas foi atribuído a cada serviço ecossistêmico (SE) considerado no estudo. Em seguida, os indicadores foram classificados segundo os seguintes critérios: clareza, viabilidade, sensibilidade e relevância. Os resultados demonstraram que os critérios clareza e relevância foram os que os especialistas consideraram como os mais importantes para escolher um indicador. No geral, podemos observar que para todos os SE avaliados, os indicadores de maior pontuação foram aqueles analíticos e bem estabelecidos pela literatura. A lista de indicadores pode apoiar o monitoramento de PSA na Floresta Atlântica. Além disso, a metodologia desenvolvida pode ser facilmente aplicada em outras áreas e fornecer suporte para a definição dos indicadores mais adequados para monitorar o PSA baseado em água em diferentes contextos nos trópicos.

Palavras-chave: áreas tropicais, funções do ecossistema, indicadores de serviços ecossistêmicos, modelo em cascata.

1. INTRODUCTION

Ecosystem functions (EF) can be defined as "the capacity of natural processes and components to provide goods and services that satisfy human needs, directly or indirectly" (De Groot, 1992; De Groot *et al.*, 2002).

This idea can be considered one of the key aspects regarding the ecosystem services (ES) concept, defined as the direct and indirect benefits people obtain from ecosystems, contributing to human well-being (MEA, 2005; TEEB, 2010).

More recently, the Common International Classification of Ecosystem Services (CICES) presented the vision of the final services (FS), which retain a connection to the underlying ecosystem functions, processes and structures that generate them and most directly affect the human well-being (Haines-Young and Potschin, 2018).

These approaches have in common the aim to integrate a broad range of ecosystem functions and services, considering their interdependencies and social demand to improve the decision-making measures (Primmer and Furman, 2012). An example is the cascade model (Haines-Young and Potschin, 2010) which is a commonly applied framework consisting of steps, starting at generating ES processes until their benefits and non-monetary/monetary values (Spangenberg *et al.*, 2014). It helps to operationalize the links among ecosystem properties (biophysical structure or process), ecosystem functions, ecosystem services and, contribute to the valuation procedure. Realistically, those links are not as simple and linear as they appear in this framework, but such an approach is useful to show the relations that are generated by the ESs, and consequently to better plan interventions (Pavan and Ometto, 2018).

De Groot *et al.* (2010a), working with the cascade framework, separated the benefits from their values. They argued that, if benefits are seen as gains in well-being generated by ecosystems, then it is clear that different groups may value these gains in different ways at different times, and indeed in different places (Fisher *et al.*, 2009). Despite this modification, the fundamental tenet of the ecosystem service paradigm remains: namely, that a service is only a service if a human beneficiary can be identified and that it is important to distinguish between the "final services" that contribute to people's well-being and the "intermediate ecosystem structures and functions" that give rise to them (Potschin and Haines-Young, 2011). Thus, we observe a clear focus on a more anthropocentric interpretation with a utilitarian background, which was already discussed by other authors. In Schoröter *et al.* (2014), it is possible to find a structured debate between opponents and proponents of the ecosystem services concept.

Additionally, Costanza *et al.* (2017) stated that the connections between ecosystem processes, functions, and benefits to humans are complex, nonlinear, and dynamic. These complex connections are poorly represented by a linear 'cascade', which assumes simple linkages and effects.

The key messages that seem to emerge from these debates is that, in relation to the cascade idea, whether or not it involves three, four or more steps, or how particular boxes are labelled, the fundamental task is to understand the mechanisms that link ecological systems to human well-being. The intention of the cascade idea is to highlight the essential elements that must be considered in any full analysis of an ecosystem service and the kind of relationships that exist among them (Potschin and Haines-Young, 2011).

For any ecosystem service, there are various attributes that could be measured, from the state of the underlying system, through the functioning of the system, to the services it provides, and the benefits gained by society (Spangenberg *et al.*, 2014). Key metrics that support and inform this process are the ecosystem service indicators (ESI).

ESI can be applied for different aspects of this ‘flow’, from the ecosystems that provide services, to the benefits that are obtained by people. They include measures of ecosystem processes and functions, their use (benefit) and impact (De Groot, 1992; Balmford *et al.*, 2008; Tallis *et al.*, 2008; De Groot *et al.*, 2010a; 2010b). The main challenge is to define the most suitable indicators, which meet the specific requirement for each ES. This means, understanding what needs to be known, and then choosing an appropriate combination among the plethora of potential indicators (Berghöfer and Schneide, 2015).

Successful natural resource management is dependent on effective knowledge exchange and utilization (Roux *et al.*, 2006; Fazey *et al.*, 2013). Knowledge exchange (KE) are processes that generate, share and/or use knowledge through various methods appropriate to the context, purpose, and participants involved. KE includes concepts such as sharing, generation, coproduction, co management, and brokerage of knowledge (Fazey *et al.*, 2013). There is no single optimum approach for integrating local and scientific knowledge and encouraging a shift in science from the development of knowledge integration products to the development of problem-focused, knowledge integration processes. These processes need to be systematic, reflexive and cyclic so that multiple views and multiple methods are considered in relation to an environmental management problem (Raymond *et al.*, 2010).

Fleischman and Briske (2016) highlight professional ecological knowledge (PEK), which differs from local ecological knowledge (LEK) because it is not grounded in direct experience of natural resources to support human livelihoods, and that it differs from scientific knowledge because it is not directly derived from systematic inquiry. PEK is a unique knowledge source. It includes best management practices, procedural manuals, and technical guides that often come to be thought of as verified scientific knowledge by personnel who use them. The knowledge used by professional resource managers, particularly those in public agencies, is important because these managers play an important role in decision making about public and private land use around the world.

The KE process can be facilitated by a participatory process. The experience from some projects has shown the potential of stakeholder engagement in natural resources management processes (sometimes referred to as ‘‘diversity analysis’’, e.g., Pain, 2004). This approach has been seen as a way of generating information on the ‘‘relevant actors’’ to understand their behavior, interests, agendas, and influence on decision-making processes (Brugha and Varvasovsky, 2000). Thus, stakeholder engagement can be useful for the definition of indicators resulting in more realistic, meaningful and achievable options than those set by top-down methods (Better Evaluation, 2014). Moreover, the indicators established in a participatory way can reduce costs and ensure continued monitoring of ecosystem functions and services.

In participatory processes, it is recommended to use a stakeholder analysis method to identify the most relevant stakeholders for each case that will be included in the further processes. The participation mechanism can occur at any stage of the evaluation process: its design, data collection, analysis, reporting or managing the study (OECD, 2011a; Guijt, 2014).

In the past two decades, the number of PES schemes has significantly increased; currently there are around 550 PES programs worldwide and approximately half of these are being implemented in Latina America (Salzman *et al.*, 2018). In Brazil, the most well-known water-based PES is the Water Producer Program of the National Water Agency (ANA), ongoing since 2005. This is a national program to stimulate the implementation of water-based PES projects in the strategic basins for restoration and water supply (ANA, 2012). The official website of the Water Producer Program informs that there are 29 projects underway (ANA, 2021).

While monitoring of PES projects is essential to identify PES effectiveness and their environmental and socioeconomic consequences, the lack of adequate monitoring has been identified as a major bottleneck of these programs worldwide (Pagiola and Platais, 2007; Engel *et al.*, 2008; Pagiola *et al.*, 2012). Lima *et al.* (2021) presents an overview of monitoring water-based PES in Brazil, pointing out its main characteristics such as analyzed parameters, frequency and also identifying gaps and proposing future perspectives.

Considering these aspects, we present the results of a participatory process for ESI selection for water-based Payment for Ecosystem Services (PES) in Brazil. We propose a set of indicators able to be used to monitor the results of interventions by these PES water-based projects. Additionally, the methodology developed can be easily applied in other areas and provide the definition of the most suitable indicators to monitor water-based PES in different contexts in Brazil.

2. MATERIAL AND METHODS

This study was developed in three steps: pre-selection of EF, ES and ESI; an expert participative workshop; ESI definition and ranking.

Step 1. Pre-selection of EF, ES and ESI

The pre-selection of EF and ES was based on Costanza *et al.* (1997) and MEA (2005). We identified and worked with the ES directly associated with water resources –water supply, water regulation, erosion control, soil quality and habitat regulation (Figure 1).

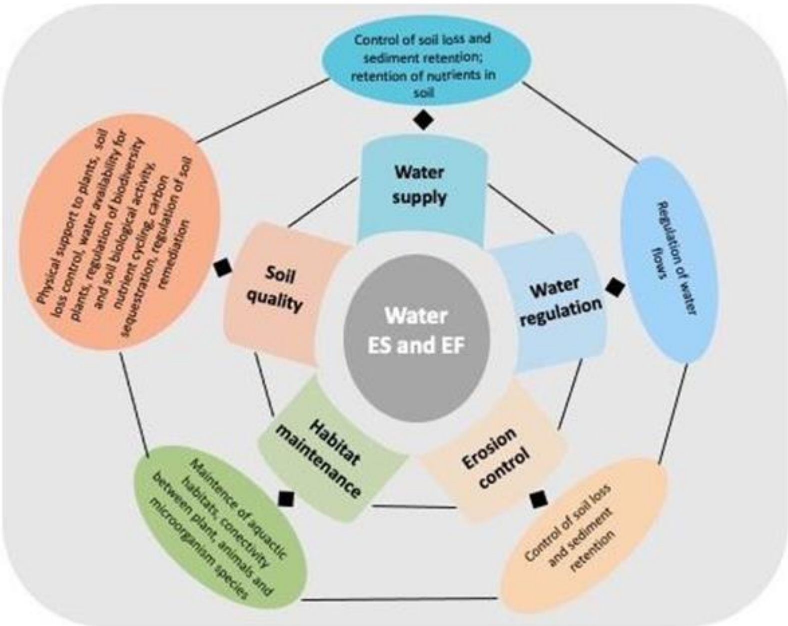

Figure 1. Ecosystem services (ES) and functions (EF) directly associated with water resources considered in this study, pre-selected from Costanza *et al.* (1997) and MEA (2005).

We then analyzed the indicators that are being used by the water-based PES programs in Brazil (Pocidônio and Turetta, 2012). From this evaluation, a preliminary indicator list was generated considering the suitability and effectiveness of each indicator, following the criteria proposed by OECD (2011b) in order to support the start of the participatory process.

Next, all of this information was organized following the cascade conceptual model

(Haines-Young and Potschin, 2010; Martin-Lopez *et al*., 2014) associated with two components: Structure and Function. We considered the structure as the ability of the biophysical environment to provide a particular ES. The function was considered the ecosystem mechanism by which the services are generated –for example, one of the forest cover functions is the potential of slowing the surface water flow, that is linked to sediment retention and soil loss control, a core capacity for the water supply/water quality ecosystem services (Figure 2).

Thus, structure and function are underpinning elements that determine the capacity of the ecosystem to deliver particular services (Haines-Young and Potschin, 2018).

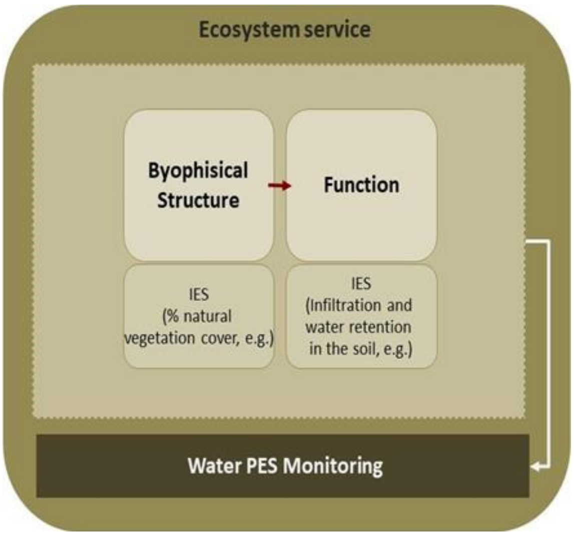

Figure 2. Conceptual model adopted for the selection of ESI.

Step 2. The expert participative workshop

A stakeholder analysis aims to evaluate and understand stakeholders from the perspective of an organization, or to determine their relevance to a project or policy (Brugha and Varvasovsky, 2000). Considering a variety of methods to identify stakeholders, as described by Reed *et al.* (2009), we selected the "project expert's consultation". We selected this method to add analytical horsepower, input external change force and stimulate exchange of knowledge in the scientific community.

Thus, a group of forty-two experts related to PES and with diverse backgrounds and expertise joined a workshop held at Embrapa Solos, in Rio de Janeiro, Brazil, on June 25th and 26th, 2013 (Turetta *et al.*, 2013).

The workshop was based on different dynamics, working with the whole group for general presentations, discussions, and decisions, and in separate working groups, according to their expertise: Group 1: Water regulation and erosion control; Group 2: Water supply; Group 3: Soil quality; Group 4: Habitat maintenance.

The first activity for the workshop participants was to analyze the preliminary list of EF and correlate with the indicators defined in Step 1. The experts were invited to review the list and to include and/or exclude EF and indicators following the recommendations in order to reduce the subjectivity and better standardize the process of ESI selection:

- Always taking into account the conceptual model defined in Step 1 (Figure 2);

- Selecting ESI for local scale application, as the monitoring of water-based PES is mostly "*in situ*";

- Prioritizing indicators with thresholds already referenced in the literature and/or in

Brazilian legislation;

- Indicators should be appropriate for the baseline (initial condition) and for the monitoring of water-based PES intervention impacts.

Step 3. ESI definition and ranking

Once the groups had finished the review and definition of EF and indicators for each ES established in Step 1, we invited the experts to assign the scores "1" (low), "2" (medium) or "3" (high) for each ESI considering the criteria: clarity, viability, sensitivity, relevance (Table 1):

Table 1. Criteria to ESI evaluation.

Criteria	Rationale
Clarity	Efficiency of understanding and communicating (association of the indicator response with the phenomenon) and simplicity of use of the indicator by the decision maker
Viability	Analysis costs and easiness of obtaining and analyzing the indicator
Sensitivity	Ability to detect the impacts and changes in the ecosystem
Relevance	Applicability of the indicator to demonstrate the ecosystems' function

No weighing factor was applied during the evaluation process, i.e., all criteria influenced the evaluation equally.

As a result, a list containing the ecosystem functions for each ES and the indicators for monitoring interventions, by criteria, was generated.

We ran the "Mode" analysis to access the most frequent score of each indicator per criterion on Excel© software to obtain the final indicators matrix.

3. RESULTS AND DISCUSSION

3.1. Overall results

Selection of effective indicators is best achieved by developing conceptual models of the ecosystem and using these to pinpoint indicators that provide the required information (Queensland Government, 2020). Based on that, the results presented here followed the analysis considering the ESI per EF presented in the conceptual model applied in this study (Figure 2).

An overall analysis that emerged from the ESIs selection process is that the ecosystem services that are connected to a high number of functions are those harder to evaluate, as there are many aspects to be considered, including quantitative and qualitative characteristics.

The highest amount of EFs identified by the experts was in the "Soil Quality" ES, while the "Water supply" ES had the lowest EFs associated. (Table 2). However, "Water Supply" presented the highest number of correlated ESI, which reflects the number of parameters and indexes already established for the assessment of water quality status.

"Water regulation" and "Erosion control" were the services with fewer ESI associated with each EF and it was possible to distinguish that the "Water regulation" concentrated most of the ESIs regarding flow aspects, while "Erosion control" presented indicators focused on the soil loss parameters (Table 2).

In some cases, the same ESIs were suggested for more than one ES (Table 2). "Turbidity", for example, was recorded as "Water supply" and "Erosion control" services. It is not a surprise as this parameter is associated with the presence of suspended solids in the water, an important feature for both services.

Table 2. ESI organized by ES, EF and criteria. Dark gray represents mode 3 (it means, the highest mode value for the indicator performance per criterion); light gray represents score 2, and white, score 1, respectively.

Water supply					
Ecosystem Function	*Indicators*	*Clarity*	*Viability*	*Sensibility*	*Relevance*
Control of soil loss and sediment retention	Turbidity	dark gray	dark gray	dark gray	dark gray
	Total solids	dark gray	dark gray	dark gray	dark gray
	Suspended solids	dark gray	dark gray	light gray	light gray
Retention of nutrients in soil	Dissolved Oxygen (DO)	dark gray	dark gray	dark gray	dark gray
	pH	dark gray	dark gray	light gray	light gray
	Biochemical Oxygen Demand (BOD)	light gray	light gray	light gray	light gray
	Thermotolerant coliforms	dark gray	light gray	light gray	light gray
	Total coliforms	dark gray	light gray	dark gray	dark gray
	Water temperature	dark gray	dark gray	white	white
	Total nitrogen (TN)	light gray	dark gray	dark gray	dark gray
	Nitrate	light gray	dark gray	dark gray	dark gray
	Nitrite	light gray	white	light gray	light gray
	Ammonia Nitrogen	light gray	white	dark gray	dark gray
	Total Phosphorus (TP)	dark gray	dark gray	dark gray	dark gray
	Dissolved Inorganic Phosphorus (DIP)	light gray	light gray	light gray	light gray
	Total Dissolved Phosphorus (TDP)	white	white	light gray	light gray
	Nitrogen / phosphorus ratio (N/P)	light gray	light gray	light gray	light gray
	Heavy metals	light gray	light gray	light gray	light gray
	Pesticides	dark gray	white	white	dark gray

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Retention of nutrients in soil	Dissolved Organic Carbon (DOC)
	Total Organic Carbon (TOC)
	Dissolved Inorganic Carbon (DIC)
	Cations (sodium, calcium, potassium, magnesium)
	Anions (carbonates, bicarbonates, chlorides, sulfates, nitrates)
	Total Hardness
	Chlorophyll A
	Oils and greases
	Salinity
	Alkalinity
	Presence of aquatic macrophytes
	Hormones
	Antibiotics
	Surface-active agents
	Chemical Oxygen Demand (COD)
	Metals (micronutrients)
	E.coli
	Virus
	Salmonella
	Electric Conductivity (EC)
	Phytoplankton algae

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Retention of nutrients in soil	Color				
	Benthic organisms				
	Standardized Toxicological Bioassays (Acute and Chronic)				
	Index of Biological Integrity (IBI)				
	Diversity Index				
	Species richness				
	Equitability (aquatic vertebrates, aquatic invertebrates - insects, zooplankton				
	Dissolved Oxygen (DO)				
	Cyanobacteria				
Water Regulation					
Ecosystem Function	*Indicators*	*Clarity*	*Viability*	*Sensibility*	*Relevance*
Maintenance of groundwater recharge	Groundwater level				
Maintenance of springs	Flow rate				
	Groundwater level				
Maintenance of reference flow	Groundwater level				
	Base flow coefficient (Qbase/precipitation)				
	Reference flow (Q7,0 or Q95)				
Attenuation of extreme events (floods)	Peak flow				
	Frequency of extreme events				
Retention of soil water	Runoff coefficient				
	Soil physical-water properties				

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Climate regulation	Heat attenuation				
	Evaporative fraction (Etr/Eto)				
	Erosion Control				
Ecosystem Function	*Indicators*	*Clarity*	*Viability*	*Sensibility*	*Relevance*
Reduction of surface erosion	Estimated soil loss per area				
	Occurrence of soil erosion (number of erosion points per area)				
	Turbidity				
	Amount of sediment retained in barriers (physical/vegetative barriers, dams, terraces)				
	Sedimentation rate in the reservoir				
	Sediment flow in the canal				
Reduction of channel erosion	Canyon fault				
	Sediment flow in the canal				
	Geomorphic channel facility				
	Clogging				
Reduction of the sediment supply in the water body	Amount of sediment retained in barriers (physical/vegetative barriers, dams, terraces)				
	Sediment flow in channels				
	Turbidity				
	Sedimentation rate in the reservoir				
	Soil Quality				
Ecosystem Function	*Indicators*	*Clarity*	*Viability*	*Sensibility*	*Relevance*
Provide physical support to plants	Resistance to penetration				
	Water Infiltration				

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	Aggregates Stability
	Structure Degree
Control of soil loss	Degree of intensity of the erosive process
	Thickness A Horizon
	Diversity of species of the production system
	% of exposed soil
	Erosion per area
Water availability for plants	Soil organic matter (SOM)
	Aggregation
	Ratio of dead coverage
	Water available
	Thickness of the A + B horizon
Soil biodiversity regulation and biological activity	Presence of earthworms and spiders
	CO efflux
	Enzymatic activity
	Decomposition rate
	Macro and mesofauna diversity
	Diversity of nematodes
Nutrient cycling (Soil Fertility)	Soil organic matter (SOM)
	Diversity of species of the production system
	Cation Exchange Capacity (CEC)

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	Biological fixation of N				
	Light organic matter				
	Decomposition rate				
	Amount of residual biomass				
	Nutrient Content				
	Export index				
	pH				
C sequestration	Carbon stock				
	Soil organic matter (SOM)				
Regulation of soil remediation potential	Soil organic matter (SOM)				
	Potential risk of contamination				
	Soil enzymatic activity				
	Waste from agrochemicals				
	Heavy metals (concern about the use of alternative inputs)				
	Aggregation				
	Habitat Protection				
Ecosystem Function	*Indicators*	*Clarity*	*Viability*	*Sensibility*	*Relevance*
Conservation status of terrestrial habitats	Species threatened of extinction				
	Occurrence of invasive alien species				

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	Habitat area
	Successional stage
	Diversity of species of native fauna and flora (richness and abundance of individuals by species)
	Species richness (number of species per area)
	Presence of key species (flora)
	Genetic diversity (genetic bench in situ)
	Litter (quality and quantity)
Conservation status of aquatic habitats	Composition of native fish communities and/or aquatic insects
	Abundance and Wealth of fish and/or aquatic insects
	Diversity of fish and/or aquatic insects
	Turbidity
	Presence of riparian forest
	Water temperature
	Biochemical Oxygen Demand (BOD)
	Presence of invasive species
	Presence of bioindicator species (fauna and flora)
	Endemism
	Ecological flow
Gene flow of plant, animal and microorganism species	Forest fragmentation index
	Proximity to protected areas

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	Permeability of the matrix of uses
	Structural and functional connectivity (dependent species)
	Landscape metrics
	Presence of pollinating species
	Presence of dispersing species
	Presence of barriers in rivers
	Presence of future barriers in river projects
	Recruitment of species, presence of regenerating stratum
Biological control (for production)	Food production
	Demand for the use of agrochemicals
	Occurrence of natural enemies
Pollination (for food production)	Food production
	Quantity and quality of litter
	Occurrence of functional species (decomposers, pollinators, N-fixers, etc.)
	Nutrient cycling
Soil quality	Quantity and quality of litter
	Occurrence of functional species (decomposers, pollinators, N-fixers, etc.)
	Nutrient cycling
	Soil quality indicators (chemical, physical, biological and microbiological)
Gene Bank in situ	Diversity of species of fauna and flora

UNESCO (2020) highlights that it is urgent to improve water quality monitoring in order to effectively deal with the complexity of tracking a large number of parameters, including new, emerging pollutants. However, for effective action, water quality must be understood in the framework of hydrological processes based on the water quality and hydrological monitoring especially because most of the current monitoring processes are mainly based on ineffective traditional approaches and are jeopardized by a lack of scientific knowledge and technical skills. Thus, we believe that the ESI proposed to "water supply" and "water regulation" services in our study can help to fill this gap, as it is possible to use them in integrative water services monitoring.

The EFs associated with the "Soil Quality" service highlighted the diversity of functions that the soil provides for the ecosystem. Soil organic matter (SOM) and parameters related to soil aggregation were one of the ESI suggested to monitor different EF. This shows their relevance for soil quality and health, especially in tropical areas (Table 2).

Changes in land use or land management practices can influence soil properties such as organic matter content, aggregates, and density (USEPA, 2006). It indicates the potential of these properties to perform as indicators to monitoring PES interventions.

The "Habitat protection" presented a similar performance of "Soil Quality" ES, with a high diversity of EFs and ESIs (Table 2). Hatziiordanou *et al.* (2019) highlighted that a systematic approach to assess the habitat ecosystem service has not yet emerged. The same authors stated that, to evaluate this service it is important to observe the anthropogenic impact on biodiversity. The combination of these criteria could provide information about conservation measures. In our study, the EF and indicators selected by the experts to evaluate this service follow this rationality and present a set of solutions to contribute for the habitat service monitoring (Table 2).

3.2. ESI performance per criteria

One of the trickiest concerns in indicator research is to reach a final list with an ideal number of choices. If the quantity of indicators is simply too high, it defeats the aim altogether (Nathan and Reddy, 2010). Thus, the selection criteria adopted in this study aimed to find out the most suitable indicator package to monitor interventions in water PES programs.

3.2.1. Water supply

"Retention of nutrients in soil" was the EF with the highest number of ESI (Table 2). Most of these indicators are connected to Brazilian water legislation, such as the CONAMA 357/2005. This regulation provides the classification of water bodies and environmental guidelines, as well as the conditions and standards for the discharge of effluents and other measures. In this resolution some parameters are defined as standards to declare the water quality status. Some examples are: chemical oxygen demand, turbidity, pH, among others. These indicators comprise the main indexes of water quality for human supply.

Also, regarding the "Retention of nutrients in soil - relation with eutrophication and water contamination" function, dissolved oxygen, electric conductivity, presence of aquatic macrophytes, and total phosphorus were the indicators that scored higher. These parameters got the score "3" for all criteria (Table 2); index of biological integrity, diversity index, salmonella and virus were the indicators that scored the lowest.

This result follows the same rationale of Griffiths *et al.* (2018), which shows that biological indicators are better considered as a step in developing a practical monitoring scheme instead of a final indicator, as there are operational issues to be solved such as ease of application, robustness, sensitivity, laboratory accuracy, throughput, economic value, and descriptiveness.

The "Viability" criterion was the one in which the highest number of indicators (17) received the lowest score (Table 2). The reasons might include specificities about sampling, analysis and costs.

3.2.2. Water regulation

This ES had six associated EFs – “Maintenance of groundwater recharge”; “Maintenance of springs”; “Maintenance of reference flow”; “Attenuation of extreme events (floods)”; “Retention of soil water”; “Climate regulation”. All the EFs received few indicators for their monitoring (Table 2).

The “Flow rate” indicator got the best scores for all the criteria, although it was related to only one EF, “Maintenance of springs”. The indicator “Groundwater level” got a high score for two EFs: “Maintenance of groundwater recharge”, “Maintenance of reference flow” (Table 2).

The “Runoff coefficient” indicator was cited twice: for EF “maintenance of reference discharge” and “soil water retention”. The advantage of this indicator is that it integrates different aspects of hydrological processes. Runoff coefficient is the ratio between the total volume of water flowed by surface runoff and the total volume of precipitation. The Runoff Coefficient can be applied for one rainfall event or a period with several events. This kind of ratio integrates the entire watershed rainfall response, showing how much of the volume of water from precipitation the watershed can retain within the soil and how much will be released through runoff. Thus, it comprises the result of a set of flow processes conditioned by: (i) soil properties, such as water infiltration capacity in the soil, soil hydraulic conductivity, soil porosity; (ii) characteristics of terrain (slope, presence of microrelief structures, vegetation cover); geological characteristic of the basin; (iii) aspects of the rainfall (volume, duration and intensity of the events) (Merz and Günter, 2009).

The “water table level” was pointed out as an indicator of three functions: “aquifer recharge maintenance”, “the maintenance of river discharge” and “springs’ conservation”. This indicator requires the installation of sensors in wells for its measurement, and its metric integrates a set of processes that reflects the response of the watershed to rainfall regime.

The indicators with the lowest score (four indicators) were set in the “Sensitivity” criteria (Table 2). The hypothesis is that these indicators were considered broad, without an established parameter for measurement.

Erosion control

The indicator “Amount of sediment retained in barriers (physical/vegetative barriers, dams, terraces)” got the highest score for the four criteria, associated with different EFs (“Reduction of surface erosion” and “Reduction of the sediment supply in the water body”). However, it is important to be clear that the performance of this indicator can be influenced by the implementation of these barriers. Points with a high percentage of terraces (greater than 50%) were subjected to a slight degree of erosion since, in such cases, land is usually not cultivated or cultivation is carried out along the contour lines (Kosmas *et al.*, 2014). In this case, it is recommended to consider the other indicators that were also high scored, such as “Turbidity” and “Estimation of soil loss per area” (Table 2).

3.2.3. Soil quality

Soil quality, compared with the other ES, presented a more extensive indicator option for monitoring. This service has eight associated EFs and a set of associated indicators. The indicators that received the highest score – “3” for all criteria – were: Aggregates Stability; Resistance to penetration; Aggregation; Presence of earthworms and spiders and CEC. It is interesting to observe that all of these ESI are related to soil structure, directly or indirectly (Table 2).

Aggregation is considered one of the most suitable indicators for soil quality and crop production (Arshad and Martin, 2002). There is evidence about the close linkage between soil organic carbon (SOC) and aggregation (Martins *et al.*, 2009; Plaza-Bonilla *et al.*, 2013). Aggregate stability is a relevant indicator of soil susceptibility to runoff and erosion, especially in tropical areas where intense rainfall is frequent (Barthes and Roose, 2002). Additionally, Coq *et al.* (2007) demonstrated the influence of earthworms in large macroaggregates. Similar results are reported by Marichal *et al.* (2014) finding that the total macroinvertebrate density was significantly correlated with macro porosity and that these characteristics relate to the SOC content.

Soil organic matter (SOM), although a minor component in most soils, is primarily responsible for structure, function, and sustainability of the ecosystems (Turetta *et al.*, 2019). For this reason, the “organic matter content” was suggested as an indicator for the EFs “Water availability for plants”; “Nutrient cycling (Soil Fertility)”; “C sequestration” and “Regulation of soil remediation potential” highlighting the influence of this parameter in many soil processes.

3.2.4. Habitat protection

Most of the indicators that scored higher – “abundance and wealth of fish” and/or aquatic insects”; “Turbidity”; “Presence of riparian forest”; “biochemical oxygen demand” – are linked to the EF “Conservation status of aquatic habitats”. This function is closely related to “Water supply” service and apparently, they followed the same rationale to suggest the most suitable indicators, such as “Turbidity” and “BOD of water” (Table 2).

It is interesting to observe a few suggested indicators, such as “Presence of invasive species” and “Presence of bioindicator species (fauna and flora)” for monitoring this service. The use of indicator species to monitor or assess environmental conditions is a firmly established tradition connected to environmental studies since the 1970s (Noss, 1990). In this case, the recommendation is to replace these indicators for others that can encompass multiple levels of biological organization.

Additionally, many parameters related to landscape metrics were suggested as indicators for this ES. Several studies indicate that such metrics are quite appropriate to describe the state of biodiversity (Walz, 2011). Still, the same author enhances that the results of such studies are strongly dependent on the scale of investigation and the underlying database. Furthermore, we highlight that the scale and database are aspects that should be carefully considered for all indicators.

“Pollination” and “Soil Quality” are classified as ES (Costanza *et al.* 1997; MEA, 2005). However, these services were suggested as indicators for monitoring this “Habitat protection” ES. It suggested a common conceptual confusion and distortion regarding ecosystem services concept, as already identified by Schoröter *et al.* (2014).

For “Habitat protection”, four indicators received the lowest score: one in the “clarity” criterion; one in “relevance” and two in “viability”. However, when we selected the ESIs with the highest score, the “sensitivity” criterion showed the lowest number of indicators compared to the other criteria (Table 2). An overall assumption is that for the experts, despite a higher number of options for monitoring this service, only few indicators are indeed sensitive to detect changes in this servisse.

3.3. Recommendations for the use of IES

For the best use of our findings, it is important to observe some aspects of the PES programs to be monitored, such as scale of the evaluation, thresholds, and others. These aspects must be assessed considering the database available, methods applied to identify the indicators and their application in public policies (Table 3).

Table 3. Aspects to be considered for the use of suggested IESs.

Attribute	Database	Method	Public Policy
Scale	✓		
Time differentiation	✓		
Quality and documentation	✓	✓	
Technological, scientifically grounded		✓	
Compatibility with international standards	✓	✓	✓
Implementation for modelling	✓		
Reference or threshold	✓	✓	✓

Source: Modified from Sieber (2019).

The database available appears a relevant aspect to be considered, whether for indicator surveys and defining references or for building scenarios (Table 3). Also, this is a core aspect for the baseline definition, which is usually a big problem for monitoring issues. The method is also an important aspect closely related to the analysis aspect and recognized standards.

Additionally, another suggestion to increase the practicality and adoption of our indicator matrix (Table 2) is to favor the indicators that received the highest score (Mode 3), since they were better evaluated by the experts and tend to be the most analytical and well established in the literature.

4. CONCLUSIONS

We presented a well-defined framework for transparent and operative selection of ecosystem services indicators, which can be used to monitor interventions on water-based PES.

In a broad field such as the ecosystem services assessment, the cascade model has proven to be useful to define the limits of the study, clarifying the flow of EF/intermediate services and how they can be impacted by PES interventions.

Four practical criteria (clarity, viability, sensitivity, and relevance) provided guidance to the experts to identify and select the best indicators for each function. The “viability” and “sensitivity” criteria received the lowest scores by the experts. In general, we could also observe in all services a preference for analytical and well-established indicators in the literature.

The methodological approach considering a pre-evaluation of intermediate services and indicators and its later discussion and validation by the experts proved to be an innovative approach for the ES indicators arena, promoting knowledge exchange in the scientific community. By doing so, we also expect to promote a more horizontal flow of information and decisions which can be helpful and easy to reproduce in other situations, improving the operationalization and governance of ecosystem services and connecting theory to practice.

The main recommendation of this study is to recognize there is no “ideal” indicator. Thus, it is recommended to consider a set of indicators for evaluation to cover possible gaps that a single indicator could present.

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