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Water assessment in a peri-urban watershed in Mexico City: A focus on an ecosystem services approach

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ABSTRACT

Among hydrological ecosystem services, water supply is one of the most relevant to society because of its role in human wellbeing; accordingly, it has been significantly modified worldwide. There has been a recent increase in the necessity of combining methods and tools to create interdisciplinary evaluations of water ecosystem services, especially in developing countries where there is a lack of systematized and updated socioenvironmental information. We propose a framework for the assessment of water supply ecosystem services that includes environmental, social and economic dimensions. We describe and develop each of these dimensions with a particular focus on identifying the key variables that are needed to answer them. First, we performed research of the literature regarding the evaluation methods that are sufficiently flexible to apply them to local scales in countries where information is limited. Then, we chose the Magdalena River Watershed to apply this perspective because it is an illustrative area of vital importance to Mexico City's ecosystem services. We believe that this proposal has outlined basic guidelines to help decision makers improve water management and may provide an opportunity to change public policies on peri-urban ecosystems.

1. Introduction

Among all ecosystem services (ES), the ES that are related to water (ESw) are some of the most relevant to society because of their role in human wellbeing (Falkenmark and Folke, 2003; Brauman et al., 2007). In particular, water supply (ESws) is one of the ES that has been significantly modified worldwide because of century-old sociopolitical issues that have induced intensive and extensive land transformations (Rockström et al., 2009).

Authors such as Pahl-Wostl et al. (2011) and Maass (2012) suggest that water management must be conducted holistically by contemplating the following three basic aspects: a) to view water as an integrated natural resource in a particular socio-ecosystem context; b) to use an ES approach to translate the biophysical functioning of ecosystems and their processes into terms that relate to human welfare; and c) to recognize watersheds as the natural ecosystem's functional units.

Watersheds have integral multidimensional and multifunctional scenarios that are ideal for promoting transdisciplinary research where biophysical and social processes can be analyzed together. Additionally, the use of watersheds as management units allows the identification of geographical areas where ES are generated and consumed and the location of the stakeholders and beneficiaries who are associated with these service dynamics (Flotemersch et al., 2015).

Peri-urban watersheds are the main source of ES for urban populations (Bouland and Hunhammar, 2009). Despite this importance, the value of peri-urban watersheds has been underestimated and has resulted in ecologically unsustainable land-use planning (Niemelä et al., 2010). This situation is concerning given that the ES that these areas provide heavily depend on land management strategies, which, in turn, depend on landowners'

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views and level of control over ecosystems and resources (Kroll et al., 2012; Cáceres et al., 2015).

The relationship between cities and ESws is crucial, particularly in large cities that require a substantial amount of water and consequently produce a considerable amount of domestic and industrial wastewater, which negatively affects their freshwater systems (UNESCO, 2010). Therefore, an ES approach to water management would help to convince authorities to integrate natural ecosystems into city management programs (Niemelä et al., 2010) because this approach elucidates how ecosystems affect human welfare.

In recent years, several proposals have been made to evaluate ESw. Although the conceptual framework of ES is understood from an interdisciplinary perspective, these types of studies have been atomized (Cáceres et al., 2015). Most studies have focused either on biophysical assessments or economic value (Hackbart et al., 2017; Villegas-Palacio et al., 2016), and few studies have addressed the social assessment (Chan et al., 2012; Martín-López et al., 2012; Cáceres et al., 2015).

In this sense, Brauman et al. (2007) proposes an assessment framework that considers the evaluation of ESw from a more holistic point of view. However, no specification of the methods to evaluate the daily practice is provided, and applying the method in specific contexts is complicated. Thus, it has been recently increasingly necessary to combine methods and tools to create interdisciplinary evaluations of ESw (Hackbart et al., 2017).

Another obstacle is that developing countries lack socioenvironmental information that is systematized and updated. In these countries, interdisciplinary evaluations are urgent because the maintenance of the environment is more vulnerable because of their current sociopolitical dynamics (Starkl et al., 2013). Consequently, to move from theory to reality in a region, it is necessary to improve past assessment frameworks by using the available information and evaluation methods.

Given the ESws is the most evident to human populations, an integrated evaluation of ESws must be present for the planning of public policies (Cowling et al., 2008). Based on the above discussion, our work poses the following research question: how can we assess ESws in areas with limited information?

Our objectives are to i) identify the methods to evaluate ESws from an interdisciplinary perspective that conforms to the previously mentioned limitations and ii) apply these methods to a case study of a peri-urban watershed in one of the largest cities in the world.

2. Methods

To identify the method to evaluate ESws, we propose an assessment framework that is based on other evaluation proposals (Brauman et al., 2007; Cáceres et al., 2015; Villegas-Palacio et al., 2016; Harrison-Atlas et al., 2016). Given that 1) all the components of the ecosystem have the same relevance in the evaluation and that 2) there is a certain liberty in the selection of evaluation methods, 3) this approach presents a transdisciplinary perspective to evaluate the service. The present assessment framework was

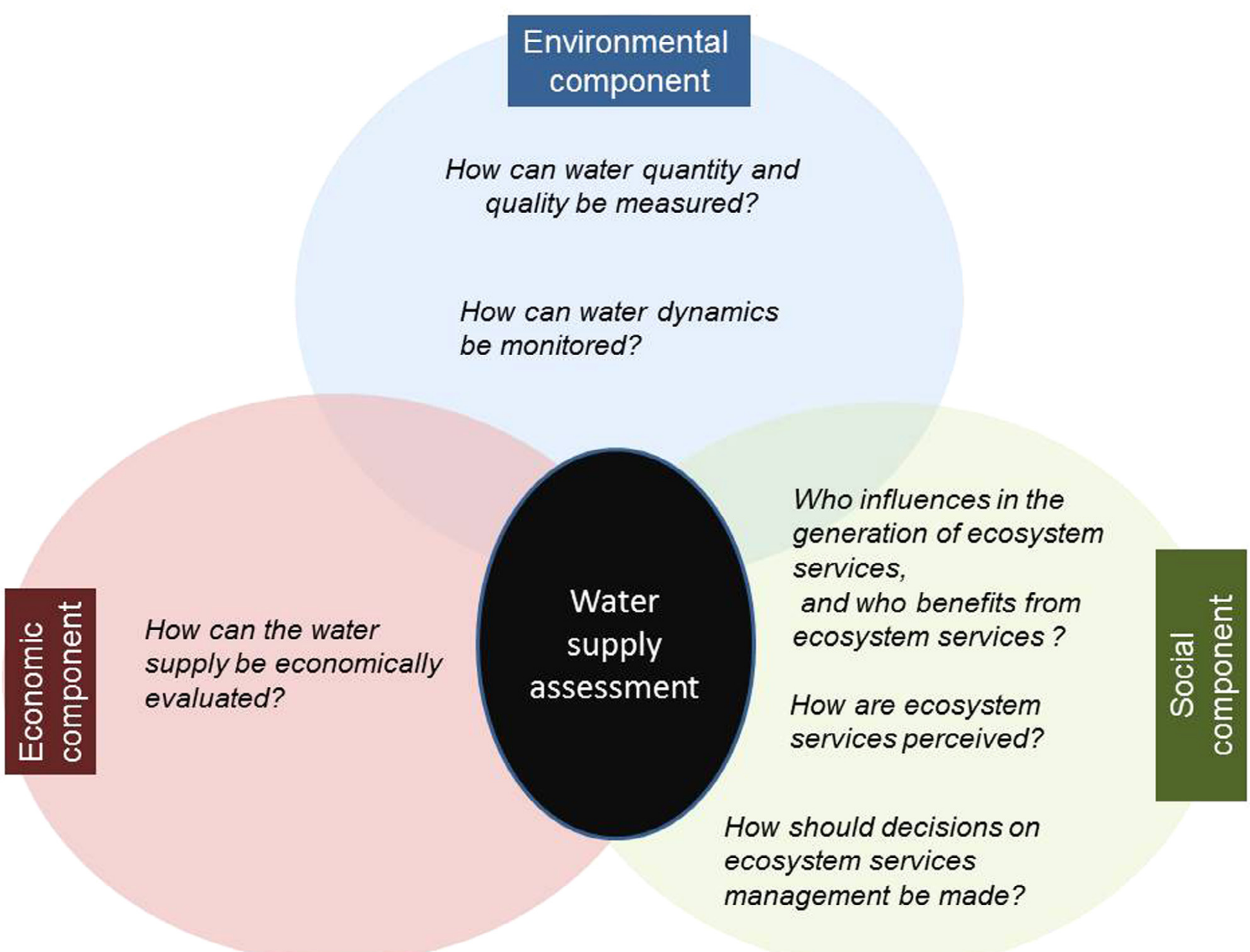

Fig. 1. Assessment framework for ecosystem service water supply.

adapted transversally for the management of ecosystems and by incorporating the vision of sustainability (Spangenberg, 2011). Our proposal comprises three components of sustainability that address such general questions (Fig. 1.)

We describe and develop each of these questions with a particular focus on identifying the key variables that are needed to answer them. First, we performed research of the literature regarding the evaluation methods that are sufficiently flexible to apply them to local scales in countries where information is limited. Then, we chose the Magdalena River Watershed (MRW) to apply this perspective because it is an illustrative area of vital importance to Mexico City's ESws. The evaluation of the ESws in this watershed involved the gathering of both published and unpublished preexisting studies of the area (see Fig. 2).

2.1. Environmental component

This component aims to reveal the biophysical generation of the ESws. For this purpose, the most important attributes according to Brauman et al. (2007) were considered to be quantity and quality. Accordingly, the following question is proposed: *how can water quantity and quality be measured?*

Additionally, and consistent with an adaptive management approach, a monitoring program must be implemented. Ecosystem monitoring consists of identifying significant long-term changes through qualitative or quantitative measurements and analyzing particular periodic data. Monitoring helps to describe the state of the environment and its trends over time (Christensen et al., 1996) and is essential to an adaptive management approach (Holling, 1978). The question that we attempt to answer is *how can water dynamics be monitored?*

2.2. Social component

The social component is a fundamental part of socioecological systems (Ostrom, 2009). To assess this component, we propose three questions as follows. 1) *Who influences in the generation of ES and who benefits from ES?* 2) *How are ES perceived?* 3) *How should decisions on ES management be made?* The identification of the main stakeholders and their cultural perceptions and preferences have been extensively studied in recent ES research (i.e., Chan et al., 2012; Cáceres et al., 2015). The institutional organization of water management has also been extensively studied (Schulz et al., 2017).

2.3. Economic component

It is fundamental to consider the economic aspect in an ESws assessment. Economic valuation encompasses the difficult and controversial task of determining a "price" for ES. Economic valuation in a monetary sense is a process through which an indicator in monetary units can be obtained. This indicator represents the

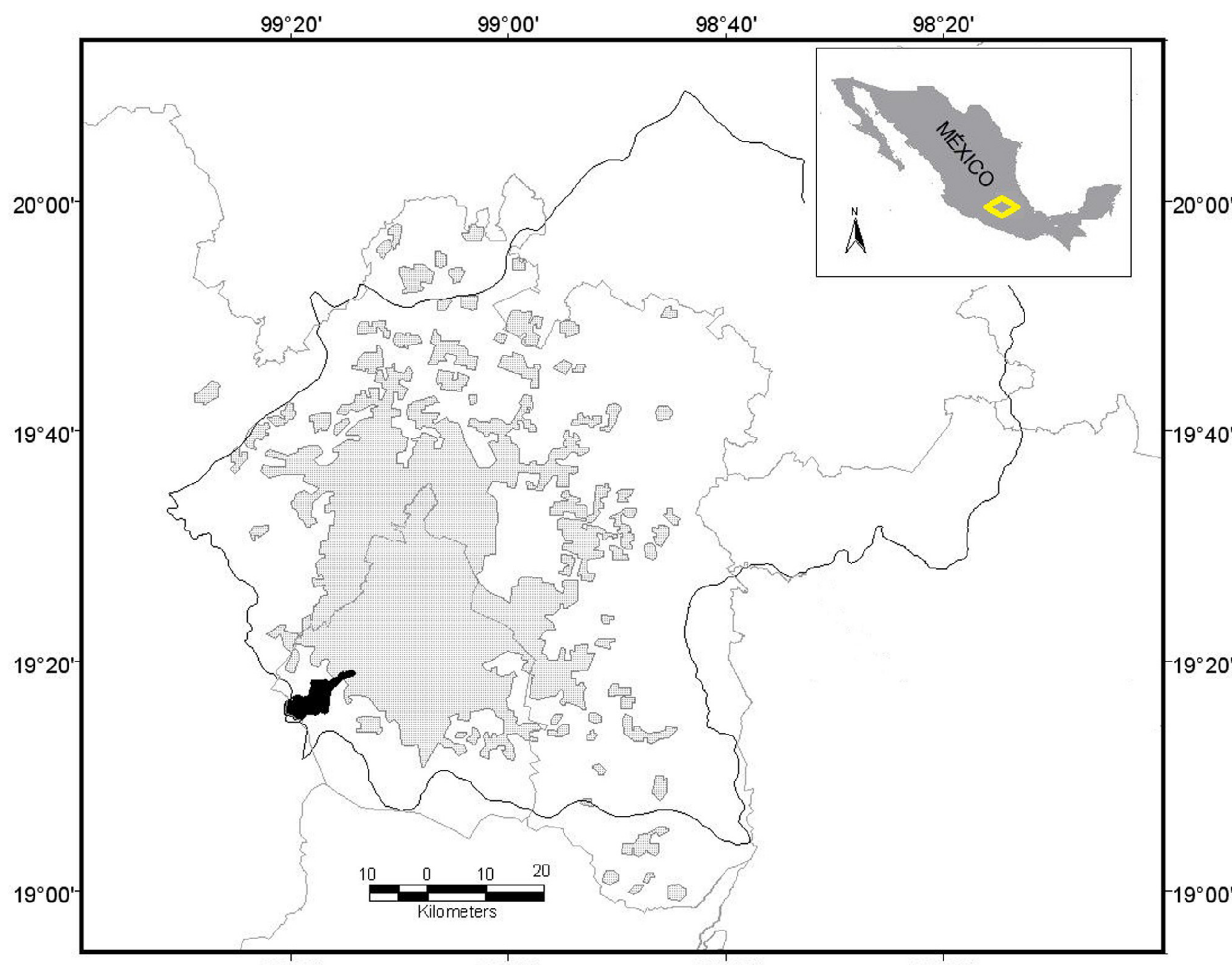

Fig. 2. Location of the Magdalena River Watershed (black), the Basin of Mexico (white) and the Mexico City Metropolitan Area (gray).

importance that a change in an ecosystem has on human wellbeing at different levels, for example, the global economy and social development (Villegas-Palacio et al., 2016; Muradian and Cardenas, 2015). In this sense, water as an economic good should be valued for being beneficial, useful, and scarce and must be regulated to ensure a sufficient supply and to prevent its waste (Montecillo and Puchet, 2000). The question that we attempt to answer is *how can ESws be economically evaluated?*

2.4. Study area

Mexico City is one of the largest metropolitan areas in the world (World Atlas, 2016). Its natural hydrological system has been greatly disrupted for many centuries. The transformation of the basin has been so profound that the original lake is practically extinct. Furthermore, most of the rivers in the city have been incorporated into the urban sewage system, which receives untreated wastewater discharges. The city currently must acknowledge the importance of rivers and their watersheds for sustainable water management (González-Reynoso et al., 2010).

The MRW, a peri-urban watershed inside Mexico City, is located at 19° 15′ 00″ N and 99° 17′ 30″ W, and its natural forest covers 30 km^2. The forest cover in the MRW is considered the most important continuous vegetation mass in the region that surrounds Mexico City, as well as one of the most diverse temperate ecosystems in central Mexico. The MRW provides to the inhabitants of Mexico City several essential ES whose ESw is vital. The Magdalena River is one of the most important open water sources in the city and provides at present approximately 200 $l\,s^{-1}$ of high quality water in the upper watershed (Jujnovsky et al., 2010). Moreover, this area has a close relationship with the historical and cultural heritage of the city (González-Reynoso et al., 2010).

3. Results

3.1. Environmental component

3.1.1. How can water quantity and quality be measured?

Water quantity can be estimated by using either direct measurements in the field (river flow and water well level measurements) or hydrological models. Hydrological models are helpful tools to understand water behavior over long periods of time when detailed environmental information is not available. Two types of tools are available for freshwater assessment, namely, traditional hydrologic tools and newer ES tools (Vigerstol and Aukema, 2011).

The Thornthwaite method is one of the simplest tools to give a general idea of water behavior over a long period of time (Dunne and Leopold, 1978). The Soil and Water Assessment Tool (SWAT) and variable infiltration capacity (VIC) are the most prominent examples of traditional hydrological tools that focus on the drivers of ES; they require post-processing for the assessment of ES.

By contrast, the Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) and Artificial Intelligence for Ecosystem Services (ARIES) represent a new generation of tools that have been specifically designed for ES, and they mainly focus on the assessment of end services and the visualization of these services across a landscape (Nelson and Daily, 2010). Traditional hydrological tools provide more detail, whereas ES tools tend to be more accessible to non-experts and can provide a general picture of a specific ES (Vigerstol and Aukema, 2011).

Regarding water quality assessment, most studies generally use physical-chemical parameters, as well as metals and nutrients to a lesser extent, and only several studies use biological indicators (from coliform to fish) (Zhou et al., 2006; Kazi et al., 2009; Zhang et al., 2010; Thomasen and Chow-Fraser, 2011). General studies have focused on the risks to human health (Gordalla, 2011; Carlson, 2012); however, for a more comprehensive assessment of an ecosystem, the "environmental quality" should be evaluated, such as the expression of the quality of the structure and function of an aquatic ecosystem (Ruza-Rodríguez, 2005). The environmental quality of a river can be assessed by using some of the structural and functional properties of the different levels of biological organization, given that communities respond under altered environmental conditions (Segnini, 2003; Lampert and Sommer, 2007).

According to the European Water Framework Directive (DMA, 2000), some biological indicators include the composition and abundance of aquatic flora and benthic organisms. Macrophytes can be used to detect any tendency toward eutrophication, changes in river dynamics, and changes in mineralization. Diatoms are sometimes used as an indicator of productivity. Macroinvertebrates are the most widely used group, and they are useful for detecting water organic pollution and acidity. Because of their longevity, position in the food chain, and mobility, fish are particularly valuable as indicators of ecological status (Fernández et al., 2002; Oscoz et al., 2007).

Case study. As we note above, water quantity can be calculated by using various methods depending on the availability of environmental information and the skills of the individuals who take the measurements. Water quantity in the MRW was evaluated by applying two different methods, specifically the Thornthwaite method and the SWAT 2003 model (Jujnovsky et al., 2010, 2012).

The results show that the watershed provides 18.4 hm^3 of water per year. The base flows contributed most of the runoff at 85%, while surface runoff only accounted for 15% of the total runoff. The lateral subsurface flow contributed 98% of the base flow, and only 2% drained to the unconfined aquifer as groundwater flow. The water base flow allows the Magdalena River to provide these ES year round to nearly 80,000 inhabitants (Jujnovsky et al., 2012).

Water quality in the MRW was evaluated by using physical-chemical and biological indicators. Several surveys have been conducted along the Magdalena River since 2003, in well-preserved forested areas and peri-urban areas. The results show that the water quality generally worsens from the natural area to the peri-urban area. The primary river pollution consists of mostly solid, inorganic, and organic carbon, as well as bacteria that is associated with fecal matter, generally from sewage water (Jujnovsky et al., 2010; Mazari-Hiriart et al., 2014). The essential parameters that have been used to evaluate the quality of drinking water include dissolved oxygen and electrical conductivity, which were measured *in situ*, as well as biochemical oxygen demand, ammonia, nitrogen, nitrate, total suspended solids, total dissolved solids, and fecal coliforms, which were determined in a laboratory (PUMA-UNAM, 2009).

3.1.2. How can water dynamics be monitored?

Water quantity and quality cannot be adequately assessed at only a single or several points in time. Therefore, monitoring is necessary. One way to reduce labor costs and incorporate an educational component into the process is "participatory monitoring" in which stakeholders monitor the ecosystem through simple methods with supervision and technical support from a local university, governmental institution, or NGO. From a participatory perspective, the data that are obtained should be a useful tool to generate reflective processes in local communities (Danielsen et al., 2005; Shirk et al., 2012).

Participatory monitoring has great potential in developed countries, where quick decision-making can address key threats to natural resources and the population. These outcomes can empower local communities to improve resource management and to refine strategies for sustainable use to improve the wellbeing of local residents (Danielsen et al., 2009). Various international programs have promoted participatory water monitoring, which has led to the implementation of successful water monitoring systems in several countries around the world (Table 1). Despite this success, in developing countries, these experiences are rare because very few skilled professionals are available to oversee these types of projects (Danielsen et al., 2005; Shirk et al., 2012).

The parameters and the techniques that are proposed by these groups (Table 1) may vary, but they all focus on physical and chemical analyses. Some of the programs also include bacteriological and biological indicators. The vast majority of studies on water quality as an ecosystem service use the same parameters (Zhou et al., 2006; Kazi et al., 2009; Zhang et al., 2010; Thomasen and Chow-Fraser, 2011).

Fewer studies use macrophytes, diatoms, and macroinvertebrates as indicators of changes in river dynamics; however, some international protocols are designed to include the biological component in environmental quality assessment (USEPA, 1999; DMA, 2000). The use of these parameters is most likely limited because some species or families must be identified in a laboratory or with the help of an identification guide or an expert.

Case study. A participatory monitoring in the MRW has been implemented, although this work is in progress and unpublished. Local actors were actively involved throughout the process, from identifying the problem in the beginning to decision making. Monthly physical-chemical and bacteriological water samples (using kit LaMote®), benthic macroinvertebrate assemblages and measurements of the environmental quality of riparian areas (following the CERA-S protocol; Encalada et al., 2011) were taken. At the end of the data collection process, the results were discussed among local monitors and academics to make local decisions. As a consequence of this process, considerable data have been collected in the past three years.

3.2. Social component

3.2.1. Who influences the generation of ES, and who benefits from ES?

Identifying stakeholders is usually an iterative process, and additional stakeholders are added as the analysis continues. However, there is a risk that some stakeholders are accidentally omitted because it is virtually impossible to recognize and include all of them. Accordingly, it is important that the researcher has a clear objective regarding why he or she must identify the stakeholders (Meffe et al., 2002; Reed et al., 2009). According to Reed et al. (2009), the most utilized techniques to identify stakeholders are expert opinion, focus groups, semi-structured interviews, snowball sampling, or a combination of these techniques. These same authors recommend defining a stakeholder according to the degree that they can influence or be affected by a problem or action. In our study, a stakeholder can be considered to be whoever has an interest in ESws because they benefit from it and/or have an influence on its provision.

Case study. The identification of the stakeholders in the MRW was conducted by Ramos (2008). However, for the purposes of this article, and as suggested by Reed et al. (2009), we only describe the stakeholders with a higher influence on the generation of the ES or the stakeholders who are benefiting from it. Initially, we identified the stakeholders in the MRW by using the snowball sampling technique. However, our presence in the community over time has

Table 1
Parameters used to monitor water in different participatory programs.

Participatory programs	Dissolved oxygen	Turbidity	T°	pH	Electric conductivity/Salinity	Solids	Alkalinity	Total hardness	Nutrients	Bacteria	Diatoms, macro-algae, mosses and/or micro-algae	Macro-invertebrates	Other animals	Water quantity	Others
1.	X	X	X	X			X		X	X	X				
2.	X	X	X	X			X	X		X	X	X		X	X
3.	X		X	X	X					X					
4.	X	X	X	X	X	X					X	X		X	X
5.	X	X							X	X					
6.	X	X							X		X				
7.	X	X	X	X	X	X			X				X		

1. The Watershed Watch of the University of Rhode Island, 2. The Alabama Water Watch of Auburn University, 3. Clean Water Program at the University of Maine, 4. Aquatic Ecology Program of the University of Alaska Anchorage, 5. Delaware Sea Grant College Program, 6. Florida Lakewatch, 7. Coastal Georgia Adopt-A-Wetland Program.

allowed us to identify different stakeholders as they have emerged. The inclusion of local actors has been very helpful in this regard because they have facilitated the identification process.

The stakeholders who we have identified in the MRW are government authorities, community owners, vendors, landless inhabitants, visitors and research teams. Some stakeholders have more influence in the generation of ES than others, and some of them are beneficiaries of these ES.

The government authorities at the local and federal levels are closely related to the generation of ES not only because they are directly responsible for the ecosystem management of lands but also because they design and enforce public policy. For example, in the MRW, the Mexico City Natural Resources Agency (DGCORENA), the Municipal Mayor (Delegación La Magdalena Contreras), and the Forest Management Federal Agency (CONAFOR) implement programs and/or provide support for the implementation of works in the forest. The Mexico City Rural Development Agency (SEDEREC) provides support for the development of agricultural and fishing activities. Mexico City's Water Agency (SACM) conducts activities that relate to drinking water and sanitation. Unfortunately, these government authorities do not have a common vision, and/or in some cases, their activities overlap; therefore, their actions can have a negative impact on the generation of ES.

Community owners, vendors and groups that offer nature tourism and/or environmental education services are also stakeholders who generate ES. The Magdalena Community is the main owner of the MRW. Most of the members are employed in the tertiary sector outside the MRW. However, some of these stakeholders depend economically on the productive activities related to forest maintenance, or they work in these activities; therefore, their activities can modify the generation of ES.

Vendors are a group of stakeholders who are economically dependent on visitors, and the majority of them are engaged in food services. This group is relatively well organized and is formed by both community owners and landless people who have been working in the area for a long time. There are also groups that offer nature tourism and/or environmental education services; these groups mainly comprise community owners. These groups can modify the generation of ES mainly because of waste and sewage generation. In turn, these tourism-related stakeholders and visitors benefit from ESws as an ecosystem service in the watershed. Outside the watershed, the beneficiaries of a drinking water supply are the inhabitants who live in the southwest area of the city (Jujnovsky et al., 2012).

3.2.2. How are ES perceived?

The inclusion of cultural perceptions toward the environment elucidates how communities construct images of reality and how they assign meaning to their experiences in relation to the environment (Chan et al., 2012). People have multiple interpretations of the environment, which are socially constructed according to the cultural context and the relationships in each social group. Therefore, the integration of knowledge regarding the environment should begin with the recognition of different forms of knowledge, such as traditional and ecological knowledge, and the inclusion of this knowledge across spatiotemporal scales (Raymond et al., 2010).

To understand cultural perceptions, both quantitative and qualitative methods are used. We use qualitative approaches because they allow an understanding of the different aspects of the environment from the perspective of local stakeholders (i.e., Racevskis and Lupi, 2006; Chuenpagdee et al., 2010; López-Medellín et al., 2011; Cáceres et al., 2015).

Case study. An unpublished study described the ES that local stakeholders recognize based on qualitative data-gathering tools. This study showed that ESws was the ecosystem service that local stakeholders mentioned most often. In addition, stakeholders who are most involved with the MRW mentioned other ESw (such as water quality, erosion control, and flood control), and in general, they recognized the relationship between vegetation cover and ESws.

3.2.3. How should decisions on ES management be made?

The political discourse on water management is characterized by a shift from the concept of "government" to the concept of "governance" (Pahl-Wostl et al., 2011). Governance should be implemented with as many actors from different institutional environments to develop and implement water management policies. This approach is an alternative to having the traditional one government that acts as the sole authority of the decision-making process and having state authorities exercise control over civil society groups (Pahl-Wostl et al., 2011).

Several countries have modified their legislation to ensure more comprehensive water management (Díaz et al., 2003; Sancho and Parrado, 2004; Cotler and Caire, 2009; Pahl-Wostl et al., 2011). Nevertheless, these experiences provide insufficient information to assess the impact of these institutional changes, where the method to implement local participation remains missing.

Case study. According to our framework, for the process to be transversal, local stakeholders should be involved in the decision-making process of water management. This involvement enhances the implementation of decisions.

Mexico has recognized the need to manage water based on an Integrated Water Resources Management (GIRH) scheme in watersheds (Cotler and Caire, 2009). At a local scale, the MRW has a watershed committee that has been legitimated by the Water Management Federal Agency (CONAGUA). However, to date, this watershed committee only has representatives, and in practice, it is not operating.

Another example that has emerged from the concept of governance is the "Rescue Environmental Program of the Magdalena and Eslava Rivers". The objectives of this public action should be determined and defined through a consensus among the participants. Similarly, the capacity for action and regulation should be developed through the shared responsibility of government agencies along with social and private organizations. Nevertheless, to date, civil society has not been integrated into the decision-making process, and the local water agency (SACM) has the sole responsibility of handling the distribution of resources, without any regulation of its own governance.

3.3. Economic component

3.3.1. How can ESws be economically evaluated?

In recent years, the economic value of ESws has been determined by using many different methods, including market price, hedonic pricing, the avoided damage cost, replacement cost, substitute cost, contingent valuation and the benefit transfer method (Wilson and Carpenter, 1999; Zhongmin et al., 2003; Hensher et al., 2005; Birol et al., 2006; Tang, 2010; Elsin et al., 2010). This extensive variety of methods responds to the complex characteristics of public goods such as water.

The discussions regarding valuation methods generally focus on the relevance of ecological, economic, and social issues (de Groot et al., 2010). Additionally, we should note that economic valuations of ES are only approximations. Ecosystems are complex, highly interconnected, and characterized by non-linear interactions among the variables at different time and space scales, which cannot be included in any valuation method (Cheen, 2004). Therefore, to ensure that an assessment reflects reality and to select the most appropriate method to assess ES, a clear understanding of the ecological processes behind the generation of ES is needed, including the biophysical measurements of the provision and depletion of ES.

Case study. To assess the economic component of ESws in the MRW, the replacement cost method was applied (Caro-Borrero, 2012). This method involves measuring the economic value of the ecosystem function by determining the cost of replacing it through technological means (Shabman and Batie, 1978). Previous information on water balance was used (Jujnovsky et al., 2012). Once the economic value was assessed, the discount rate to obtain the future value of the resource was calculated (without limit because the objective is to maintain it forever). The technology that was selected as a replacement for the ecosystem function was an infiltration well, because this technology is the most appropriate for the MRW, given the geological, hydrological, and hydrogeochemical properties of the watershed. The features and technology costs were estimated at the level that is required to replace the subsurface runoff as ESw.

With these data, we compared the technologies according to the infiltration capacity, cost, and year when the technology was proposed. This comparison was important to comply with the assumptions of the replacement cost method (Shabman and Batie, 1978). The ESws cost for the use of this simple technology in the watershed was calculated to be \$333 U.S. dollars ha^{-1} - year^{-1}; this estimated cost is one order of magnitude higher than the current cost of hydrological services. This calculation was performed through the Payment for Environmental Services program, which is calculated to be only \$29.35 U.S. dollars ha^{-1} year^{-1} and uses the opportunity cost as an economic valuation method (Caro-Borrero, 2012).

4. Discussion

4.1. How can we make an integrative evaluation of ESws in areas with limited information?

The present work collects some of the most used methods to evaluate biophysical, social and economic aspects that are linked to the management of water. Our intention is to show these methods as an integrated proposal that is framed in sustainability.

Many of the studies that are presented here were not designed based on an ES approach and were conducted based on scarce information, which limits their scope. Nonetheless, their usage is valid because the functions of the ecosystem, seen from any perspective, can be understood as ES when ES are recognized as a component of human wellbeing (Hackbart et al., 2017). This integrated evaluation attempts to establish that despite the limitations in obtaining basic socioecological information, it is possible to move from theory to practice. The results may inform decision-making processes that can be applied in contexts with high sociocultural and environmental diversity that continuously transform the relationship between people and nature (Villegas-Palacio et al., 2016).

Regarding the environmental component, the Thornthwaite method provides a general idea of water behavior over a long period of time. The advantage of this method is that little environmental information is required; only the data on vegetation and soil type, monthly rainfall measurements and air temperatures for at least a 10-year period are required. The disadvantage of the Thornthwaite method is that it cannot separate runoff into its components (surface and base flows).

In contrast, the SWAT model exhibits greater precision than the Thornthwaite method in terms of the types of runoff that are generated and shows the relationship between the elements of the hydrological cycle and vegetation. The limitation of this model is that it requires a substantial amount of environmental information (which sometimes is based on assumptions) and the same number of years for hydrometric and meteorological data records. Despite these requirements, the SWAT model has been extensively used to evaluate ESw (Francesconi et al., 2016). For future assessments, we recommend the use of ARIES or InVEST for an ES approach, which is suggested by Terradoa et al. (2014), given that these approaches are more practical for decision making.

Peri-urban rivers are constantly endangered by growing cities; this is the case of the MRW (Mazari-Hiriart et al., 2014). To evaluate its quality of water, it is necessary to consider physical-chemical factors and factors that are related to the health of the ecosystem. Accordingly, it is necessary to make periodic measurements at an academic and participative level. For the participative level, it is recommended to incorporate biological indicators, such as benthic macroinvertebrates and macroscopic algae and diatoms. They are good indicators of environmental quality in the MRW; therefore, studies of this type can be used in participatory monitoring due to the specificity that relates to functional changes in the aquatic ecosystem (Caro-Borrero et al., 2015; Carmona et al., 2016).

Regarding the social component, for the scope of this article, we describe stakeholders as the people with greater influence on the generation of ES or the people who directly benefit. We recommend that the stakeholders who own and manage the land be identified because they can alter the generation of the service, and they should be compensated, for example, in a socioenvironmental program such as "payment for environmental services (PSA)". Identifying the individuals who will benefit from the generation of ES is also important because these individuals may compensate other stakeholders. However, it is important to consider that ES are generated and consumed in different places and at different scales (Maass et al., 2005). A participatory process in which the people who identify the stakeholders are themselves stakeholders can increase the accuracy of the identification process (Montañés, 2009).

An understanding of the stakeholders' cultural perceptions, needs, and desire to change ES substantially contributes to the success of a management proposal (Díaz et al., 2011). Additionally, how and who should make the decisions to achieve and execute the proposed actions must be defined. In fact, truly transdisciplinary research can only be conducted by incorporating stakeholders into the research agenda (Maass and Equihua, 2015). Accordingly, there is a current need to produce more research to know what favors or hinders the vertical or horizontal relations and what promotes a governance process (Schulz et al., 2017).

Regarding the economic component, we chose the replacement cost method because it considers the biophysical information of the watershed instead of the preferences that are revealed by the individuals. For this reason, the replacement cost method is considered to be more objective (Villegas-Palacio et al., 2016). The economic valuation within the conceptual framework of ES should be used as a reference for conservation rather than an attempt at monetization. This is because the proper norms of collective actions and local values positively influence conservation and do not need the intervention of the market (Muradian and Cardenas, 2015).

Thus, it is important to indicate that economic valuations alone are not always helpful in decision making because of a lack of care in selecting adequate valuation techniques (Villegas-Palacio et al., 2016). These techniques may also undermine the intrinsic value of conservation that depends on the sociocultural context (Midler et al., 2015). Therefore, the MRW should be maintained at its current state without attempting to replace its function with manufactured goods. The detriment of a component of the ecosystem cannot be translated directly into the loss of a single function and consequently, the absence of one particular ES.

4.2. Decision-making implications

This type of evaluation may be useful from three different aspects in the implementation of a decision-making process as follows (Bergstrom et al., in press). 1) Decisive, the generated information of this article may be the baseline for many public policy projects of conservation and management of ecosystems in the Conservation Area of Mexico City. Currently, they are proposed in development and in the local management, such as in the "Green Plan" Government Program of Mexico City, but they require theoretical support to be developed at a local level. 2) Technical, some programs such as the payment for ES are already operating in the area; nevertheless, there is still a need to adjust to the local conditions where they work. This study may function as an implementation guide to these existing programs. 3) Informative, the information herein may serve to provide evidence and data that may indirectly influence decision making not only in the area of study but also in other peri-urban areas with similar problems. Here, it is important to emphasize that an integral evaluation of the service is the first step to move from basic science to decision making, but to achieve this transmission, it is necessary to change the government structure (Cowling et al., 2008). Consequently, and as stated by Brauman et al. (2007), effective policy will respond to science, society, and valuation, and for effective ES protection, research in these areas must be driven by the needs and constraints of policy.

5. Conclusion

This paper aims to develop guidelines for water assessment through an ES approach in a peri-urban watershed with limited data. We incorporated various perspectives, including scientific and local knowledge and methods depending on the specific requirements and needs. The use of various approaches was a fundamental aspect of the assessment and allowed an iterative process of creating knowledge and implementing it by reflecting on the development of an understanding of a socio-ecosystem. We were able to answer all of our questions and to address most of the steps that are proposed in the framework, even in an area for which research has provided fragmented information, has used different scales of examination, and has employed different methods of sampling and analysis.

Efforts in ES assessment in developing countries must address challenges concerning the limited access to information and the lack of cooperation between communities and institutions. However, it is still necessary to generate new information, apply the acquired knowledge for the conservation of ES, and develop systematic criteria for sampling and analysis in comparative studies. We believe that an adaptive management approach, which acknowledges that information may never be sufficient to completely understand the structure and function of all ecosystems, allows the available data that are generated by researchers and local inhabitants to be used as a source of information for the ecosystem management process.

Environmental issues should be a top priority on the agenda of megacities as they aim to improve their sustainability. Mexico City must reverse the centuries of mismanagement of its water resources. We believe that this proposal has outlined basic guidelines to help decision makers to improve water management and may provide an opportunity to change public policies on peri-urban ecosystems.

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