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Payment for ecosystem services in Peru: Assessing the socio-ecological dimension of water services in the upper Santa River basin

Rosa María Dextre [a,*], María Luisa Eschenhagen [b], Mirtha Camacho Hernández [c], Sally Rangecroft [d,e], Caroline Clason [d], Laurence Couldrick [f], Sergio Morera [a,g]

[a] Instituto Geofísico del Perú (IGP), c. Badajoz, 169, URB. Mayorazgo, 4ta. Etapa-Ate, Lima 15012, Perú
[b] Escuela de Ciencias Sociales, Universidad Pontificia Bolivariana (UPB), Circular 1 70-01, Medellín, Antioquia 050031, Colombia
[c] Instituto Nacional de Investigación en Glaciares y Ecosistemas de Montaña (INAIGEM), Av. Centenario, 2656-Sector Palmira, Huaraz 02001, Perú
[d] School of Geography, Earth and Environmental Sciences, University of Plymouth, Drake Circus, Plymouth PL4 8AA, United Kingdom
[e] School of Geography, College of Life and Environmental Sciences, University of Exeter, Exeter, EX4 4RJ, United Kingdom
[f] Westcountry Rivers Trust, Rain Charm House, Kyl Cober Parc, Stoke Climsland, Callington PL17 8PH, United Kingdom
[g] Maestría de Recursos Hídricos, Universidad Nacional Agraria La Molina, Av. La Molina s/n-La Molina, Lima 15024, Perú

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ABSTRACT

Increasing pressures on ecosystems in the Latin American region, as well as the adoption of multilateral conservation commitments, have led to the implementation of instruments that are economic in nature but oriented towards the recovery, conservation, and functioning of ecosystems such as Payment for Ecosystem Services (PES). In the Peruvian Andes, hydro-climatic factors and land-use changes are affecting the capacity of the ecosystems of the glaciated Cordillera Blanca to provide water services, in terms of both quality and quantity, to the main users of the Santa River basin. Thus, this study analyses how the socio-ecological interactions affect, and are affected by, the planned introduction of water-related PES in the Quillcay sub-basin, the most populated sub-basins along the Santa River basin. We use a conceptual model based on the current evolution of the water metabolism approach to integrate into a common language of analysis the multiple dimensions of water: water as an ecological fund, as a service, and as a political asset. To explore the interface of these three domains of analysis we rely on a mixed-method data collection: primary data collection through a stakeholder survey and interviews and a review of information from secondary sources. The result of our case study shows that both the ecological dimension and the social dimension affect on the PES project and vice versa. These complex interactions could result in the design of a mechanism in which not all stakeholders benefit equally. This raises the need to recognise the multidimensional nature of water in the design and implementation of policies, and the importance of identifying processes and barriers which affect the success of these policies without making invisible the direct effect they also have on social-ecological systems.

1. Introduction

Payment for Ecosystem Services (PES) has been introduced as a policy instrument for environmental conservation on the international agenda (Gómez-Baggethun et al., 2010). For the South American region, these instruments have also become a strategy for adapting to climate change in the populations of the high Andes (Llambi & Lindemann, n. d.). In line with these international trends as well as increasing pressures on ecosystems, Peru has been formally adopting these policies under the name of "Reward Mechanisms for Ecosystem Services" (MERESE by its Spanish acronym) (Quintero & Pareja, 2015). This mechanism has been regulated since 2014 by the Law n° 30,215 and recognises 13 ecosystem services (Fig. 1) that could be managed under this approach.

Abbreviations: PES, Payment for Ecosystem Services; MERESE, Mechanisms of Rewards for Ecosystem Services; ESs, ecosystem services; IWRM, Integrated Water Resources Management; ARD, Acid Rock Drainage; DWC, drinking water company; DWU, drinking water users; RC, rural communities; NGO, non-governmental organization; TEC, technical actor; GO, government actor; ACA, academic actor; HNP, Huascaran National Park; INAIGEM, National Institute of Glacier and Mountain Ecosystem Research; SUNASS, National Superintendency of Sanitation Services; MVCS, Ministry of Housing, Construction and Sanitation.

* Corresponding author.
E-mail address: rdextrem@gmail.com (R.M. Dextre).

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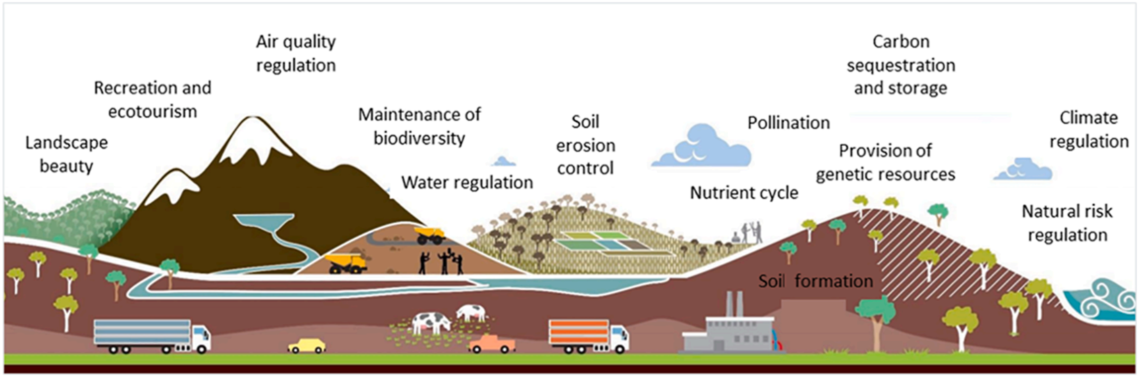

Fig. 1. Diagram illustrating the main 13 ecosystem services recognized by Mechanisms of Rewards for Ecosystem Services (MERESE). Adapted from MINAM (2017, fig. 2).

Water services are the most regulated services under PES schemes in the Latin America region (Balvanera et al., 2012; Martin-Ortega et al., 2013) including in Peru. The unequal distribution of its population with respect to water availability in the territory represents a major challenge in the country's water management. The Pacific slope contains 70% of the total population and has only 2% of the country's water availability; while the Atlantic slope has 97% of the water availability and only 26% of the total population (Burstein-Roda, 2018; Drenkhan et al., 2015; Seehaus et al., 2019). Thus, even before the enactment of the Law n° 30215, there were already 22 water-related PES initiatives in the country (Quintero & Pareja, 2015). Likewise, due to climate change, water security is one of the country's main challenges in glaciated mountain regions where almost 4 million people living in these territories are influenced by, and depend on, glacier water (Rosario et al., 2016). In the Andes, tropical glaciers are highly sensitive to climate variation (Seehaus et al., 2019); and in light of this, 54% of the total glacier area was lost in Peru between 1989 and 2016 (Dávila et al., 2018). Therefore, there is growing concern about the future supply of water and the maintenance in quantity and quality of the ecosystem services this region provides (Carey et al., 2017; Drenkhan et al., 2015; Mark et al., 2017).

The Peruvian Law states that PES or MERESE schemes are voluntary and aimed at ecosystem conservation, restoration and sustainable use. A MERESE agreement establishes that one or more buyers (beneficiaries of the ecosystem service) can pay or compensate to one or more sellers (contributors of the service). However, water PES agreements implemented by drinking water companies in Peru (hereinafter referred to as DWC) have a complementary mandatory regulation as they are financed through water tariffs. This tax-like PES (see Hahn et al., 2015) is the fastest developing in the country as DWC are obliged to implement them. Thus, water users must pay a MERESE tax in their water bills as a fund to protect the upstream ecosystem.

Water-related PES initiatives have the central expectation of improving watershed water supply and regulation (e.g. Grima et al., 2016; Kosoy et al., 2007; Martin-Ortega et al., 2013). However, the implementation of these mechanisms also has a social background although it is not explicitly conceived in this way in the Peruvian regulation. Wunder et al. (2008) identified secondary effects of PES in the global south, especially on local livelihoods such as diversification and increased income from conservation. The latter is very attractive for countries such as Peru, characterized by abundant natural resources and social inequalities (Balvanera et al., 2012; Castro-Díaz, 2014; Lorenzo & Del Pilar Bueno, 2019). Therefore, the ecosystem services approach and its management through PES schemes is fundamentally political because it frames ecosystem needs with societal needs (Kull et al., 2015).

As a political project, PES design and implementation is a complex governance process that requires dialogue and cooperation among a multitude of actors (Chen et al., 2020); actors that shape different value systems and material interests in ecosystem services management (Loft et al., 2015). Although the Peruvian experience is recent and we do not yet know much about the impacts of these schemes, water PES policy can be very well framed within the country's water policy. Lynch (2012) argues that water scarcity and vulnerability in Peru is also a consequence of an unequal water policy. Thus, these processes can face many gaps between what is expected in the policy instrument and how it ends up being executed (Loft et al., 2015). In Andean societies, evaluation of central water policies suggests that they are implemented without recognising local forms of water governance (Boelens, 2014; Damonte & Lynch, 2016; Paerregaard, 2018) and are geared toward efficiency in resource use through market creation (Urteaga, 2010).

In the upper Santa River basin, one of the most important glacial basins in northern Peru, a water-related PES in the framework of the Peruvian regulation has become a priority for decision-makers due to increasing glacier loss and degradation of ecosystems that regulate water services. The water PES project for the Santa River basin is a taxes-like PES, whose implementation might seem straightforward because of its top-down approach, yet DWC in Peru are not all private and a substantial component of the water tariff is subsidised by the State. Thus, recognising that water decision-making processes involve multiple dimensions and scales of analysis (Cabello et al., 2015), we evaluate a PES project in the upper Santa River basin as a case study to answer the research question: how do the socio-ecological interactions affect, and are affected by, the planned introduction of water-related PES? For this purpose, we use and adapt a conceptual model based on the current evolution of the water metabolism approach to integrate into a common language of analysis the multiple dimensions of water: water as an ecological fund, as a service, and as a political asset.

This paper opens with a review of the conceptual approach behind PES instruments, its relationship to water services as one of the multiple definitions of water and the definition of a conceptual model for the study of these multiple dimensions of water. We then present our case study and the method employed for data collection and analysis. Key results related to each dimension included in the conceptual model used are presented in sequence. In the Discussion we present brief overviews of the contribution of this research and key challenges related to water PES in the Peruvian context.

2. Conceptual approach

2.1. Discourses on ecosystem services

The evolution of the Ecosystem Services (ESs) approach has been consistent with changing environmental paradigms throughout history (Gómez-Baggethun et al., 2010). There are three approaches to understanding the evolution of the concept (Martín-López et al., 2009; Vandewalle et al., 2008). i) The ecological approach, which defines ESs as "conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfil human life" (Daily, 1997, p. 3). Bruckmeier (2016) argues that from this approach no theoretical clarification is required because ESs are designed for applied ecology. ii) The economic approach, which defines ESs as "flows of material, energy and information from natural capital stocks which combine with manufactured and human capital services produce human welfare"(Costanza et al., 1997, p. 254). iii) The hybrid approach, which understands ESs as the benefits (direct or indirect) to human well-being (MEA, 2005; TEEB, 2010).

The use of ESs in current sustainability science often lacks methodological, epistemological and theoretical coherence and reflection (Bruckmeier, 2016), shortcomings in which the term is being socially constructed (Barnaud & Antona, 2014). Moreover, ESs as a concept and a tool simultaneously embed pedagogical, technical, scientific, social, cultural, political and economic notions (Kull et al., 2015). The conceptual gaps of ESs and their use in academia and decision-making processes have led to the development of various critiques of the approach. Most of the counter-arguments focus on the valuation aspects of the ESs such as the methods, the lack of an environmental ethic and the commodification of nature (Budds, 2013; Büscher et al., 2012; Gómez-Baggethun et al., 2010; Lomas et al., 2017; Simpson, 2017). Schröter et al. (2014) group these counter-arguments within the science-policy interface as they emphasise on the strategies for ESs management. In the following section we will focus on PES schemes as a dominant strategy for ESs management.

2.2. PES as a political project

According to Kull et al. (2015), the emergence of ESs framed as PES schemes reflects broader socio-political trends between neoliberalism and ecological modernisation. Thus, PES is one of the main market-based instruments for neoliberal conservation (Büscher et al., 2012; Gómez-Baggethun et al., 2010). Its purpose is to correct positive environmental externalities such as ESs that society benefits from but no one pays for (Grima et al., 2016; Kosoy & Corbera, 2010). Thereby, the aim is to generate funds for the conservation and recovery of ecosystem functions through ESs transaction agreements (Gómez-Baggethun et al., 2010).

Wunder (2005) introduced PES as a voluntary transaction in which one or several users of an ES "pay" an ES provider on the condition of maintaining the flow of the good or service. Aligned with this, Gómez-Baggethun et al. (2010) further elaborate on the commodification criteria of these instruments to: i) identify a service (a well-defined ESs); ii) assign a value or quantification; iii) formalise property rights; and iv) create the market (where they come from and who the potential buyers are). This rationality of commodification of nature frames the main critiques of this instrument and of the ESs approach itself (Martin-Ortega et al., 2019; Simpson, 2016) as many of the political and economic purposes of these agreements could create more resource exploitation practices (Bruckmeier, 2016; Gómez-Baggethun et al., 2010; Grima et al., 2016).

In addition, the economic valuation of ESs is not just about assigning value, but also about transforming the intrinsic and socio-cultural values of ecosystems into an exchangeable value (Martín-López et al., 2012). The ecological or intrinsic value of the ecosystem is determined by the integrity of the ecological structures, their processes and functions, as well as their complexity and dynamism (De Groot et al., 2002). Socio-cultural value is associated with the non-material well-being of society, with the social perception and its relation to tradition, culture, identity, spirituality and pleasure (Martín-López et al., 2012). The integration and weighting of these types of values determines the design of the scheme.

The emergence of PES instruments is based on the highly political nature of ESs approach (Barnaud & Antona, 2014; Kull et al., 2015) allowing ecosystems to be easily integrated with the needs of society (Balvanera et al., 2012). The cases of Costa Rica (Sánchez-Chaves & Navarrete-Chacón, 2017), Colombia (Balvanera et al., 2012) and Ecuador (Chafla & Cerón, 2016) reflect the impact of PES as multi-sectoral policies in Latin America. Recently, Hausknost et al. (2017) claimed that PES projects are first and foremost political projects. Although the main arguments against PES focus on the bias of these projects towards a market ideology (Kosoy & Corbera, 2010; Kull et al., 2015), in practice, its implementation varies according to the particular needs and characteristics of each context (Muradian et al., 2010; Vatn, 2010), moreover, the institutional design of the policy may not always be consistent with commodification criteria (Hahn et al., 2015).

For the Peruvian case, despite the PES policy defining MERESE as a voluntary incentive for generating economic resources aimed at the conservation, restoration and sustainable use of ecosystems (Ley n.°30215, 2014), water PES are regulated according to the type of water service user since water management in the country is multi-sectorial. Hence, based on the degrees of commodification of biodiversity and ESs policy instruments proposed by Hahn et al. (2015), the PES policy in Peru is both a taxes-like PES (non-voluntary, degree 4) and a market-like PES (voluntary, degree 6). The degree to which PES is voluntary or mandatory depends on the type of service marketed, on the estimated value method, and on the modality of payment of the agreement (Gómez-Baggethun et al., 2010). For example, PES regulation for drinking water companies are mandatory (non-voluntary) as they are financed through water tariffs, however, economic valuation is not mandatory, is referential, and willingness to pay or any other negotiation process that the parties consider appropriate may be considered.

On the other hand, compared to other countries in the region, the Peruvian experience is recent, and the results of the water PES experiences for the cities of Lima (Zucchetti et al., 2012), and Moyobamba (León-Morales & Renner, 2012) are not fully conclusive as to the functioning and effectiveness of the mechanism. Hence, we decided to analyse the water PES policy in the framework of the country's water policy. In the decision-making processes, water regulation and supply services are often a priority (Balvanera et al., 2012) as they require capital of human origin for their use (Martín-López et al., 2009). This could explain why the regulation of water-related PES policies in Peru has a different timeline of development than the general regulatory framework of the PES. Although water services are included within the Law of MERESE, water management in Peru is institutionalised through the paradigm of the Integrated Water Resources Management (IWRM). The IWRM has been formally introduced into the Peruvian water policy since 2009 and it is an approach whose effectiveness for the Peruvian case has been widely questioned in the scientific literature, both in terms of the design of the water policy and the difficulties in its implementation (Damonte & Lynch, 2016; French, 2016; Hendriks & Boelens, 2016; Urteaga, 2010). The unequal distribution of the Peruvian population with respect to water availability in the territory represents a major challenge as users are in constant competition for access to water. Moreover, the rules, rights and laws that determine the distribution and allocation of water also generate conflicts (Hendriks & Boelens, 2016).

These characteristics, which will be discussed in detail in the presentation of the case study, have shaped the current metabolic pattern of water in Peru's river basins, each with its own particularities, but strongly influenced by water policy. Thus, we argue that the emergence of water PES will eventually complement the IWRM paradigm and monitoring the implementation of this new asset of the water policy requires a socio-ecological perspective.

2.3. The need for a socio-ecological perspective

According to Stuart Chapin III et al. (2009), the world as a global system and the systems embedded in it (regional and local systems), should be understood as a socio-ecological system or coupled human-environment system. In these networks of interrelated systems, "people depend on the resources and services provided by ecosystems, and ecosystem dynamics are influenced, to varying degrees, by human activities" (Stuart Chapin et al., 2009, p. 6). Yet, commonly cited definitions for ESs (hybrid approach) reduce complex ecosystem dynamics to mere instrumental purposes — instrumental goals that also reduce social dynamics that are complex in themselves (Budds, 2013; Castro-Díaz, 2014; Gudynas, 2003). Bruckmeier (2016) argues that the use of hybrid terminologies in interdisciplinary science is not always sufficiently developed at the epistemological and methodological levels. In this way, Martín-López et al. (2009) define ESs as those linkages between ecological and social systems. Linkages that represent the multiscale and multidimensional interrelationships of complex systems (Raskin, 2014).

Balvanera et al. (2011, p. 58) argue that the analysis of ESs "must be approached from the perspective of complexity and through interdisciplinary work". For Bruckmeier (2016, 2019), an interdisciplinary socio-ecological theory with various levels of abstraction and forms of integration of social and natural scientific knowledge could help in this reformulation. Thus, a useful theoretical model for this purpose is social metabolism (Bruckmeier, 2016).

Social metabolism is a conceptual framework for the interdisciplinary study of ESs (Balvanera et al., 2011). Based on the classical theory of Karl Marx, the term emerged as a metaphor for biological metabolism to critically analyse the social process of colonisation of nature (Fischer-Kowalski, 1998; Toledo, 2013). Since then, metabolism studies have been further developed in sustainability science because of their usability as a methodological toolkit for the accounting of matter and energy flows (González de Molina & Toledo, 2014). Thus, concepts such as industrial metabolism (Ayres, 1997; Kennedy, 2015), metabolism of agroecosystems; or rural metabolism (González Acevedo & Toledo, 2016) have emerged. Each discipline has adopted and readapted methodologies for quantifying various material and energy flows to its needs and objectives in order to synthesise information on more specific metabolic patterns (Infante-Amate et al., 2017). Yet, in metabolism studies different terms coexist (Madrid-López, 2014). The emergence of hybrid disciplines such as ecological economic and political ecology has provided a deeper theoretical reflection on social metabolism (González de Molina & Toledo, 2014). Hence, as a theoretical approach to explain the biophysical impacts of power relations, urban metabolism (Barles, 2010; Dijst et al., 2018; Gandy, 2018; Swyngedouw, 2005; Wolman, 1965) and social metabolism of ecological-distributive conflicts (Martínez-Alier, 2008; Martínez-Alier, 2013) have also emerged.

Despite the evolution of the term, social metabolism still requires further epistemological and methodological reflection. Moreover, the use of the term in the current mainstream scientific literature has been reduced to a flow accounting approach (González de Molina & Toledo, 2014). In rejection of this, Giampietro and Mayumi (2000) developed the methodological framework of the Multiscale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM). This framework is backed up by theoretical work in the field of non-equilibrium thermodynamics, complex systems theory, theoretical ecology, bioeconomics, and tradition in social sciences (Giampietro et al., 2014). Thus, the metabolism of socio-ecological systems is introduced by recognising the need that the metabolic pattern of society and ecosystems can only be observed at different spatial, temporal and organisational scales (Giampietro et al., 2009, 2011, 2013; Giampietro & Mayumi, 2000).

For this purpose, we use the metabolism of socio-ecological systems approach to analyse the convergence between the implementation of the PES policy (as another water policy) and water metabolic patterns (Madrid-López, 2014). In the rest of the article, we will use the term *water metabolism* when referring to the water metabolism of socio-ecological systems.

2.4. Water metabolism

Water-related services are those most aligned with the logic of PES (Grima et al., 2016). Water services encompass the benefits people obtain from the complex processes between the water cycle and ecosystem's hydrological functions (Brauman et al., 2007). From an anthropocentric perspective, ESs are the use that humans give to ecosystem functions (Song et al., 2014); thus, water becomes a service or a resource only when it is useful for humans. As mentioned above, the simple logic of ESs needs to be reformulated from socio-ecological theory and interdisciplinary work (Balvanera et al., 2011; Bruckmeier, 2016) as it suppresses the prior existence of ecosystem functions and structures (Lomas et al., 2017; Maris, 2011). Here we present the basic fundamentals of water metabolism and its relevance for the reformulation of water services management.

Water as a service is only one of the many meanings of water (Madrid-López & Giampietro, 2015). Cabello (2015) argues that the multiple definitions of water that co-exist are key to its scientific study. These definitions or narratives depend on the context, the actors involved, and the scientists and their disciplines (Cabello, 2015). The latter is important for the framework of this research as different scientific disciplines also represent different ways of addressing environmental problems (Eschenhagen, 2017). In the development of a water science, this means different understandings and solutions to water security problems (Madrid-López, 2014). These reflections have been recognized in water science only very recently, for example, traditional hydrology has for a long time excluded the intrinsic social nature of water (Linton, 2008), however, this was never lost in the Andean hydrocosmological cycle (Boelens, 2014).

The recent rise of new narratives produced by hydrosocial research (Linton & Budds, 2014), as well as socio-hydrology (Sivapalan et al., 2012) and its merger with eco-hydrology (Pataki et al., 2010) have allowed the emergence of a new science culture of coupled water-human systems. However, addressing these hybrid approaches requires truly collaborative and interdisciplinary research at the interface of hydrology and the social sciences (Rangecroft et al., 2021), as there are a number of challenges around and barriers between what each discipline can cover and what they can exclude (Bruckmeier, 2016). For Madrid-López and Giampietro (2015) the inclusion of water in metabolism studies and the new approaches of coupled water-human systems can converge as complementary fields for the development of an interdisciplinary approach.

According to Cabello (2015, p. 42), "water systems operate at several interconnected levels, in which they express different identities (holons) that cannot be reduced to each other" (see, e.g., Koestler, 1970). The water metabolism approach recognises each water identity or narrative in descriptive domains to represent the identity of the whole socio-ecological system (Madrid-López, 2014). The MuSIASEM provides water metabolism with a common language of those non-equivalent narratives or descriptive domains in a water grammar (Madrid-López & Giampietro, 2014). Water grammar is a coherent water flow accounting method that integrates two non-equivalent domains: the watershed and problemshed (Madrid-López, 2014).

The watershed represents the external view (levels e + i/e) of water metabolism and "focuses on the processes that make water available to social systems" (Madrid-López, 2014, p. 97) such as water cycle, ecosystem functions, and the recharge of water bodies (Fig. 2); while, the problemshed represents the internal view (levels s/s-i), where social processes of water take places (Madrid-López & Giampietro, 2014), such as society and societal functions (Fig. 2). However, Cabello (2015, p. 161) added a third transversal descriptive domain called the "infoshed" (the information side of any holon) for the assessment of policies and regulations that drive metabolic change and mediate relationships between social and ecological holons, thus, a further variable is added to the focal level (level i). The interface between these non-equivalent views composes the socio-ecological system (level e,i,s). Therefore, we use this conceptual framework to characterise water as an ecological fund (in the watershed dimension), as a social flow (the problemshed dimension) and as a political asset (the infoshed dimension). Fig. 2 integrates the current evolution of water metabolism to represent the conceptual model used for this research where the infoshed level is replaced by the PES policy.

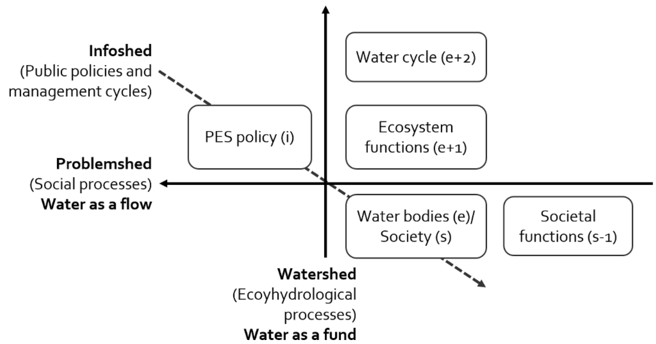

Fig. 2. Conceptual framework. Adapted from Cabello (2015).

The multilevel accounting of these water funds and flow use typologies that can be adapted to each case study at each level of observation (Madrid-López, 2014). However, to assess water as a political asset we had to use a new typology (PES policy) based on the features of our case study. The details of the operationalisation of each level of analysis will be explained in the following sections.

3. Research site and methods

3.1. Case study description

The Santa River basin is located in north-central Peru (Fig. 3). The basin is composed of nine hydrographic units (main drainage areas within the basin), ranging from the high Andes mountain ranges (6768 m a.s.l) to the arid Pacific coast. The hydrological unit of focus here is the upper Santa hydrographic unit, also known as the upper Santa basin (ANA, 2015). The upper Santa basin is mainly bordered to the east by the Cordillera Blanca, one of Peru's most important tropical glacial mountain ranges (Dávila et al., 2018); and thanks to this ecosystem, the whole Santa basin is also one of the 10 most important glacial basins providing water for big cities in Peru (Obregón et al., 2009). Although suspended sediment fluxes in watersheds appear to be a major problem (Morera et al., 2013), the Santa River basin provides crucial water supplies for water-food-energy security for residents inside (366000 inhabitants) and outside the basin. The water of the Santa River is used in the generation of 10% of the country's hydropower (Drenkhan et al., 2015), and in the lower reaches of the basin, large coastal cities such as Chimbote and Trujillo (north of Lima) are supplied with water for human consumption from the Santa River (Lynch, 2012). Furthermore, almost 76% of the average annual discharge of the Santa River is diverted to mega irrigation projects (Chavimochic) in the coastal deserts of nearby regions (Drenkhan et al., 2015). These socioeconomic characteristics make it possible to dimension the complexity of the relationships between its various upstream and downstream social actors.

At the ecosystem level, the study area is characterized by a seasonal precipitation regime (Baraer et al., 2012) with a wet season occurring in the austral summer (November – April) with precipitation that is primarily orographic (Obregón et al., 2009), and a dry season occurring in the austral winter (May – October) when the contribution of glaciers can exceed 40% of the total annual discharge of the Santa River (Baraer et al., 2012). However, due to climate change, the accelerated deglaciation of the Cordillera Blanca has been altering the hydrological regime of the entire basin (Baraer et al., 2012; Seehaus et al., 2019). Thus, among the most latent hydrological risks in the upper basin is the decrease in the quality of water services due to natural Acid Rock Drainage (ARD) and sediments (Mark et al., 2017). As glaciers retreat, they expose metal-rich rock to the atmosphere, accelerating the detachment and entrainment of metals into water bodies (Drenkhan et al., 2015; Grande et al., 2019). Therefore, the capacity for provision and regulation of water services in these ecosystems has also decreased (Polk et al., 2017) and will continue to do so under future warming.

At the social level, the Santa River basin is a territory characterised by divisive political dynamics and high levels of competition for the use and control of water resources among its various stakeholders (French, 2015). Water management in the basin extends far beyond the

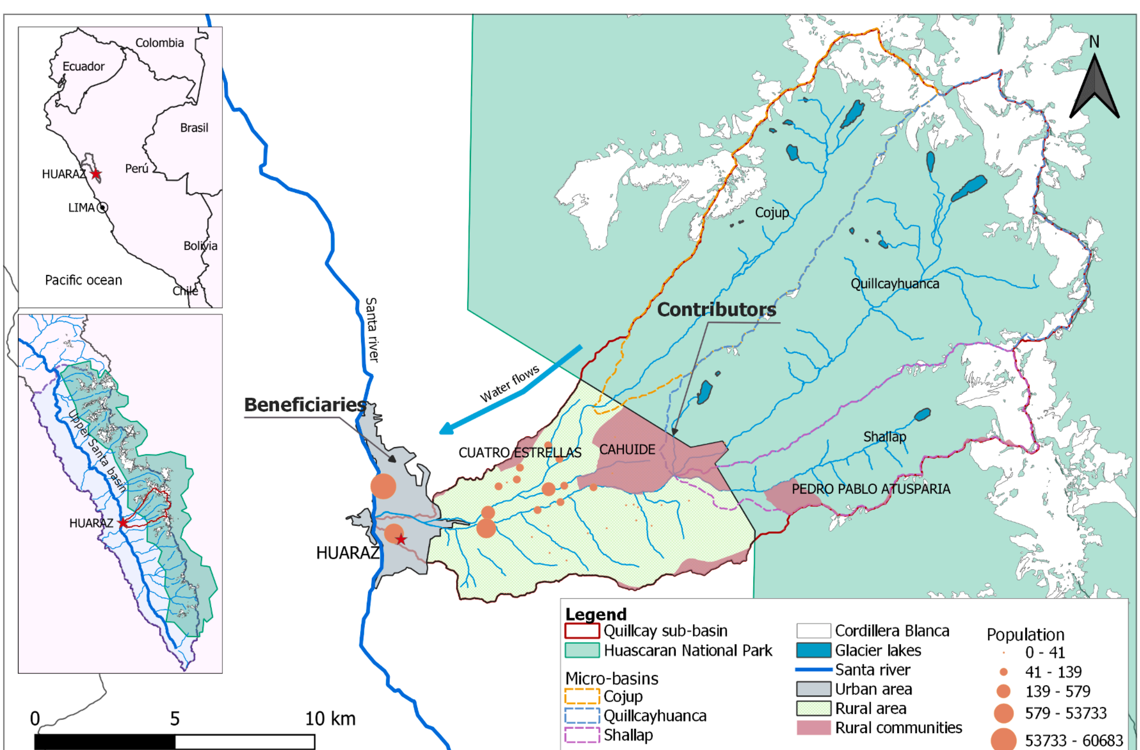

Fig. 3. Location map of the Quillcay sub-basin study area. Inset figures show the study area within Peru (top), and its location within the upper Santa basin (bottom).

hydrographic boundaries as it overlaps two distinct regional jurisdictions. Lynch (2012) groups these social and power dynamics along three axes: i) intra- and inter-regional jurisdictional disputes; ii) competition between economic sectors and sub-sectors; and iii) competition between upstream and downstream users. All these particular dynamics have obstructed the consolidation of a "Basin Water Resources Council" who have the primary role of developing a Water Resources Management Plan for the Santa River basin (key to the implementation of the IRWM paradigm and water policy). Hence, the water governance in the Santa River basin is a highly politicised process that faces hydro-climatic change and pressures as well as uncertain social dynamics (French, 2015).

One of the main tributaries of the Santa River is the Quillcay sub-basin which is situated on the western-facing slope of the Cordillera Blanca and supplies water to the Andean city of Huaraz (Fig. 3), home to more than one-third of the total population of the Santa basin (ANA, 2015). A potential hydrogen characterization study of the water in the Quillcay sub-basin reported values that could be a risk to human health and ecosystems (Martel et al., 2018). Since 2005, the local drinking water company of Huaraz has experienced issues in satisfying the demand for water for treatment because one of its two main catchments sources (the Auqui river) has high concentrations of heavy metals (Muñoz et al., 2017), and in the dry season, this problem is exacerbated due to a lack of dilution with limited precipitation (Mark et al., 2017). Thus, the implementation of a water PES for the Quillcay sub-basin has become a priority for decision-makers, with an ambition to gradually cover the entire Santa River basin. While in other catchments of Peru a water PES has the central expectation of improving water quantity (Quintero & Pareja, 2015), in the upper Santa basin the main objective is to improve water quality.

As a requirement of the existing regulation, new implementation of PES must follow some pre-established guidelines: i) rapid water diagnosis; ii) identification and characterisation of ecosystem service providers; iii) plan of interventions/actions; v) establishment of a network of different public and private actors linked to the mechanism (driving group); and vi) design of a monitoring system. A water PES for the Quillcay sub-basin, and in general for the entire Santa basin, is a very complex governance process that converges with water quality problems upstream of the basin. The Quillcay sub-basin PES project is an initiative that began in 2015 thanks to the leadership of an NGO who financed the development of technical studies such as the willingness to pay of the urban population to design and implement a project for the conservation and improvement of the upper ecosystems (e.g. Alarcón et al., 2014). However, when the private funding ran out, the sustainability of the project could not be guaranteed by public institutions and local actors. Therefore, at the time this research was carried out, the project only had the driving group in place, and the other guidelines had been left half-finished and others had not even been designed.

In Fig. 3, we identify the potential agents willing to provide the service that the regulation refers to as "contributors" who are located in the middle and upper parts of the sub-basin, including rural communities, private landowners, and the Huascaran National Park. Likewise, in our case study, while the direct beneficiary is the DWC, the indirect beneficiaries are the users who pay for the drinking water service. On the other hand, in the PES implementation process, many other actors with different power relations play the role of intermediaries in the definition of the ecosystem service, some even play a dual role. In our case study, these stakeholders are the regional government, public institutions involved in water management and ecosystem research, Non-Governmental Organizations (NGOs), and universities.

This background context demonstrates that the Santa River basin is a hydrological system where the processes of water are impacted not only by glacial meltwater and rainwater regimes, but also by political, economic and cultural power relations over water. In this way, a water PES for the basin is a political process "where different interests, worldviews and power constellations clash and fundamental decisions about future uses of the ecosystem are made" (Hausknost et al., 2017, p. 117).

3.2. Methodological approach

This study analyses how the socio-ecological interactions under the water metabolism approach affect, and are affected by the introduction of water-related PES in the Quillcay sub-basin. Thus, we used the accounting system of water funds and flows from the MuSIASEM expressed in a water grammar (Giampietro et al., 2013) to characterise our case study as a water metabolic system. Water funds represent what the system is and water flows what the system does within a specific context (Giampietro et al., 2013). The water grammar employed "can be seen as a formal system of rules" (Giampietro et al., 2014, p. 15) that combines traditionally two non-equivalent domains of water mentioned above: the watershed and problemshed (Madrid-López & Giampietro, 2014). The integration of these different levels of linguistic significance of water is represented in semantic categories that are formalised with methods from different scientific narratives (Madrid-López, 2014). It is equivalent to the operationalisation of variables, as formal categories provide indicators and ways of measuring water flows (Canales, 2006). The formalisation acts to "generate a set of forced congruence relations" (Giampietro et al., 2013, p. 6). These relationships are non-linear and non-deterministic; thus, their verification allows the use of multidimensional (simultaneous use of different variables) and multilevel (use of different hierarchical levels of analysis) representations of the socio-ecological system (Giampietro et al., 2014).

As this approach is based on complex system theory it is unrealistic to use the semantics of the water grammar as a universal protocol (Madrid-López & Giampietro, 2014). Semantic categories used in MuSIASEM "have to be tailored to the specific situation and context" (Madrid-López & Giampietro, 2014, p. 121). Thus, to characterise our hydrological study unit, we adapted the semantic categories of water grammar to allow for the combination of different methods of data collection that will be explained in detail in the following section. Table 1 shows the formal categories to analyse our conceptual framework. As it is a glaciated sub-basin, glacial meltwater input and water quality losses due to glacial retreat are added under the category of ecosystem water recharge.

Water grammar under the MuSIASEM approach has previously been used to assess the integration of water and agricultural policies in rural systems (Cabello & Madrid-Lopez, 2014). This demonstrates the usefulness and flexibility of the tool to integrate biophysical and social aspects in the same framework of analysis. Hence, for this research we used the third non-equivalent domain for water grammar proposed by Cabello (2015) referring to public policies "as a mirror of social values (…) shaping relations between societies and ecosystems" (p.45). As she describes, "this is not a physical holarchy, but represents the information side of any holon" (Cabello, 2015, p. 46). In our case study, the third transversal axis is expressed through the political dimension of PES projects (Hausknost et al., 2017).

As the PES project for the upper Santa basin is just in the implementation stage, the semantic category of this axis focuses on the socio-

Table 1
Water grammar for the Quillcay sub-basin (adapted from Madrid-López (2014)).

Role	Level of analysis	Semantic categories	Water types	Formal categories
Water as a fund	Water cycle (e + 2)	Climate	Precipitation	Average data of water balance (hm^3/year)
	Ecosystem functions (e + 1)	Ecosystem water recharge	Runoff	Average data of water balance (hm^3/year)
			Recharge	
			Infiltration	
			Glacial input	
			Ecological requirements	Ecological flow (hm^3/year)
			Qualitative loss	Average naturally polluted water (hm^3/year)
	Water funds (e)	Water appropriation	Surface water	Available water (hm^3/year)
			Subsurface water	
			Qualitative loss	Average polluted water (hm^3/year)
Water as a flow	Society (s)	Gross water use	Diverted water	Total appropriated water (hm^3/year)
			Water in situ	
			Quantitative loss	Average water lost in distribution (hm^3/year)
	Social functions (s-1)	Net water use	Drinking water	Average urban drinking water (hm^3/year)
				Average rural drinking water (hm^3/year)
			Agriculture	Average irrigation water (hm^3/year)
			Others	Average water for other uses (hm^3/year)

political context that characterise the institutional arrangements of PES schemes (Hausknost et al., 2017). De la Mora (2019) argues that once these policies are implemented, social actors and their interactions build and transform these instruments over time and on different scales. We argue that social actors build and transform PES schemes even during its implementation. For our case study thus, we formalised this category through the perception analysis of the different actors involved in the implementation process of the PES project with the role they play, a different method to the discourse analysis and policy assessment originally suggested by Cabello (2015). Data collection methods for this axis were designed based on a review of the Peruvian PES policy guidelines, the details of which are explained below.

3.3. Data collection

To analyse the two traditional non-equivalent domains of water (see Table 1), a bibliographic review from secondary sources was employed to estimate the quantities of water flows at each hierarchical level. In this way, to characterise the watershed dimension, available water statistics have been synthesised from official local and national reports up to five years old, paying special attention to the quality and temporality of the data as well as the hydrological model applied. Likewise, as the Cordillera Blanca is one of the most studied glacial ecological systems worldwide from disciplines such as hydrology, climatology, and glaciology (Carey et al., 2017; McDowell et al., 2019), we took advantage of this scientific background to complement our analysis. The data linked to the problemshed for estimating gross and net water use have been extracted from water use authorisations in the Quillcay sub-basin. This enabled us to build a Sankey diagram to show the quantifications of water flow and their social uses at each of the hierarchical levels of the water grammar defined in Table 1 for the study area.

Finally, to assess the interface between these traditional levels with the third non-equivalent domain of the water grammar (the infoshed), we focused on the perception analysis of the social actors directly or indirectly involved in the PES project for the Quillcay sub-basin. Due to the special features of our case study and COVID-19 restrictions, it was necessary to use digital tools for primary data collection to assess this domain. To begin with, we first conducted an exploratory stakeholder analysis as a tool to characterise actors involved in the implementation of the PES project. The criteria for the design of the stakeholder mapping in this research were based on a structuring proposed by Tapella (2007) and the guidance of Ortiz et al. (2016). The current Peruvian PES law states that any PES scheme must ideally start with the setting up of a driving group (a network that pushes the project forward) composed of any interested stakeholder. In our case study, this driving group is currently composed of government institutions and NGOs. Thus, the stakeholder analysis was carried out through an online questionnaire for members of the driving group.

Table 2
Number of participants by data collection methods used for each actor in the PES scheme.

Actor PES role	Data collection method			
	Stakeholder analysis	Semi-structured interviews	Survey	Review of secondary sources
Beneficiary (direct)	1	-	-	-
Intermediary	7	13	-	-
Potential contributor	-	-	-	X
Beneficiary (indirect)	-	-	76	-
Total	8	13	76	-

Results of the exploratory stakeholder analysis provided the basis for combining different data collection methods by type of actor identified (Table 2). Thus, primary data also weres collected from both semi-structured interviews and an online survey based in Huaraz. In total, 13 interviews were conducted virtually via Zoom with officials of public institutions, academics, and NGO members, most of them as part of the driving group. An open sampling approach was applied during the interviews, meaning that, “sampling is open to every person, place and situation that offers us the greatest opportunity for discovery” (Strauss & Corbin, 2016, p. 225).

Stakeholder analysis also revealed that neither potential contributors nor the indirect beneficiaries of water service were involved in the current PES design. Therefore, parallel qualitative data collection was conducted through an online survey targeting urban drinking water users (hereinafter referred to as DWU) and disseminated through a campaign on social media[1] and local radio stations from 7 to 21 August 2020. The purpose of the online survey was to gather people’s perceptions of water services and ecosystems. For this data collection method, the sampling method was non-probabilistic and the sample size criterion was saturation sampling (Cea D’Ancona, 1996; Hennink & Kaiser, 2022). In order to reduce sample biases in the online survey, we included validation questions such as the Global Positioning System

[1] The campaign on social media included the design of a special website to disseminate the research survey (see here) to the target audience.

(GPS) location of the participant when answering the questionnaire. Altogether 76 surveys were completed in the urban area of Huaraz. Likewise, in order to respect ethical principles in research with rural communities, we decided not to include rural potential contributors in the primary data collection as face-to-face data collection is necessary, hence, the review of secondary sources was used to complement the perception analysis.

Through the case study method, the research adopts both a descriptive character of the dynamics that could help to answer the research question, and an explorative element, by trying to bring theoretical conceptions and social practice closer together (Eisenhardt, 1989; P. Martínez, 2006). Thus, the use of these techniques allowed us to obtain varied but complementary information to answer the research question.

3.4. Data analysis

The processing and analysis of information followed the structure of the two central domains from our conceptual framework: i) a unidimensional description to characterise the watershed and problemshed dimensions; ii) a closure multidimensional description to synthesise the interface of these two traditional domains of water grammar with the political dimension of the third transversal domain (the socio-ecological system). For the first two domains, we applied a bottom-up and top-down statistical analysis. The results in flow and fund quantities of water sources were organised in a Sankey diagram to show the different hierarchical levels and dimensions analysed.

In the same way, for the third domain, qualitative data from interviews were analysed according to an inductive-deductive coding approach (Strauss & Corbin, 2016). We also used matrices and descriptive statistics to analyse the data collected through the stakeholder questionnaire and the citizen survey. As the citizen survey also included open questions, we used an inductive coding for its analysis, while quantitative data collected in the surveys were analysed as a frequency count (Jansen, 2013). Table 3 summarises the issues assessed by each PES actor according to the data collection method employed. These issues also served as a coding framework where necessary, as they correspond to social dynamics around the perception among stakeholders; social dynamics ranging from social value to more complex political dynamics that influence the integration of any PES scheme (R. Martínez, 2008).

Following Ortiz et al. (2016), we understand power relations as a formal decision, such as the ability to influence decision-makers or the ability to oppose or block decisions in the implementation of the PES project. Thus, in the case study, three criteria grouped within the power relations variable were used to characterise the driving group in a stakeholder matrix: i) Level of interest, which referred to organisational and networking capacity measured on a scale of low, medium and high; ii) Level of influence in decision making measured on a scale of low, medium and high; and iii) Relational level, which includes those relational types that intertwine actors from different sectors such as trust or collaboration, tension or conflict, intermittency, absence of relationship, and influence over (see Ortiz et al., 2016). Note that the power relations analysed with this tool refer to a very general perspective of the relations between actors at the time the study is carried out. Furthermore, it is important to highlight that stakeholder mapping is a means to another end (Ortiz et al., 2016) and is therefore used in this research as a complementary tool.

Semi-structured interviews were used to unravel socio-political perceptions of the PES driving group. Pre-determined questions allowed us to explore bottlenecks in the implementation of the PES project at an economic, institutional, political, legal, social, and technical leveles. On the other hand, knowledge was a variable that emerged during the interviews and it grouped participants' perceptions and personal experiences in the implementation of PES projects. The survey employed for the indirect beneficiaries of the PES scheme was aimed at exploring the recognition of these terms, the legitimacy of local water management authorities and the social value. As secondary data was restrictive, only social value was analysed for the potential contributor of the PES.

4. Results

The results are presented following the structure of each descriptive domain used. The first two parts show the characterisation of the watershed and problemshed from our metabolic system. Fig. 4 shows the results of water flow accounting and its physical movement from watershed to problemshed (left to right), across different hierarchical levels according to the water metabolism approach. The ecosystem-society interface with the transversal infoshed domain is presented in the last part.

Table 3
Issues assessed for the perception analysis of the different PES actors.

Actor PES role	Source of the data	Issues
Beneficiary (direct) & Intermediary	Stakeholder analysis	**Power relations**[a]**:** Level of interest/influence, and relations between stakeholders.
Beneficiary (direct) & Intermediary	Semi-structured interviews	**Bottlenecks**[b]**:** Issues stalling and holding up the implementation of the PES (e.g. Economic, institutional, politic, legal, social, technical, and others). **Knowledge:** Participants' experience in the implementation of PES projects; perceptions of the social and ecological impact of these water management schemes.
Beneficiary (indirect)	Survey	**Knowledge:** Knowledge of the meaning of ESs and PES policy. **Legitimacy:** Evaluation of their local authorities in water management and conservation. **Social value**[c]**:** Relative importance of an ecosystem and its services to society. Measured through the intrinsic and socio-cultural value of water.
Potential contributor	Secondary data	**Social value**[c]**:** Relative importance on ecosystems and its water services to society. Measured through the intrinsic and socio-cultural value of water.

[a] Taken from Ortiz, Matamoro and Psathakis (2016, pp. 6–10).
[b] Taken from Quintero & Pareja (2015).
[c] Taken from Martín-López et al. (2012, pp. 47–49).

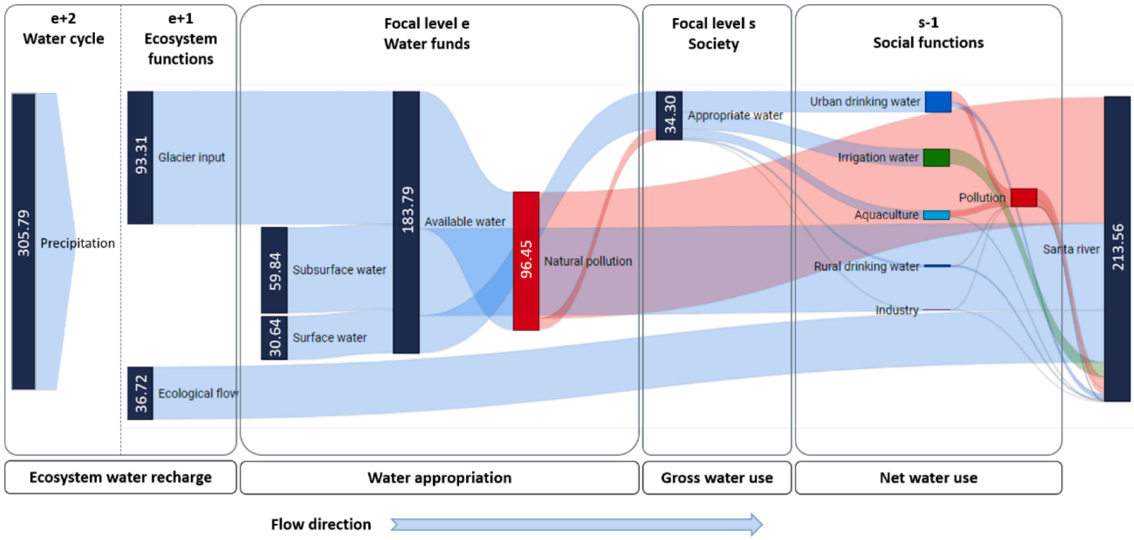

Fig. 4. Water grammar applied to the case of the Quillcay sub-basin for diagnostic analysis. Data obtained from secondary sources (see Table 4 and 5). Note: all quantities of water flows are reported in hm^3.

4.1. The watershed dimension of the Quillcay sub-basin

The left side of the grammar (Fig. 4, levels e + 1; e) represents the watershed domain and it is focussed on the water supply expressed in annual historical data (Table 4). At the level e + 1 where the water recharge of the ecosystems takes place, it was not possible to adapt all the water balance statistics. We only included historical annual precipitation (183.79 hm^3) as the main inflow to the sub-basin. We also excluded the ecological processes of the other ecosystems (grasslands, wetlands, etc.) in the regulation of water flow as we could not find any studies that could be adapted for our purposes. From the focal level e, it was possible to adapt the water statistics more accurately. The amount of flow available in water bodies corresponds to theoretical estimates of water supply. Only studies of surface sources (rivers and streams) and subsurface sources (ponds and springs) were available (Muñoz et al., 2017). Also, naturally polluted flows were estimated from a bottom-up analysis of water allocation (ANA, 2020a) and monitoring data (ANA, 2020b; INAIGEM, 2020), such that more than half of the available water (96.45 hm^3) comes exclusively from the Quillcayhuanca micro-basin is polluted (Fig. 4).

4.2. The problemshed dimension of the Quillcay sub-basin

The right side of the grammar (Fig. 4, levels s; s-1) shows the problemshed domain and it focuses on water use within the social system (Table 5). At the focal level s, only 19% of the total water available in the water bodies is formally used and any human activity has a wastewater recovery system, hence all the polluted flow returns to the water bodies of the sub-basin or is discharged directly into the Santa River. At level s-1, more than 60% of the appropriated water is used for human consumption. Drinking water was divided into urban (14.64 hm^3) and rural areas (1.4 hm^3), as the water infrastructure in rural areas is more precarious. The net water use for urban consumption is only 76% of the total amount diverted (24% is lost from the catchment to the treatment plant), without subtracting losses in the distribution network to household (Rivas et al., 2014); while the net water use in rural area corresponds to only 35% of the total amount diverted. The second most important social function is agriculture: gross irrigation water demand is theoretically estimated at 32.13 hm^3 (Santiago & Mallqui, 2019), which is twice the theoretical demand for drinking water. However, only 12.01 hm^3 have been formalised. Irrigation efficiency is also very low, with Muñoz (2017) estimating the efficiency of between 30–35%. The other water social uses found are aquaculture and industry.

Table 4
Organization of data on the watershed for the case of Quillcay (internal view).

Water type by level of analysis	Water accounting (hm^3/year)	Formal categories	Source details
e + 2		**Total inflow (hm^3/year)**	Hydrological model with "RS Minerve" (a software for runoff simulation) developed by Muñoz (2017) with hydrometeorological data between 1983–1991 (for calibration) and between 1991–1998 (for validation).
Precipitation	305.73	305.73	
e + 1		**Water recharge (hm^3/year)**	
Glacier input	93.31	220.51	
Ecological requirement	36.72		
e		**Water available (hm^3/year)**	ANA (2020b) monitoring data showed a value of pH = 4.3 in the Auqui river (main tributary of the Quillcay river). Upstream, INAIGEM (2020) monitoring data show that the tributaries in the Quillcayhuanca and Sallap micro-watersheds (which give rise to the Auqui river) also have acidic pH values.
Surface water	30.64	183.79	
Subsurface water	59.84		
Natural pollution	-	96.45[a]	

[a] Water available in the Auqui river to grant water use rights according to ANA reports (2020a). This value is already included in the inflows from surface water and glaciers.

Table 5
Organization of data on the problemshed for the case of Quillcay (external view).

Water type by level of analysis	Water accounting (hm^3/year)	Formal categories	Calculation data	Source details
s		**Gross water use (hm^3/year)**	**Use efficiency (%)**	Data disaggregated by type of water use according to the resolutions of right of use granted by ANA until 2020 for the Quillcay sub-sector (Ana, 2020a).
Urban consumption	14.64	34.31	76	
Rural consumption	1.40		35	Efficiency percentages were extracted from hydrological characterisation studies by Mallqui et al. (2016) and Santiago and Mallqui (2019).
Irrigation	12.01		35	
Aquaculture	6.24		95	
Other (industrial)	0.01		95	
s-1		**Net water use (hm^3/year)**	**Polluted outflows (%)**	A return value of 70 % was assumed as wastewater for all social functions, except for industrial where all water used returns polluted (Muñoz, 2017); no data on irrigation were found.
Urban consumption	11.13	21.77	70	
Rural consumption	0.49		70	
Irrigation	4.20		-	
Aquaculture	5.93		70	
Other (industrial)	0.01		100	

4.3. The ecosystem-society interface of the Quillcay sub-basin

In the infoshed dimension, stakeholders "can and/or should influence environmental decision-making processes" (Prell et al., 2009, p. 502). Thus, a social actor or stakeholder "is any unit that generates action and social relations" (Tapella, 2007, p. 3), and it can be an individual, group, entity or organisation affected, in our case study, by the PES project. Table 6 shows all the actors identified and classified according to the role they play in the design of the PES, including beneficiaries (direct and indirect), intermediaries, and potential contributors.

To present the power relations in the PES decision-making process we built an influence/interest matrix with chord diagrams using the information collected from eight representatives of the project's driving group designated by their institutions to participate in the research. Fig. 5, shows the position of each actor type within the PES project: the role of each actor is differentiated by colour and their relationships by different types of links. Thus, despite playing only an intermediary role according to the regulation, the National Superintendency of Sanitation Services (SUNASS) is the actor with the highest degree of influence and interest followed by the DWC which according to the norm should be the main player. Then we find rural communities (RC), Ministry of Housing, Construction and Sanitation (MVCS) and Huascaran National Park (HNP) in the same quadrant, although by the time this research was completed, no representatives of the RC had been invited to participate in the decision-making process despite their central role in the PES. The same situation was found in the "keep satisfied" quadrant where no DWU representative is involved in PES implementation decisions. This means that the members of the driving group recognise prospectively the influence/interest of RC and DWU but in practise these actors have not yet been included. Therefore, only the intermediary actors, the direct beneficiary and one of two potential contributors are part of the decision-making process.

The exclusions of the main actors affected by the PES project (DWU & RC) are also reflected in the types of links that bind them to the key players: SUNASS, DWC and MVCS all perceive an intermittent or non-existent relationship with these actors who have no real say in the project. Thus, the information gathered from the interviews helped us to deepen these initial findings. Six of the 13 interviewees were part of the Quillcay PES driving group or were involved in the past (codes: NGO, TEC, GO), the others were State public actors (code: GO), NGOs (code: NGO), and academia (code: ACA), linked to the implementation of similar schemes in other regions of Peru. Based on broad categories defined by the theoretical framework and the interview question guides, Table 7 shows examples of the main perceptions we classify under the category of bottlenecks.

Table 6
Actors involved in the PES project for the Quillcay sub-basin according to the regulation.

PES role	Actor (code)	Actor type	Function
Beneficiary (direct)	Drinking Water Company (DWC)	State (Local company)	Provide drinking water service; they administer the resources collected by the MERESE
Beneficiary (indirect)	Drinking Water Users (DWU)	Civil society	Pay for drinking water service
Intermediary	National Institute of Glacier and Mountain Ecosystem Research (INAIGEM)	State (General administration)	Provide technical and scientific information for the development of the Rapid Water Diagnosis
	National University Santiago Antunez de Mayolo (UNASAM)	State (Academia)	Provide technical and scientific information for the development of the Rapid Water Diagnosis
	National Water Authority (ANA)	State (Local department)	Manage water resources in the study area
	Regional Government (RG)	State (Regional administration)	They implement their sectoral objectives within the framework of the country's water policy; they also promote and execute water conservation projects.
	National Superintendency of Sanitation Services (SUNASS)	State (General administration)	They approve and incorporate into the water tariff the costs of MERESE
	Ministry of Housing, Construction and Sanitation (MVCS)	State (Local department)	Promotes the installation of water supply and drainage throughout the country
	Mountain Institute (MI)	NGO	Promote the conservation of mountain ecosystems
Potential contributor	Huascaran National Park (HNP)	State (Local department)	Administration of the reserve area
	Rural communities (RC)	Civil society	Largely from the community of Cahuide; private landowners; pasture users' committee; and irrigation committee

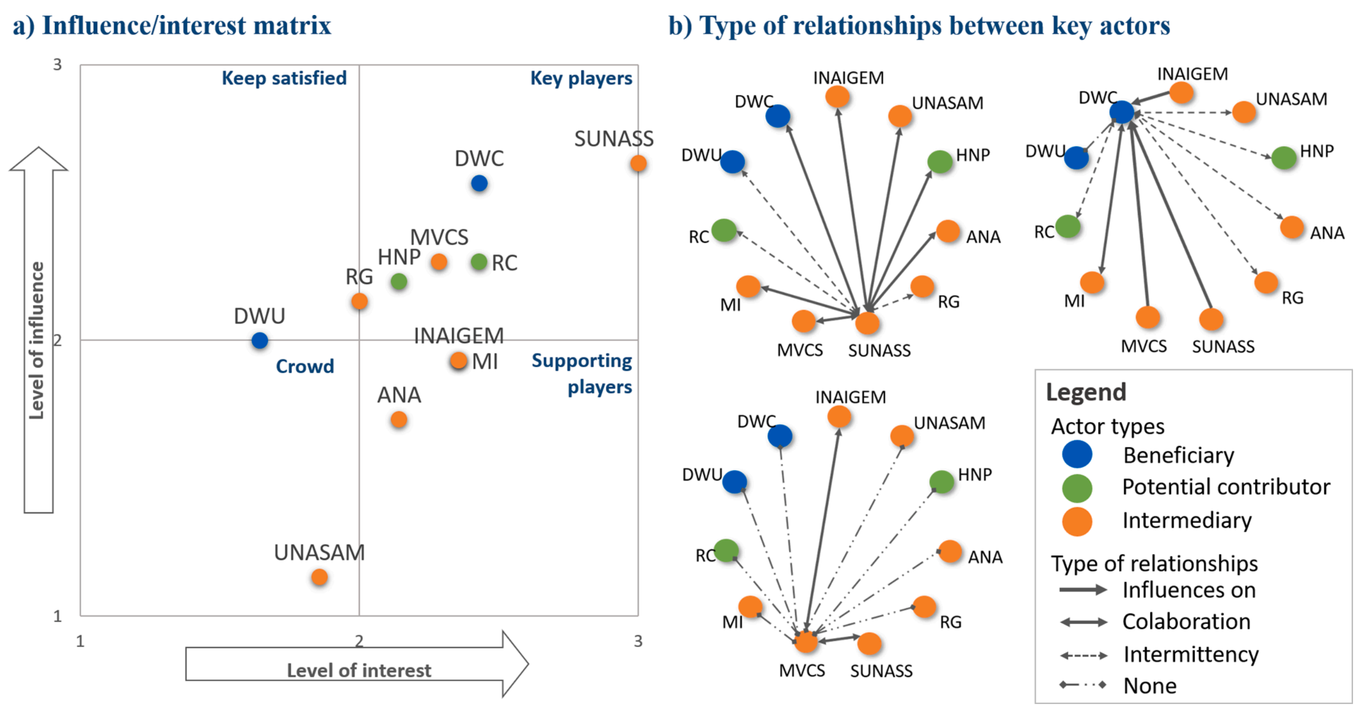

Fig. 5. Power relations between the driving group are illustrated with: a) Interest vs Influence matrix (left); and b) categorised relations between key actors (right).

Table 7
Tabulation of perceptions on bottlenecks in water PES project for Quillcay.

Subcategories	Example of perceptions	Frequency
Economic: Scarcity of financial resources during the design, implementation & sustainability of the PES.	"*to carry out the management, money is necessary, funds are necessary, what the meetings are going to be managed with, because management is a set of meetings to reach an agreement, to reach a consensus among all the users*"(GO1, video call, 04.09.2020) .	1
Institutional: Capacities of existing organisations and bodies for PES implementation.	"*The meetings that I have been able to attend have been attended by, let's say, most of the institutions that have been called, but the issue is that there is very little continuity. The classic, one day one representative goes, the next day another one goes, so this cut the dynamic of what we want to move forward*" (TEC1, video call, 18.09.2020)	12
Political: Lack of political will or politicisation of PES initiatives.	"*When you do something for publicity for the RG, and you have to show yourself there, there is a presence [of actors], but [when] you see that when the people who maintain [the process] disappear (…) everything falls apart and things don't move forward*"(NGO2, video call, 15.09.2020) .	9
Legal: Legal obstacles, or loopholes; legal limitations in the design of the scheme; difficulty in designing agreements or contracts between the parties.	"*The RG understands PES in one way, the DWC in another, and it is important to start with clarity, because in the retribution [or payment] there is money involved, there is always a tendency to misunderstand that this money is of free will*"(NGO1, video call, 04.09.2020) .	1
Social: Willingness of villagers or civil society to support and promote PES initiatives; social conflicts that prevent reaching agreements for conservation.	"*This is a very difficult area (…) the people in the jungle are much more affordable, that is the reason why in Moyobamba these mechanisms [PES] have progressed, they have solved the problem, but here it will be very difficult, for example, to tell them "you are going to pay 20 cents more in water per m*^{3} *or receipt", we will see what can happen when this happens*"(GO1, video call, 04.09.2020) .	14
Technical: Knowledge gap on PES design, ecosystem status, and conservation and/or restoration actions.	"*the DWC is tough (…) they have well-parameterised work schemes, [they are] a group of technicians who have worked 30 years doing the same thing and who are not necessarily willing to be helped either*"(NGO1, video call, 04.09.2020) .	4
Other: Emerging themes during the interview (role of academia; lack of identity in the population).	"*The local university does not have a mechanism for delivering information to society, I have not seen it, I do not know if they do, and I hope I am wrong*"(NGO1, video call, 04.09.2020) .	8

From interviews, we found in total 35 narratives related to more than one subcategory within the bottleneck category: 40% of cases are related to social bottlenecks followed by institutional (34%) and political (26%). Linking the last two main subcategories, NGOs perceive tensions between the state actors that constitute the PES driving group and this perception is shared by State actors from the central administration, especially towards the DWCs. The GO3 actor argues that "DWCs have never had experience of conservation, of recovery (…) So for them it's all very new. They don't have the experience. From one point of view it gives them a responsibility that they did not want to take on" (video call, 10.09.2020). In contrast, NGOs are perceived as strategic actors in the design and implementation of PES; NGOs collaborate with government actors to create the conditions necessary to implement these schemes. In addition, although only one narrative related to economic bottlenecks

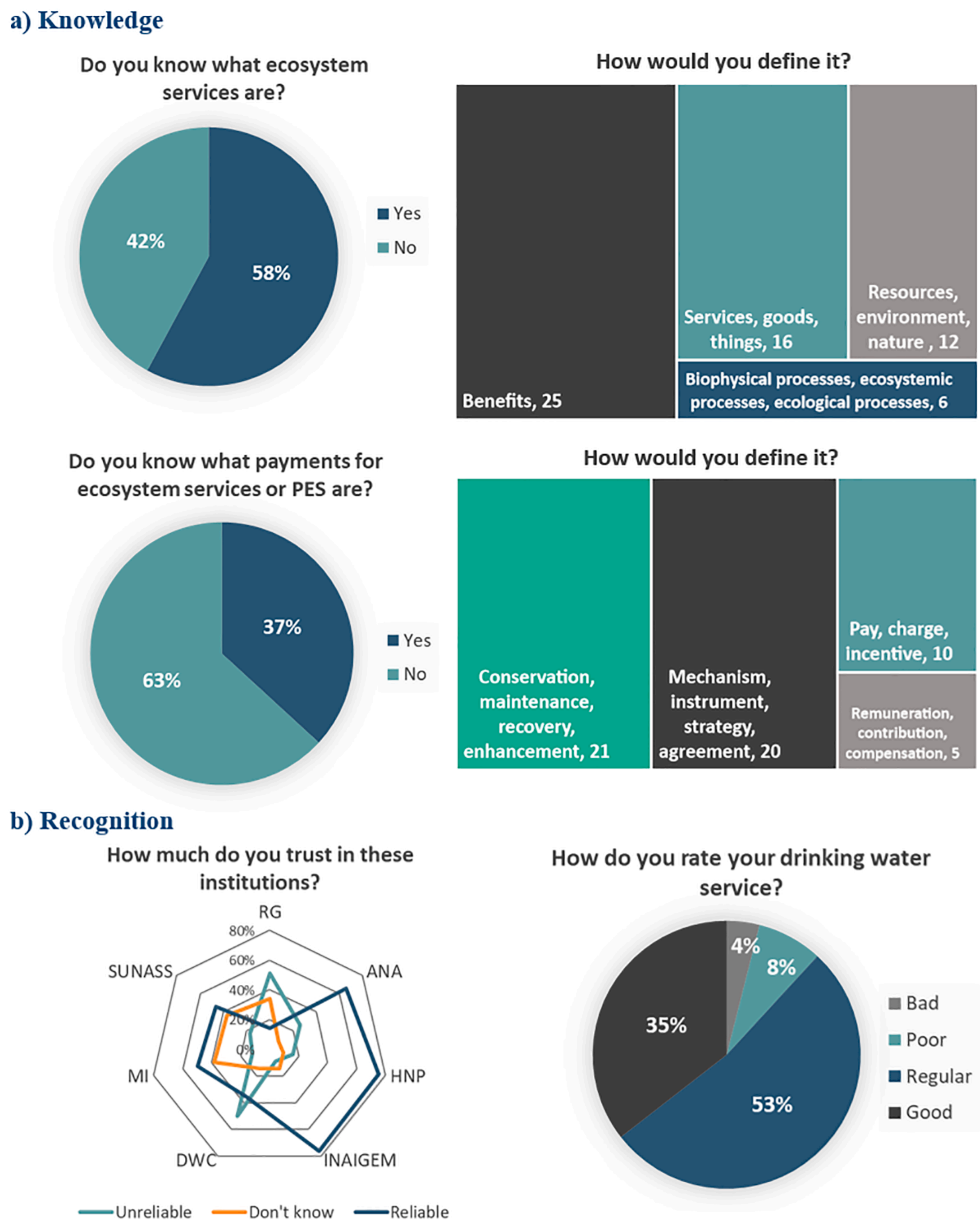

Fig. 6. Online survey results from the Drinking Water Users on the core issues of the case study and legitimacy of the project's driving group: a) Knowledge; b) recognition. Data established from online survey 2020 (n = 76).

was identified, together they explain why it has so far been difficult to include DWU and RC in the PES decision-making.

Findings within social bottlenecks are even more complex. Emerging issues from interviews show a perception of RC as the main driver of upstream ecosystem degradation due to poverty and ignorance.

> One of the big problems in the countryside is that precisely because of the process of misuse of the land [it] has generated a process of loss of water regulation, and the first people affected by this loss of regulation are them [the communities] (…) we are talking about areas where the main problem is poverty and the product of this poverty is the degradation of the watershed, and that is what needs to be addressed precisely with the mechanisms [MERESE]. (GO2, video call, 23.09.2020).

Even in cases where communal practices of sustainable resource management have been found, they do not fit in with modern technical solutions. It is only from the academic sector that the use of these discourses to justify the intervention of this kind of project is criticised as at the local level "a logic of solidarity, of equity, of sharing" (ACA1, video call, 09.09.2020) predominates. In relation to DWU, governmental and NGO actors agree that it is more important to promote awareness-raising actions with them than their active participation in decision-making processes.

The urban population is much more complex, the populations are larger and there is a lot of work to be done to raise awareness, first on the proper use of drinking water and then on the need to pay for it, and not only to have drinking water, but also to conserve the basin and guarantee the availability of the resource. (GO2, video call, 23.09.2020).

In order to compare the main bottleneck perceived by the interviewees focusing on social factors, Fig. 6 represents the main results of the analysis of the survey data related to the categories of knowledge and recognition from a sample of 76 participants, of whom 53% were male and 47% female; with a majority age range between 18–32 years and 39–46 years (70%); and with a dominant occupation in engineering, students and others (79%). First, we asked the citizens (DWU) in the survey if they knew what ESs and PES were. Over half of the participants indicated that they knew what ESs are (58%) and 37% of the participants answered that they knew what PES was. “Benefits” was the word most associated with the definition of ESs (N = 25) and “conservation”, “maintenance”, and “recovery” followed by “mechanism”, “instrument”, “strategy” or “agreement” were associated with the definition of PES (or MERESE) (Fig. 6a). The lack of familiarity with PES among almost two-thirds of respondents further validates the social bottlenecks perceived in the interviews. Other factors that could strengthen this argument include the level of trust that DWU have in their authorities to manage

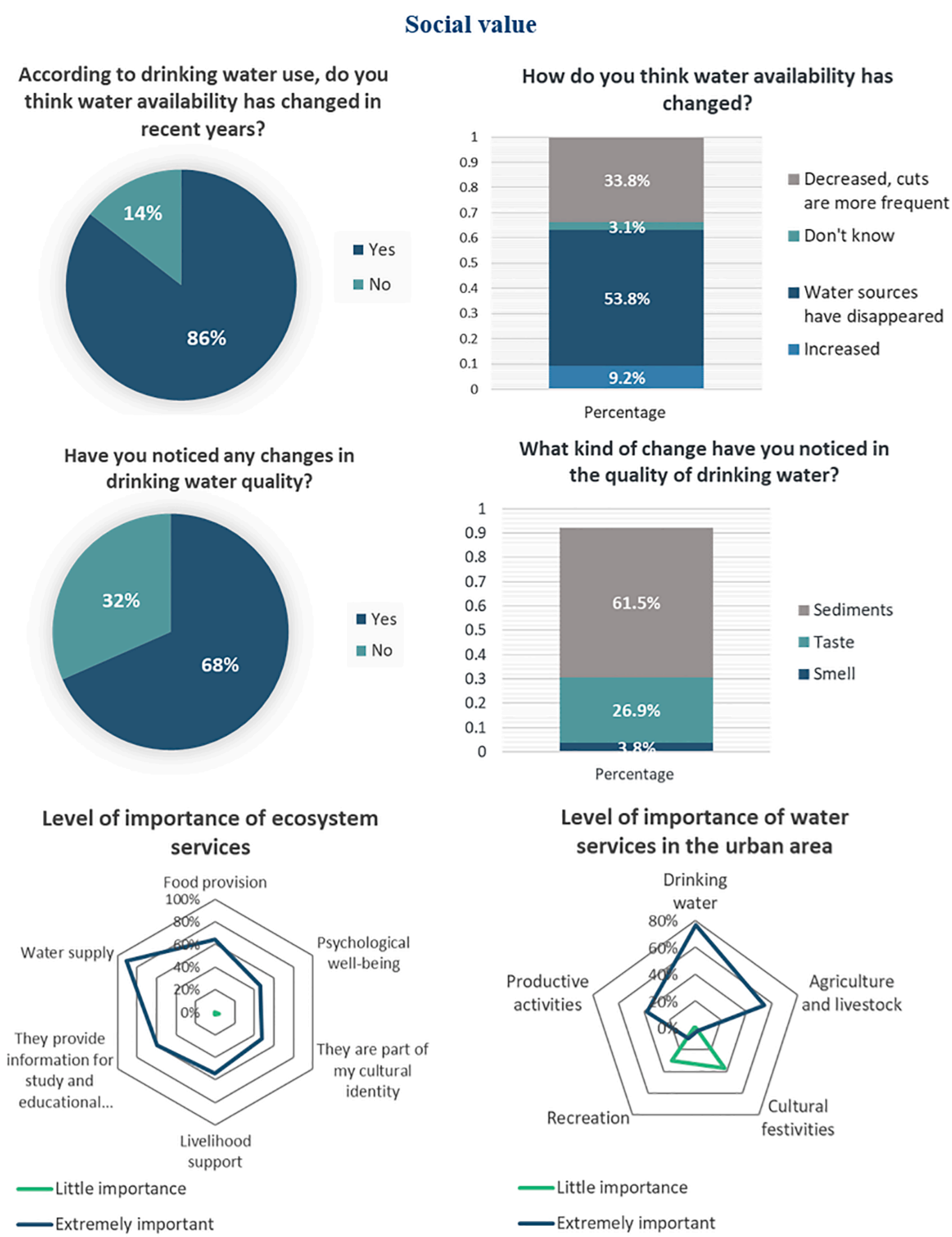

Fig. 7. Online survey results from Drinking Water Users showing the social value of ESs and water services in the Quillcay sub-basin.

and conserve water services as well as the level of satisfaction with the drinking water service. Thus, the population have more confidence in technical institutions such as INAIGEM (76%) or the HNP (75%). The level of satisfaction with the drinking water service provided by the DWC, on the other hand, was rated as regular (53%) by the population (Fig. 6b).

Even if people do not know the meaning of ESs or PES, they might recognise the importance of ecosystems in their lives. Thus, the social value category helped us to complete the social perception analysis assessed in the third domain of our conceptual framework. From the literature review, it is known that water scarcity is a process socially perceived to a greater degree by the rural population upstream of the sub-basin (French, 2019; Mark et al., 2017). Aligned with this, Vergara (2015) developed a survey and focus group in the communities of the Quillcay sub-basin concluding that the villagers perceive a decrease in rainfall, the disappearance of springs, the increasing disappearance of their glaciers and poor water quality, especially in rivers. The study attributes these changes mainly to pollution and climate change. Zimmer (2016) further identifies these problems as latent factors in conflicts between neighbouring communities and villages competing for access to water of good quality. Moreover, Paardenkooper (2018) analysed the effect of ARD on rural livelihood and found that 27% of the surveyed households had seen their livestock die while drinking from a polluted river; 67% of the polluted irrigation water users claim to have bad crop lengths, and a significant amount of people also perceived health problems. In the urban area, on the other hand, a change in the availability of water (86%) as well as in the quality of the water (68%) in the last years is perceived (Fig. 7).

In addition, we asked participants to rate a list of ESs according to their level of importance. A summary of the results is presented in Fig. 7, where the radial chart compares the multiple variables according to the percentage of responses obtained for each variable. Water provision is viewed as an extremely important ecosystem service (91% of cases) for DWU, followed by food provision (64% of cases). Next, respondents were asked to assess the importance of the social uses of water. The results show that human consumption (76% of cases) and agriculture and livestock (54% of cases) are extremely important for DWU.

We did not ask the participants about their willingness to pay a fee for the conservation of the ecosystems upstream of the sub-basin. However, 100% responded that these ecosystems should be conserved. Socio-cultural values related to “provisioning”, “regulation” and “culture” were seen as the main driver for their conservation (53% of cases) followed by words such as “life”, “vital”, and “source of life” as the main reason (36% of cases). Intrinsic or biophysical value was less recognised by participants and it was associated with words such as “biodiversity” and “equilibrium” (16% of cases).

To deepen the interface analysis, data related to the previous experience of participants in the design and implementation of PES schemes were coded in the category of knowledge. Thus, knowing that institutional arrangements of PES are based on the design of the political instrument (Hahn et al., 2015), we classified 94 narratives found in this category as limitations and impacts of the current regulation. Perceptions related to the limitations of the political instrument agree that: i) the studies required by the norm are too simple to characterize all the complex functions that take place in ecological systems; ii) that it matters very little which service valuation methodology is used because an economic study is not sufficient to capture the various valuation languages present; and iii) that the conservation needs in the watersheds are so great that PES through DWC alone cannot fill the gap. With regards to the impacts: i) PES institutional arrangements generate high expectations among the high Andean population to improve their livelihoods but these projects alone cannot satisfy all social demands; and ii) at an ecological level, “the gap of degraded ecosystems (…) is enormous; we are talking about millions of degraded hectares. So, (…) it would not be serious to think that this [PES] could be the only solution” (GO3, video call, 10.09.2020).

5. Discussion

The assessment of the interface between the three descriptive domains addresses our research question. However, to critically analyse the central findings of this research, we must return to focal levels from the water grammar in Fig. 4. By visualising the transformations of the hydrological funds and flows it is possible to identify not only the biophysical processes that generate water services (beneficial or detrimental to human well-being), but also the socially unequal forms of their use. In the case study, the set of water funds and flows exchange shows a surplus of water from ecosystems (focal level e) in terms of historical annual volume, but it is important to note that this multi-scale characterisation does not consider the changes during the dry season when water availability decreases from 183.79 hm^3 to 19.36 hm^3 (Muñoz et al., 2017) and the social demand for water (focal level s) is at high risk of water scarcity both in quantity and quality. This can be viewed as a limitation of the water metabolism approach, however, only one space-time scale, either of the social or ecological system, can be observed and represented in quantitative terms (Giampietro et al., 2014).

On the other hand, although a surplus of water supply can be seen, at the social level, water allocations are part of a negotiation process with the Local Water Administration, which is in charge of granting water use rights. Likewise, the water grammar for the Quillcay sub-basin also shows an appropriation of water flows exclusively for human consumption and for the development of local agriculture. In a basin with this set of relationships, it is difficult to find a considerable number of actors willing to pay or retribute for conserving the ecosystem functions under the market logic, thus, local DWC are the best-suited social actor to implement the MERESE. However, the findings show that perceived institutional and technical bottlenecks in the DWC do not allow these actors to become more involved in water management, i.e. beyond “pipes and cement” to solve water scarcity in the sub-basin. Therefore, the assessment of water as a political asset (focal level i) based on the perception of social actors involved in the PES project allowed us to deepen our understanding of the human values systems and material interest behind water funds and flows exchange in focal level s, which the traditional water metabolism approach does not consider.

The assessment of the infoshed domain shows that the implementation of the norm is far from a straightforward governance process. Perceived bottlenecks, mainly of a social nature such as the delegitimisation of political institutions for water management by the population, do not even come close to debating the economic nature of the PES mechanism and its impact on local systems, as they express a dominant disruptive social relationship. Perceived institutional and political bottlenecks show the precariousness of local actors to conduct processes highly political. Moreover, the power relations between the driving group of the PES express a typical identity of the way water policies are implemented in the country; through technocratic imposition and by reducing social participation in the water management (Damonte & Lynch, 2016; Urteaga, 2010). In the case study, rural stakeholders are perceived as both destroyers and responsible for the conservation of upstream ecosystems, despite the fact that evidence has shown that heavy metal contamination of the water in the Quillcay sub-basin is mainly natural. The exclusion of these actors in the PES decision-making process as well as the dominant perception of the role they play within the water management are promoted by the PES policy itself, as it makes invisible the fact that water scarcity problems do not affect all actors equally. So, conservation initiatives with little participation and involvement of citizens and communities in decision-making generate uncertainty as to the effectiveness of these mechanisms within the uppers Santa basin.

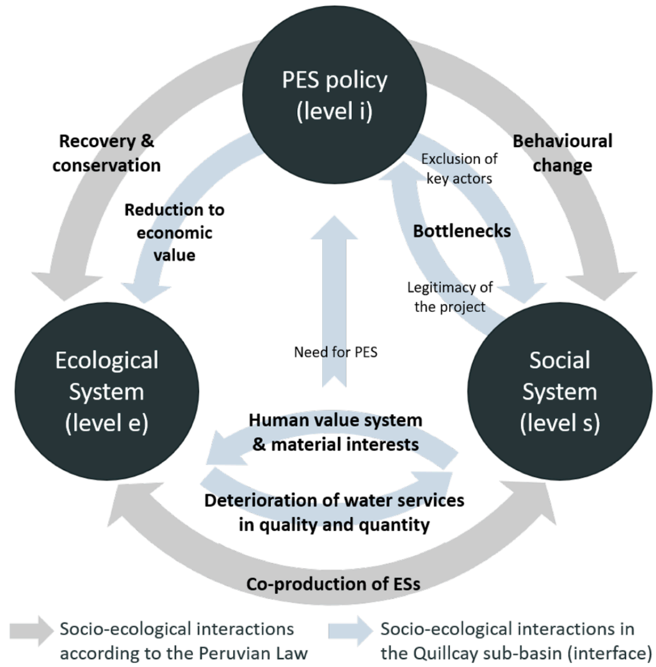

Fig. 8. Synthesis of the interface analysis of the metabolic system (local level) compared with the socio-ecological interactions expected by the Peruvian Law (national level).

While experiences in water PES are recent in the country and results at the ecological level may take years, limitations perceived by social actors about the knowledge gaps in the hydrological functioning of ecosystems also catch our attention. There remains uncertainty on how to evaluate the results of these schemes at the ecological level if there is still high uncertainty in the quantification of water services and the mechanisms that generate them. Technical bottlenecks found in decision-makers suggest the need for specialised studies and standardised protocols for quality control of these studies. However, the norm does not reduce these knowledge gaps because it does not assign resources to local actors to carry out these studies. On the contrary, it promotes the simplification of ecological processes in order to facilitate its implementation, especially in drinking water companies where the norm is mandatory. This finding is in accordance with the statements proposed by Hausknost et al. (2017), who argued that the definition of the ecosystem service within the design of PES projects clashes with different interests, worldviews and power constellations. Likewise, at the social level, there is still an important information gap that is not being properly collected and analysed. The multi-stakeholder assessment carried out in this research showed why it is important to know every point of view, since, as we have argued, these are inherently biased. Therefore, using and adapting the water metabolism approach in the way we did it is possible to identify social key drivers shaping these interactions in other study regions.

All these socio-ecological dynamics in the upper Santa basin have been the main driving force behind the water PES project. Fig. 8 summarises the findings in the interface level of our metabolic system, its effects on the PES project and vice versa (light blue arrows), in contrast to the main narratives found behind the Peruvian PES policy (lead arrows). Furthermore, it highlights the differences between the expectations generated by the implementation of a PES under Peruvian Law and the socio-political dynamics faced by this instrument when it is to be implemented at the local level. Therefore, at the interface between levels e, s and i, PES institutional interventions also regulate water-human interactions.

On the other hand, our work has identified many aspects within the PES schemes that have been left out of this work due to the characteristics of our case study, and that we suggest to be addressed in future research that considers social-ecological approaches, such as the evaluation of the impacts of water PES on socio-ecological systems after its implementation. The monitoring of the interventions implemented through this policy instrument is established by Law but only at ecological level. ESs as a policy-frame notion (Kull et al., 2015) was the main basis of this research as it frames society-environment relationships. Thus, monitoring and follow-up studies of actions as set out in the norm cannot be conclusive about the other impacts that PES may have. This is especially valid for water-human assessment in Andean societies where water has multiple valuation languages far from economic value (Boelens, 2014), such as societies directly influenced by glaciers where these ecosystems are not only a source of subsistence for their livelihoods, but also form part of their cultural and religious identity (Gagné et al., 2014). All these complex relationships are usually ignored in traditional approaches to water policy assessment (Drenkhan et al., 2015; Lynch, 2012). Although the results of this research could not go deeper into the way different rural actors may get affected, we show with this research that water-human interactions affect and are affected by the introduction of a water policy even from its implementation.

6. Conclusions

With this research we emphasise the importance of assessing a coupled human-water system including all social and ecological dimensions of water. The results show that these interactions in the upper Santa river basin affect and are affected by the introduction of a PES even from the design of this policy instrument. In the ecological dimension, glacial retreat, hydroclimatic factors, as well as increasing degradation of water bodies, are the main drivers of these water governance structures. However, the current design of a PES for drinking water companies has limitations that promote the simplification of complex ecological processes to facilitate its implementation. In the social dimension, power relations between local PES stakeholders, their interactions, and perceptions are affecting decision-making processes in the local water governance. Likewise, one of the main bottlenecks to a successful implementation of PES in the upper Santa River basin stems from institutional and political issues, including a lack of continuity of those involved in the decision-making processes, as well as the exclusion of core stakeholders groups from the decision-making process itself. The latter plays a critical role in the institutionalization of the Peruvian PES policy because it allows us to understand that local socio-political processes have their own functioning logic and the implementation of this policy under a traditional top-down and vertical water governance structure does not guarantee results in which all participating actors benefit equally.

Literature available and cited above on Peruvian and other South American countries' experiences in implementing PES arrangements generated through DWCs indicates that these are the most successful mechanisms in the MERESE framework, as the sustainability of conservation funds is guaranteed through water service tariffs. Yet, water management responsibilities promoted by PES policy are unfair, moreover, force local actors to implement these projects without adequate resources and tools. The research findings show a different perception of the roles of upstream and downstream stakeholders in the conservation of water sources. The key question remains how to find a balance between the ecosystem conservation needs and socio-ecological justice, i.e. rural stakeholders as both destroyers and conservationists. The current design of this takes-like PES raises the need to recognise the multidimensional nature of water in the design and implementation of this water policy, and the importance of identifying processes and barriers which affect the success of these policies without making invisible the direct effect they also have on social-ecological systems.

With this research, we want to awaken in the readers a critical analysis of the way in which water PES are being implemented by the water drinking companies in territories with highly disruptive social processes such as the Santa river basin in Peru, and open the debate that water issues are fundamentally social and political, and that the challenge remains at the level of governance structures such as PES schemes where the art is trying to understand and balance different social values, interests, and power relationships, not just the changes in water quantity and quality.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Co-author currently affiliated with one of the institutions with which data was collected for this research-M.C.H. We declare that this co-author was not part of the group of actors interviewed for this research in compliance with the fundamental ethical principles of scientific research.

Data availability

Data will be made available on request.

Acknowledgments

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