




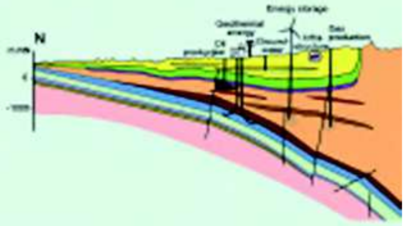

Advances in Groundwater Governance

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Chapter 3

Understanding groundwater governance through a social ecological system framework – relevance and limits

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ABSTRACT

This chapter looks at how groundwater governance can be framed and analysed from a social ecological system perspective, which considers the importance of balancing ecosystem flows, health and functions with socioeconomic well-being in an equitable manner, while taking into account issues of power and political economy at different scales. Under this analytical frame, groundwater systems are perceived as having inherent properties like resilience, non-linear feedbacks, redundancy, diversity and modularity composed by human, biophysical and ecological variables and components, which are interdependent on each other. The chapter outlines this approach, its main components as well its main challenges and opportunities to help better understand groundwater governance.

3.1 INTRODUCTION

This chapter deals with the rationale and governance consequences of understanding groundwater governance through a social ecological system framework (SES hereafter). This approach is sometimes neglected in the literature dealing with groundwater governance. The aim of this chapter is to stress the main interests and limitations of such an analytical framework to deal with groundwater governance issues.

One of the main challenges to which groundwater governance is confronted with is how to balance ecosystem health with socioeconomic goals in an equitable manner. Since no panaceas exist to solve these challenges (Ostrom, 2007), an integrative systems approach that tackles the interactions of human and natural variables in each scale and context can be useful to find the most appropriate governance process to achieve sustainable outcomes for context specific situations and scales (Barreteau *et al.*, 2016).

Social ecological systems[1] (SES) are interdependent systems of people and nature, where humans must be seen as a part of, and not apart from, nature (Berkes *et al.*,

[1]Some authors use the terms 'socio ecological systems', 'socio-ecosystems' or 'coupled human-environment systems'.

2003). SES are complex systems with inherent properties like resilience, non-linear feedbacks, redundancy, diversity and modularity (Levin *et al.*, 2012), composed by human, and biophysical variables interdependent on each other. Systems' thinking is a way to picture the complexity of ecosystems and societies, understanding how systems can respond to external disturbances, as well as internal changes – a systems perspective in which all variables are interconnected. Problems do not emerge isolated and there are different scales at which challenges need to be tackled. An advantage of making use of SES conceptual approaches is that they incorporate into their analytical frame polycentric and/or multi-scalar approaches, although with a heavy emphasis on the local scale. It provides the framework to relate the human and the ecological or biophysical variables that each system contains, acknowledging the different scales that governance entails and what key variables and components influence the sustainable or unsustainable outcomes of the governance system. Adopting a social ecological system framework can provide useful tools to analyse groundwater governance, acknowledging the potential vulnerability of this SES and stressing the need for adaptability, robustness and resilience of the institutional arrangements designed to govern groundwater resources.

The chapter outlines the development and main components of a SES framework, as well as its main limitations, especially when considering groundwater dependent systems. Section 3.2 presents a number of related but slightly different approaches closely linked to the SES framework, namely the key elements in groundwater governance, a Common Pool Resource (CPR) collective action approach, the co-evolutionary development model of (informal) groundwater economies, the role of power relationships and finally an ecosystems and resilience approach. The third section then goes into details on the key defining components for a SES analytical framework (namely social, economic and political settings, actors, resource units and systems and governance systems), as well as the key performance criteria for a robust SES. The fourth section then critically analyses how the SES framework could be combined with other approaches that could overcome some of its analytical shortcomings. The final section concludes on the main added value of using a SES framework to analyse groundwater governance, as well as on its limitations.

3.2 GOVERNING GROUNDWATER RESOURCES: EMPIRICAL CHALLENGES AND THEORETICAL APPROACHES

Groundwater is not merely water stored underground. Groundwater bodies or aquifers are biophysical systems with particular flow dynamics, which can be connected to a river basin or to other ecosystems such as wetlands, where use is subjected to social, political and economic drivers. However, while groundwater intensive use is on the rise globally, groundwater governance is often lagging behind. Generally speaking, groundwater governance *comprises the enabling framework and guiding principles for collective management of groundwater for sustainability, equity and efficiency* (Groundwater Governance project, 2016a: 7). According to Ross (2016: 146), *Groundwater governance is defined as the system of formal and informal rules, rule-making systems and actor networks at all levels of society that are set up to*

Table 3.1 Lessons learned from case studies across key governance elements.

Governance Elements	*Lessons Learned*
Institutional Setting	Governing is often a thankless task, yet it requires popularity Legislation does not always translate into implementation Conflict resolution is central to groundwater governance Sufficient funding is of the utmost significance for governance
Availability and Access to Information and Science	Natural systems, social systems, and institutions all have been understudied and would benefit greatly from additional research Trust is a necessary element for all research Urbanized landscapes are critical components of groundwater governance
Robustness of Civil Society	Equity is an essential ingredient of groundwater governance Community-based governance requires deliberate, purposeful intention Leaders can unite stakeholders
Economic and Regulatory Frameworks	Economic incentives can be effective, but may sometimes yield unintended, even opposite results "Indirect" management approaches may be suitable in certain settings, but they should be used cautiously The effectiveness economic incentives as use-control mechanisms depends greatly on the system employed

[Source:Varady *et al.*, 2016: 16]

steer societies towards the control, protection and socially acceptable utilization of groundwater resources and aquifer systems.

In addition to these definitions, a recent analysis of ten case studies of groundwater governance across the globe (Varady *et al.*, 2016) stressed the importance of four cross-cutting governance issues (see Table 3.1). These four elements are: (1) the institutional settings; (2) availability of and access to information and scientific knowledge; (3) civil society and its robustness; and (4) the economic and regulatory frameworks. Despite acknowledging that contextual factors are crucial to determine and shape groundwater governance processes and path dependencies, these authors argue that all groundwater governance approaches will entail the four mentioned elements.

These governance elements put particular emphasis on the regulatory framework and institutional settings for groundwater management, as well as on the collective action processes driven by groundwater users and civil society at large.

The above-mentioned elements are central, but the literature on groundwater governance has also been enriched over the past decades thanks to the work on three distinct approaches (Faysse and Petit, 2012), and a fourth emergent one: i) the study of groundwater governance as collective action initiated by E. Ostrom (1990), ii) the analysis made by T. Shah (2009) on informal groundwater economies and iii) the work of A. Prakash (2005), A. Mukherji (2006) and T. Birkenholtz (2009) drawing on political ecology, and finally iv) an ecosystem services and resilience approach which has recently come to the fore (CGIAR, 2015; Knüppe and Pahl-Wostl, 2011; Knüppe *et al.*, 2015; Custodio *et al.*, 2016).

The first approach considers groundwater resources as common pool resources (CPRs) subject to overexploitation when rules for managing these resources are not

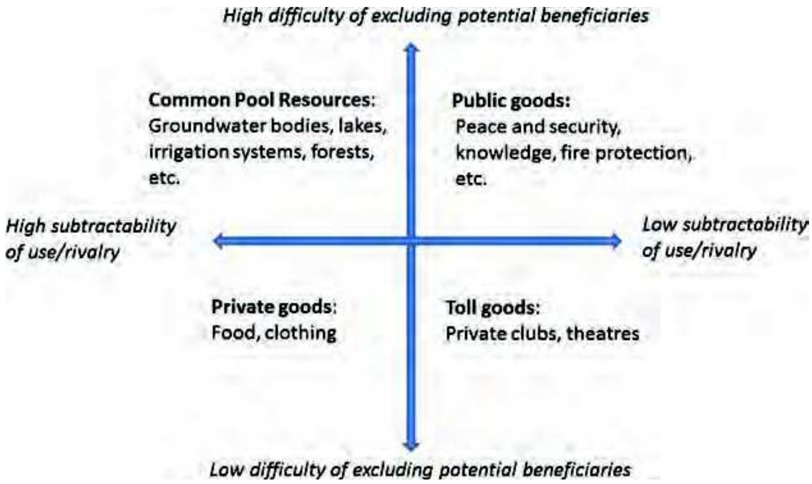

Figure 3.1 Type of goods. Modified from Ostrom (2005).

established and enforced (Ostrom, 1990). Common pool resources are defined by their high subtractability and low excludability. Subtractability by one user limits availability to others[2], and given the nature of CPRs, it remains difficult to exclude potential users from the access to the resource (see Figure 3.1).

Institutional analysts argue that in the case of groundwater governance the emergence of collective action can offer a realistic management model for this particular type of resource, and thus avoid the tragedy of the commons (Blomquist, 1992). The Groundwater Governance project (2016b) also highlights the need to support and recognize groundwater stakeholders' organizations. The nature of groundwater as a CPR therefore poses critical and specific governance challenges. These challenges draw from the ease of access and difficulty in excluding users (or closing the resource to new users), and the fact that the appropriation by one user will affect other users. Good examples are the difficulties that regulators face to quantify groundwater use or enforce regulation compliance (De Stefano and López-Gunn, 2012), and the effect that the intensive use of one pumper can have over the groundwater table of another pumper's well, not realizing about this externality (Shah, 1993). In addition, important inherent resource qualities (low upstart costs, on site availability, resilience to droughts, etc.), combined with increased uncertainty due to climate variability and change, make groundwater an attractive resource.

This attribute of groundwater as a CPR has implications on its use, management, and governance. Decisions triggered by self-interest increase the resource consumption, regardless of the social and environmental consequences unwanted by the group as a whole. When cooperation does not take place, we say we face a 'CPR social

[2]Moreover, one important governance challenge is the slow response of aquifer to external impacts as a result of which users/managers tend to ignore the impact of subtractability that will not become apparent at least in a few years' scale.

dilemma'. However, it has been shown that users can cooperate for the governance of the resources and thus avoid such a social dilemma (Ostrom 1990). Users can self-organize and regulate to share the resource, taking initiative on collective action. This alternative is based on cooperation and self-regulation by users, cooperating as well with regulatory agencies if they exist, as in the Spanish case (López-Gunn, 2003; López-Gunn and Martinez Cortina, 2006; Rica *et al.*, 2014). It is based on different activities, such as negotiating that abstractions are done according to shared priorities and are consistent with groundwater availability, especially when the operation is adversely affecting groundwater levels, river flows, groundwater-dependent wetlands or water quality, as it is increasingly frequently found in coastal areas.

The second approach by contrast, looks at the co-evolution of governance models associated with informal groundwater economies and links to the resource type base (type of aquifer). The analysis of groundwater governance developed by T. Shah (2009) starts from groundwater use at farm level. He then looks at the economic impacts created by the agricultural groundwater use at regional level and studies the co-evolution of groundwater resources levels with the development of groundwater economies. Shah's main focus is on groundwater economies in South Asia, where a variety of trajectories can be identified – the key element explaining these various trajectories is the aquifer types (hard rock aquifers, versus alluvial aquifers for instance).

According to Shah, the informal use of groundwater resources by thousands of individual farmers makes it difficult to control and limit groundwater use (through public or through community-level initiatives). Thus, groundwater governance is mainly limited to pragmatic solutions depending on the type of aquifers. For instance, groundwater governance can focus on the improvement in water availability (*i.e.*, groundwater recharge programs in hard rock aquifers) or on indirect demand management measures like *e.g.* energy pumping costs, to act on groundwater use in alluvial aquifers. In this context, T. Shah is very skeptical about the possibilities to adapt the Integrated Water Resources Management (IWRM) toolbox in South Asia, simply because three important pillars of IWRM (water law, policy and administration) are currently lacking.

The third approach stresses the importance of power relationships between the actors dependent on groundwater resources. This approach draws on the works of political ecology to analyse the intensive use of aquifers for irrigation. The diversity of actors, power relationships and constitution of coalitions between actors is analysed. The design of groundwater governance mechanisms is also analysed, in order to understand how these mechanisms are legitimised, implemented and sometimes contested. The inequalities in access to groundwater and the differentiations between farms are then discussed. The analyses performed by the authors belonging to this third approach (Prakash, 2005; Mukherji, 2006; Birkenholtz, 2009) led to a general critique of top-down policies to regulate groundwater access and use, and to developing a plea for the establishment of bottom-up institutions, which could be better able to take into account the lot of the poorest and marginalized farmers.

The fourth approach is looking at groundwater from an ecosystem services and human well-being perspective. Here the emphasis lies on the functions provided by groundwater systems, the associated ecosystem services and the resilience of groundwater systems to continue to provide these services when faced with *e.g.* intense use or even groundwater mining (Knüppe and Pahl-Wostl, 2011; CGIAR, 2015; Knüppe *et al.*, 2015; Custodio *et al.*, 2016).

Table 3.2 Four approaches to groundwater governance.

Approach and Key authors	*Main features*
CPR/collective action (Ostrom; Bloomington School)	Groundwater as a Common pool resource (subtractability and non-exclusion); self-governing rules to avoid social dilemmas;
Evolution of (Informal) groundwater economies (Shah)	Co-evolution of governance modes and aquifer characteristics; role of informal institutions vis-à-vis formal institutions
The Political ecology of groundwater (Mukherji)	Importance of political ecology- power relationships as determinant factors, equity/inequity of access and use
An Ecosystem services and resilience approach to groundwater systems (Knüppe)	Emphasis on ecosystem functions and services, system approach to groundwater systems resilience, human well-being and groundwater dependent ecosystems

Interestingly, even if the epistemological foundations of the various approaches presented here are rather different, Faysse and Petit (2012: 113) argue, concerning the first three approaches, that *studying the resilience of a groundwater territory, defined as a social ecological system, and assessing the adaptive nature of the governance processes implemented, is one of the issues that would probably benefit from a cross-reading of the authors studied here*. Frameworks to analyze groundwater governance can be enriched integrating different Social Ecological Systems related approaches. Table 3.2 summarises the main features of these four approaches.

3.3 GROUNDWATER GOVERNANCE THROUGH A SOCIAL ECOLOGICAL LENS

Even if the four theoretical approaches presented in the previous section have methodological frameworks globally compatible with Social Ecological Systems (SES), the mostly used – though not perfect – frame of analysis can be found in the adaptation of the Institutional Analysis and Development (IAD) framework developed since the mid-1980's by the Bloomington school (Kiser and Ostrom, 1982; Oakerson, 1992), which has experienced interesting complements when E. Ostrom started to work with several leading figures of the resilience alliance[3] (McGinnis and Ostrom, 2014).

In this perspective, SES can be understood as complex adaptive systems, in which the components, and the structure of interactions between them, adapt over time to internal and external disturbances (Anderies *et al.*, 2004). When analysing SES, certain key components can be identified (see Figure 3.2): actors related to the resource, the governance systems, and resource systems and units. This approach acknowledges the role of the social, economic and political settings, as well as the related ecosystems attributes. All these variables influence the "action situation", where actors interact with each other and jointly influence outcomes that are differentially valued by those actors (McGinnis and Ostrom, 2014).

[3]https://www.resalliance.org/

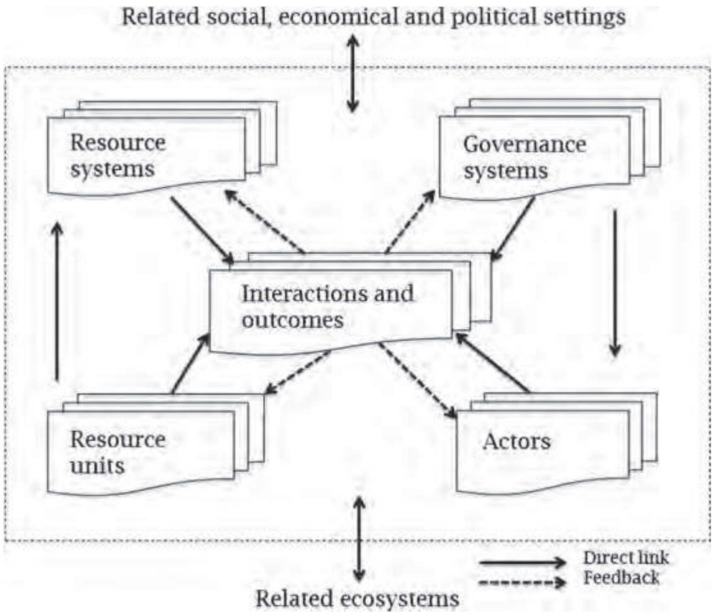

Figure 3.2 SES framework, with multiple components and interactions at different scales. Source: McGinnis and Ostrom (2014).

Though SES approaches are not a panacea for groundwater governance, some authors have claimed that the SES conceptual paradigm can provide a powerful analytical framework for the governance of natural resources (Ostrom, 2007). According to McGinnis and Ostrom (2014), "*A framework provides the basic vocabulary of concepts and terms that may be used to construct the kinds of causal explanations expected of a theory. Frameworks organize diagnostic, descriptive, and prescriptive inquiry. A theory posits specific causal relationships among core variables. In contrast, a model constitutes a more detailed manifestation of a general theoretical explanation in terms of the functional relationships among independent and dependent variables important in a particular setting. Just as different models can be used to represent different aspects of a given theory, different theoretical explanations can be built upon the foundation of a common conceptual framework*". The SES framework has helped facilitate: (1) increased recognition of the dependence of humans on ecosystems; (2) improved collaboration across disciplines, and between science and society; (3) increased methodological pluralism leading to improved systems understanding; and (4) major policy frameworks that now incorporate social-ecological interactions (Fischer *et al.*, 2015).

3.3.1 Main components of the SES framework: settings, actors, governance systems and resource systems and units

The SES framework promoted by the Bloomington school provides a multi-tiered set of variables, with the option to play and combine different subcomponents of each system component, to take into account different scales (See Figure 3.2). Thus there are different variables that can influence an outcome. Although we already stated that there are different frameworks, the SES framework developed by Ostrom is one of the most commonly applied, and its holistic, integrated and multidisciplinary character offers lessons worth taking into account.

Using a SES approach to groundwater governance can be useful to acknowledge the complexity of the interactions between groundwater use and society. Different factors, internal and external to the system and the set of direct actors, are influencing the way groundwater is used and managed, and the decisions taken at various scales. We can frame groundwater dependent systems or territories as SES to better understand their intrinsic complexity and allow adaptive governance processes. The following sub-sections explain these different main components of the SES analytical framework.

3.3.1.1 Social, economic and political settings

This important set of variables may operate at larger scales or levels and involve other actors outside the 'groundwater territory'. Variables include issues related to economic development and economic sectors, demographic dynamics, political trends and stability, governance and governmental frameworks, policies and compliance, such as land use and agriculture trends and policies, infrastructure and technological development, market influence, media interest on social or environmental issues. These variables may apply at the local, regional, national or even at international levels.

3.3.1.2 Actors

Resource users must decide whether it is worthwhile engaging in a collective process to address the problems they are confronted with, given the associated transaction costs (López-Gunn and Martínez-Cortina, 2006) and when incentives of engagement can take a long time. The same users can decide to self-organize in order to share the resource, taking the initiative of the collective action and collectively crafting rules concerning resource use. On the other hand, authorities like *e.g.* central government or development agencies can incentivize the creation of user associations, like the Spanish case where certain Groundwater User Associations were created top down as a measure to avoid intensive groundwater use. However, evidence on the slow and rare emergence of Groundwater User Associations in Spain highlights that these "top-down" measures did not have the expected success, and conflictive issues such as water rights regulation were not solved (Rica *et al*., 2012). Hence, top-down approaches are not guaranteed to succeed in the long run, as observed in the case of Andhra Pradesh Community Groundwater Management (AP CGM) initiated by World Bank, FAO and other partners. While AP CGM was successful in mobilizing the local community and creating institutional mechanisms to govern groundwater resources in a democratic manner, a recent visit by one of the authors found that external drivers such as drought and increasing water demand had resulted in relatively less active groundwater management communities than anticipated.

Traditionally, in the IAD framework, the main actors of the SES are the resource users (McGinnis and Ostrom, 2014) – for instance farmers irrigating their land with

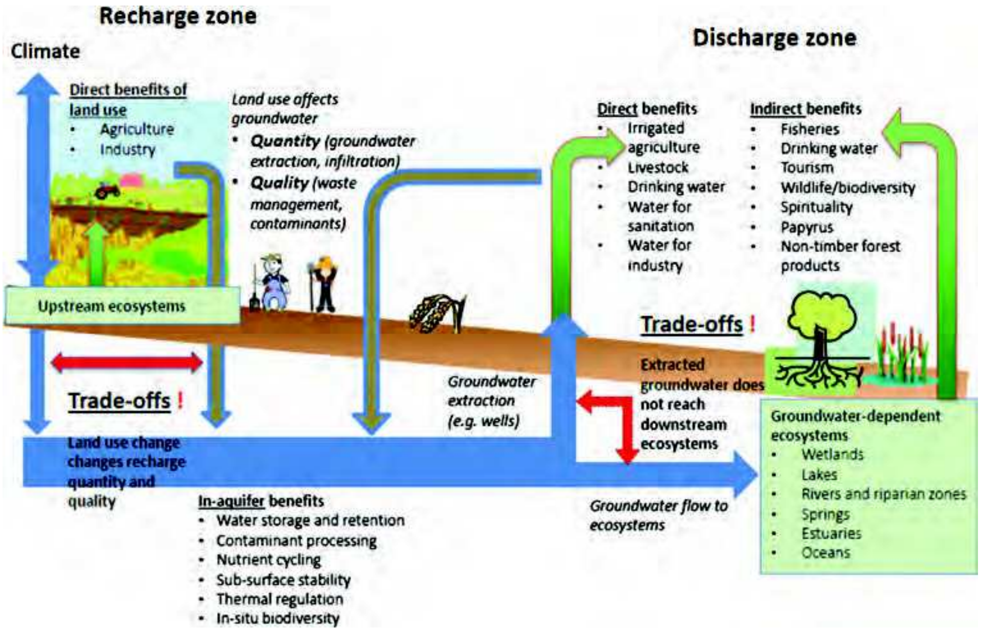

Figure 3.3 Groundwater flows, benefits and tradeoffs (Source: CGIAR, 2015).

groundwater. However, other actors (State representatives from various ministries, local level administrative staff, environmental NGO's, etc.) have to be taken into account. Attention should be paid to the socioeconomic attributes of these actors, their social capital, gender, resource dependency, past experience, leadership patterns and access to technology.

3.3.1.3 Resource systems: their units and related ecosystems

It is common to find these two components of the framework separated. However, due to the need to highlight ecological connectivity, flows and ecological health, we are considering both as a whole. These components comprise variables regarding the biophysical nature of the resource providing ecosystem services, and the dynamics of this process (Figure 3.2). Such variables would include the clarity of the system boundaries, the size of the resource system, the type of human-constructed facilities, system productivity, predictability of system dynamics, storage, type of replacement rate, economic value, spatial and temporal distribution, etc. In the case of groundwater, it is important to track information regarding recharge and discharge flow rates so that impact of an action could be predicted both in space and time.

Hydrogeology and aquifer profiles can determine the governance settings, as observed in the cases of alluvial and hard rock aquifers in India (Shah, 2009). Groundwater-surface water interaction, recharge rates, vulnerability to pollution, groundwater dependent ecosystems, will generate a different governance response for each specific context (Figure 3.3). Aquifers can be embedded in larger social ecological systems, such as river basins, and processes at others scales may affect -or be affected by- the governance arrangements at the aquifer level.

Moreover, the degree of mobility and storage can affect institutional strategies adopted to use and manage the resource (Schlager *et al.*, 1994), as well as the nature of the aquifer itself. This can be seen in India in alluvial aquifers where there is more storage capacity than in hard rock aquifers, and yet users do not perceive the common good and groundwater levels are decreasing with no response from users. On the other hand, in hard rock aquifers there have been some initiatives by certain groundwater user communities in ways that make the groundwater economy sustainable in the long run by mitigating water scarcity (Shah, 2012).

3.3.1.4 Governance systems

As already stressed in the previous sections, groundwater governance comprises four essential components: a conducive legal framework; accurate and widely-shared knowledge of groundwater systems together with awareness; an institutional framework characterized by representation and leadership, sound organizations and capacity, stakeholder engagement and participation, and working mechanisms to coordinate between groundwater and other sectors; and policies, incentive structures and plans aligned with society's goals.

An approach to governance from a SES perspective would need to, at least, determine a) governmental and non-governmental organizations, b) actors' network structure and information sharing, c) property rights systems and bundle of rights, d) different set of rules: operational-choice, collective-choice, constitutional-choice and e) monitoring and sanctioning rules. We will see later how this governance approach can be enriched.

Box 3.1: Polycentric governance and groundwater resources

Groundwater governance can, to a certain extent, be considered polycentric. A political order is polycentric, according to McGinnis (1999:2) "*when there exist many overlapping arenas (or centers) of authority and responsibility. These arenas exist at all scales, from local community groups to national governments to the informal arrangements at the global level*". In the context of groundwater resources, there are different actors at different levels taking decisions on the use of the resource, and where applicable, there are also water authorities with stakes on the resource regulation. Polycentric governance systems for groundwater resources already exist and have been studied in the US in States like California (Blomquist, 1992), Texas and Arizona (Sugg, 2016). In a multi-level governance system, local levels may benefit on the one hand from financial or technical resources only available at supra-local levels, and on the other hand from their own capacity to access and manage the common resource with their local knowledge. In addition, these systems may be more efficient to solve problems related to non-cooperators or local inequities. In this kind of systems it is important that "bridging organizations" mediate between different actors such as users and water authorities.

Thus, to summarise, when using a SES approach, it is central to look at the dependencies and relations between social and biophysical elements. Interactions among system subcomponents will determine what is called "action situations" in the SES framework. Proposed interactions and outcomes, not limited to the SES framework, are the harvesting of water and other metabolic relations, information sharing through different methods by actors, conflicts among actors, investment on the resource, networking and lobbying capacity, rulemaking at different levels, monitoring and control activities, co-management performance, processes of evaluation of the resource situation and of the effects of management initiatives, evolution of access to the resource by different users, but also power dynamics and the effects and responses to market mechanisms.

All these elements are important factors which need to be taken into account when looking at groundwater governance through a SES lens. However, if taken separately, they do not necessarily inform us as much as system dynamics. This is the reason why several key criteria must also be identified to shape groundwater governance through a SES lens.

3.3.2 Selecting criteria to shape groundwater governance outcomes through SES lens

The purpose of using a SES approach is not merely to picture and frame the interactions between groundwater and society, but rather to assess and stimulate the adaptive capacity of the governance process. The diagnosis approach must not be a panacea, but rather based on societal and environmental objectives tailor made for different governance contextual settings, taking into account possible trade-offs between levels, and including linkages out of the water box.

For any diagnosis we need a criterion, to use as a guide for the evaluation of the outcomes of a process. Following the SES framework ontology, this subset of criteria may coincide with (good) groundwater governance principles or indicators (Lautze *et al.*, 2011; Groundwater governance project, 2016b). Delgado-Serrano and Ramos (2015) defined certain outcomes for SES governance: efficiency, socio-economic sustainability, equity, accountability, effects of deliberation processes, empowerment and adaptation strategies. When evaluating the governance of SES, the main desired outcome is resilience, as well as allowing adaptive capacity for the system to be resilient. However, despite the integrative view of the SES approach, and in particular when looking at resilience, it is difficult to the social and the ecosystem or resource subunits to be seen as one undifferentiated system. It may also be important to consider resilience as a neutral outcome, as there can be systems in undesired states, and resilience of these systems would only perpetuate a negative impact (Petit *et al.*, 2017).

The resilience of the social subunit of the system may not go hand in hand with the resilience of the ecosystem subunit, or the system as a whole. It may in fact be contradictory with the definition of SES, but it seems that at certain scales it happens that the equilibrium among subunits is not stable (Rica *et al.*, 2014). There may be a moment when the ecological subunit cannot stand the disturbance but the social subunit draws upon external resources in order to keep resilient. In other words, the "social subunit" breaks the dependency interaction with the groundwater resource, and it would mean a sequential destruction of natural resources (Anderies *et al.*, 2004).

This is another way to explain socioeconomic development or growth at the expenses of groundwater over-abstraction and resource system transformation (López-Gunn *et al.*, 2012).

Box 3.2: Resilience, adaptability, transformability – what are we talking about?

First introduced in the field of ecology by Holling in 1973, nowadays resilience stands as a central interdisciplinary concept which is being used in several research fields besides ecology such as psychology, economics, or sociology. It summarizes the magnitude of disturbance that can be tolerated before a system moves into a different state and a different set of controls (Holling and Meffe, 1996). It has also been called robustness with a similar meaning, "A SES is robust if it prevents the ecological systems upon which it relies from moving into a new domain of attraction that cannot support a human population, or that will induce a transition that causes long-term human suffering" (Anderies *et al.*, 2004). Carpenter *et al.* (2001) highlight three properties for resilience, namely a) the amount of change the system can undergo; b) the degree to which the system is capable of self-organization; c) and the degree to which the system is able to learn and adapt.

"Adaptability" refers to the ability of an SES of learning, combining experience and knowledge to adjust to changing factors, and further develop within a domain of stability (Berkes *et al.*, 2003). Some authors have defined adaptability as "the ability of the actors in the system to influence resilience" (Walker *et al.*, 2006), concept linked to robustness. The "transformability" on the other hand, refers to the ability of the system to transform their internal or external components to create another social ecological system, where ecological, economic or social structures make the existing system non-viable (Folke *et al.*, 2002).

3.4 MAIN CHALLENGES OF A SOCIAL ECOLOGICAL SYSTEMS FRAMEWORK FOR GROUNDWATER GOVERNANCE

The SES framework adapted to groundwater governance comes up against a number of challenges which need to be taken into account in order to better understand the many different aspects of groundwater governance. These challenges and limitations can be complemented by mobilizing the different approaches of groundwater governance presented in the second section.

First, groundwater governance is only rarely a matter of local institutions alone. Various scales and institutional levels are mobilized to understand the relationships between actors, sectors and issues. For instance, focusing only on groundwater resources users can be useful to understand the collective action mechanisms implemented by the end users to share groundwater resources according to the rules they have themselves implemented. However, groundwater access also depends generally on property rights and economic incentives established at the national level and the (often ambiguous) role of the State must be taken into account to study groundwater governance mechanisms (Wester *et al.*, 2011; Fofack *et al.*, 2015; Molle and Closas, 2017). Thus, authorities at different levels can be active participants in collective action processes. Then, we could be talking of co-management, when formal -or informal- responsibilities are shared among different actors (Rica *et al.*, 2012; Molle and Closas 2017).

Groundwater governance is often a question of multi-level governance analysis, which refers to the dispersion of authority away from central government. Decisions are not made at a single level, either only at the top (highest level of government enforcing decisions), or the intermediate (state or provinces enforcing decisions beneficial for their regions), or the individual level (Pahl-Wostl, 2009). The coordination between the various stakeholders in charge of governing groundwater resources is however often difficult. This idea is known as the "problem of interplay" (Young, 2002). According to Theesfeld (2010: 138): *When different authorities need to work together, ambiguity often exists in the definition of their respective central and local responsibilities. Often the central level basically tries to retain control over local decisions while simultaneously reducing expenditures for regional development.*

Second, issues of group heterogeneity may increase governance complexity and therefore need to be well addressed from a social-ecological system perspective. Particularly in larger aquifers, actor's heterogeneity can be high. Eight design principles were identified by Ostrom (1990) as key conditions that lead to optimal resource governance: define clear group boundaries, match rules governing use of common goods to local needs and conditions, ensure that those affected by the rules can participate in modifying the rules, make sure the rule-making rights of community members are respected by outside authorities, develop a system, carried out by community members, for monitoring members' behavior, use graduated sanctions for rule violators, provide accessible, low-cost means for dispute resolution, build responsibility for governing the common resource in nested tiers from the lowest level up to the entire interconnected system. These principles have been tested and replicated in different studies. However, it is unclear whether these would apply to larger-scale environmental governance dilemmas (Fleishmann *et al.*, 2014). These design principles can be useful when analysing or strengthening groundwater governance. However, it is also important to keep in mind that other factors such as system size, or group heterogeneity can increase governance complexity, and in fact can be more determinant than these design principles (Rica *et al.*, 2014). Recent efforts are being made in order to integrate group heterogeneity on the study of larger social ecological systems (Cox, 2014).

Third, power relationships between actors are not properly addressed in most SESs analysis (Fabinyi *et al.*, 2014). It has been shown that power dynamics and the inherent politics of groundwater governance often determine how water is actually accessed and how access to decision making or appropriation of groundwater use is not frequently equal among different actors or social groups (Rica *et al.*, 2014; Kulkarni *et al.*, 2015; Pells, 2015). We need to develop approaches on governance and sustainability that also incorporate power relations in decision making, as considered by political ecology (Mukherji and Shah, 2005; Birkenholtz, 2009).

Fourth, one key issue that is not always addressed in groundwater governance studies is equity (Hoogesteger and Wester, 2015). Access to groundwater and water rights distribution is often conflictive, and less powerful groups or the environment tend to be disadvantaged. Perreault (2014) suggests that equity in water governance must be determined analyzing critically the institutional arrangements of the market, the State and civil society through which water is allocated and accessed. This is where the concepts of social and environmental justice arise, allowing to define a framework to analyse groundwater (in)justice (Hoogesteger and Wester, 2015; Ameur *et al.*, 2017). Some argue that the SES framework does not tackle these questions properly, and it may be better to complement the framework with a political ecology analysis. Political ecology helps to detect problems related to inequities of access embedded at multiple scales and problems related to the exercise of political and economic power (Swyngedouw, 2009). Neal *et al.* (2016) argue why environmental and social justice should be integrated into groundwater governance, including local communities and the environment in the decision-making and allocation process in order to avoid or ameliorate potential social and/or environmental injustices. They provide examples from Northern Australia and Saudi Arabia, highlighting the gap between the meaning of justice and equity for individuals and 'equitable use' in international water law, and the trade-offs between water rights and environmental justice – water rights for some may in effect deny basic human rights to water for others (Mirosa and Harris, 2012). These situations are replicated all around the world, and trigger the discussion on what uses should get priority under different circumstances, and what rationale, from a socio-economic to justice basis, lies behind the decision.

As Fabinyi *et al.* (2015) stress, the contributions of resilience science to societal challenges such as poverty, security or inequity, with intrinsic environmental dimensions, would gain from amplifying the focus towards conflict, contestation, micropower and macrosystems dynamics. Thus, shifting to *political and ethical questions as crucial drivers of social-ecological outcomes rather than 'inconvenient' politics that can be simply sorted out through institutional design* (Côte and Nightingale, 2011:484). This approach would contribute to match the analysis with the criteria of social and environmental justice, and to align governance in this regard.

3.5 CONCLUSION: GROUNDWATER GOVERNANCE FOUNDATIONS THROUGH A SES LENS

This chapter has focused on what a SES lens can bring to the understanding of groundwater governance, adopting a perspective of coupled human and natural systems. It has briefly outlined similar/complementary approaches, as well as the challenges these approaches need to integrate or overcome to frame groundwater governance more effectively.

Under a SES approach a key contribution is that it starts from the acknowledgement that groundwater governance is a complex issue, and thus adopting a complex system approach (like SES) could help to better understand groundwater governance, or complement other approaches. Frameworks that build on social ecological concepts and theories help to structure the complex interactions and feedbacks taking place between different human and biophysical elements, and at different spatial and temporal scales

The chapter though has adopted a critical approach to briefly outline the main lessons learned from previous works dealing with SES theory and groundwater governance, but also to identify the shortcomings of the commonly applied SES approach and frameworks. Thus the chapter has looked at a SES framework to look at groundwater governance from a critical yet constructive perspective that builds on the shortcomings and advantages of the SES framework based on the literature and its evolution and informed by real examples and experience from groundwater in particular.

We reviewed four different approaches, i) the study of groundwater governance as collective action ii) the analysis made by T. Shah (2009) on informal groundwater economies and iii) studies that draw from political ecology, and iv) an ecosystem services and resilience approach. We argue, that far from being alternative approaches, these can complement each other to help us analyze groundwater governance through a Social Ecological lens.

The SES framework became mainstream after the seminal work by Ostrom in the nineties on the role of collective action, followed by many other authors and the Bloomington school. This has enriched our knowledge on the weaknesses and inconsistencies (*i.e.* what we have learnt since the 1990s) which has helped make the SES analytical framework more grounded in reality and thus more usable.

Indeed collective action is not the same as governance. However it is a key element in the process to establish governance rules and structures, particularly for groundwater even if we now know it is always subject to a scale. Through a SES lens we see the key importance of self-organising systems as an emergent property- as a way to understand collective action. In Ostrom's works, collective action is mainly synonymous with self-organising systems. However, economic incentives and command and control mechanisms are also fundamental to understand the dynamics of groundwater governance. Thus, the State (at different levels) can be an active participant in co-management processes. Using frameworks that operationalize the analysis based on SES theories help us tackle issues of scale, which we argue is key to understand groundwater governance processes.

There is an emerging line of argument that defend that political ecology and resilience need to be integrated in the social ecological approach towards groundwater governance. A definition of the criteria used to analyse groundwater governance should be done carefully. This would help to avoid neglecting issues of power imbalances and politics, often inherent to realities of groundwater dependent societies, if the criteria of social and environmental equity are to be met.

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