ground water

Review Paper/

Institutional Challenges for National Groundwater Governance: Policies and Issues

by Insa Theesfeld

Abstract

Understanding the issues surrounding groundwater governance is a precondition for developing policy recommendations for both national and transboundary groundwater governance. This review discusses groundwater attributes relevant to the design of governance systems and provides a systematic review of current national groundwater governance differentiated by various policy instruments. The synthesis of both resource system characteristics and experience with policy instruments allows us to conceptualize institutional aspects of groundwater governance. This leads to six institutional aspects: (1) voluntary compliance; (2) tradition and mental models; (3) administrative responsibility and bureaucratic inertia; (4) conflict resolution mechanisms; (5) political economy; and (6) information deficits. Each of these issues embodies institutional challenges for national and international policy implementation.

Introduction

We can observe extensive water level decline, pollution, and the capture of naturally poor quality groundwater in many regions of the world (Usunoff 2005). Particularly, the problem of groundwater level declines has led to a depletion in storage in both unconfined and confined aquifer systems (Shah 2008). Although groundwater plays an important role for domestic use, its major share is devoted to agricultural activities. India, China, Pakistan, and the United States together account for more than 75% of the total reported groundwater extraction for agriculture (Moench 2004). In contrast for Africa, there is little information on the present and potential role of groundwater in agriculture (Braune and Xu 2009).

Besides hydrogeological and economic attributes, institutional aspects must be considered when analyzing the reasons for inefficient use and depletion of groundwater (Chermak et al. 2005; Usunoff 2005; Puri and Aureli 2005; Solanes and Jouravlev 2006; Fischhendler 2008). As Ostrom (1962) stated nearly 50 years ago, "Few areas. . . offer a richer variety of organizational patterns and institutional arrangements than the water resource arena." Still, at present, little is known about the institutions and policies that govern groundwater use in many different societies (Moench 2004; Mukherji and Shah 2005; Usunoff 2005, 81). This is even more important and challenging when we switch from an aquifer within a single political boundary to transboundary aquifers (Utton 1982; Ganoulis 2006, 362). This paper provides a broader review of institutional constraints than mainstream economic approaches, which typically focus on different access and forms of knowledge of the actors, different discount rates for actors, or different market rules as the institutional factors that make water use model predictions more difficult (Chermak et al. 2005). The goal of this review is to explore the institutional aspects of policy implementation toward sustainable qualitative and quantitative groundwater use by first taking into account the attributes of aquifers and second undertaking a systematic review of well-documented cases of national groundwater policies. As such, this review is inspired by the idea of the nested multitier framework by Ostrom (2007),

Leibniz Institute of Agricultural Development in Central and Eastern Europe (IAMO), Theodor-Lieser-Straße 2, 06120 Halle (Saale), Germany; +49 (0) 345 2928138; fax: +49 (0) 345 2928199; theesfeld@iamo.de

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which considers the attributes of a resource system, the resource units generated by that system, the users, and the governance systems that affect the outcomes. In this context, the resource system might be an irrigation system with a certain amount of water to be extracted, the latter defined as the resource unit. Fischhendler (2008) discusses for instance, for the Israeli case how the fragmentation of the physical and institutional structure results in inadequate governance. This paper explores a way to come to more adequate governance and new institutional insights in policy implementation by a joint consideration of ecological and socio political characteristics. A comprehensive application of such a joint view is done by Shah (2008) for South Asia. That the resource attributes of groundwater are particularly different than those of surface water already hints at specific requirements in governance system design.

The paper begins by defining groundwater as a common-pool resource and presents its characteristics in contrast to surface water. Second, the paper reviews national policies classified by regulatory, economic, or voluntary types, and provides empirical implementation cases. A synthesis of the resource characteristics and experience with the policies leads to specific institutional challenges for groundwater governance: (1) voluntary compliance; (2) tradition and mental models; (3) administrative responsibility and bureaucratic inertia; (4) conflict resolution mechanisms; (5) political economy; and (6) information deficits. Finally, conclusions will be drawn regarding institutional aspects of adequate and effective groundwater governance.

Groundwater Attributes

Groundwater can be classified as a common-pool resource with both subtractability and low excludability. According to Ostrom (1990, 31, 32), subtractability involves the possibility of approaching the upper limit of resource units which can be produced. In the context of groundwater, this means that the water level drops with every unit extracted. Theis (1940) comes to the conclusion that in fact all water discharged by wells is balanced by a loss of water somewhere and that in this respect some groundwater is always mined. Or, regarding it more locally, water pumped and spread on one farmer's field cannot be spread on another farmer's field. In addition, use may involve the degradation of the quality of the water returned to the aquifer (Brentwood and Robar 2004, xii). Low excludability means that it is difficult to exclude water users, in particular, landowners, from pumping water from aquifers. Aquifers are a source of relatively inexpensive, reliable irrigation that can be developed by individuals once either technology or energy is accessible (Schlager 2007). Both characteristics lead to the so-called tragedy of the commons, that is, the environmental degradation that occurs whenever a large number of individuals share a subtractable resource. However, it can be shown that it is actually the "tragedy of open access" that matters (Feeny et al. 1990; Grafton 2000). In regions where depletion of groundwater is in progress, either minimally enforced rules related to withdrawing resource units lead to de facto open access regimes, or unrestricted open access has been the general rule (Giordano and Villholth 2007, 2). Shah (2008) demonstrates this for South Asia.

The frequent failure to distinguish between ineffective common property regimes and no property regime at all is often responsible for pessimism regarding collective action. This conclusion has often led to proposals for institutional change in the management of common-pool resources in the direction of either full private property rights or state control. However, there are many empirically documented cases in which communities have contributed to sustainable resource management by establishing appropriation rules, monitoring the situation of the commons, controlling rule violation, and assigning penalties. For example, Kadekodi (2004) provides an overview of common-pool resource management in India, including examples of successful community action in water resource management. Failure and success in solving commons problems have been widely studied for local surface irrigation systems, among others, in Asia (Ostrom 1992; Wade 1994; Lam 1998). However, the focus of these studies has not been on aquifer management. Indeed, studies of self-governance for whole aquifers are not common, but this is changing rapidly (Schlager 2007; Lopez-Gunn 2009). Yet cases from California show that sustainable groundwater management can also be achieved based on collective action (Blomquist 1992).

Besides subtractability and low excludability, other attributes of groundwater resource systems call for specific governance options. In comparison to international rivers—on which an immense body of literature exists—the characteristics of aquifer systems are rarely discussed. Yet, Schlager (2007, 135), Puri and El Naser (2003, 417), Jarvis (2006, 409), and Moench (2004), to a degree, contrast both system attributes; these are displayed in the following:

- Irreversibility: Groundwater pumping may lead to aquifers suffering irreversible damage in storage capacities and hydraulically connected surface–groundwater systems. Likewise, once an aquifer is seriously contaminated, it may be difficult, costly, or even technically impossible to reverse this contamination.
- Time lag: In rivers, direct human intervention may immediately emerge downstream. In contrast, in aquifers, the effect of pollution or water extraction may become evident, if at all, only after a considerable time lag due to the larger spatial distance between point of intervention and noticeable effect. Impacts from neighboring countries in a transboundary aquifer can take decades before being recognized by the Aquifer States (Puri and Aureli 2005). The aquifer replenishment period is long, if at all, in non-renewable groundwater situations, and the provenance of groundwater generation is often unclear; difficulties with attributing external effects to particular pumpers

or polluters are thus typical. Management and monitoring regimes for aquifers must account for this slow hydraulic response.
- Indivisibility: Hydrological systems are interconnected and no parts can be fenced off and protected from contamination since groundwater dissipates beneath the surface irrespective of boundaries.
- Fuzzy boundaries: Defining the exact hydrogeological boundaries of groundwater resources is extremely challenging. There are uncertainties with recharge areas, flow and discharge characteristics, and the interrelationships with surface water bodies (Moench 2004). Also, it is complicated to specify the stakeholders involved in the system and to set the social boundaries of the aquifer system, as discussed by Blomquist and Schlager (2005) for watersheds. The acceptance of boundaries may also fade, for instance, due to upcoming desires of the society to protect water quality, or natural areas that are related to groundwater (Jarvis 2006).
- Hydrogeological uncertainty: Heterogeneity in use situations and uncertainty in the hydrogeology of aquifers make management and rigid legislative classifications very difficult (Puri 2003; Moench 2004; Puri and Aureli 2005). Knowledge of the interrelationships between human actions and the extent and timescale of groundwater degradation is lacking. The transmission paths by which contaminants enter aquifers are also unknown and the potential health effects, such as arsenic poisoning, are uncertain (Moench 2004, 87).
- Data needs: Reliable groundwater-related data are imperative for making knowledge-based and appropriate decisions (Van der Gun 2007). In most countries, the data available on both groundwater quantity and quality are poor and not homogeneous compared to the data available for surface water (Biswas 1999, 8).
- Structure of abstraction: Information on the average extraction per groundwater device and the number of devices provides important details as regards an appropriate governance system. In contrast to Mexico and the United States, where groundwater extraction occurs through wells with high extraction capacity owned and controlled by a small fraction of the population, in India, Pakistan, China, and Iran there are numerous small-scale groundwater extractions (Moench 2004, 88; Shah 2008). The large number of small-scale users is a major factor of agrarian growth in South-East Asia (Moench 2004). The structure of abstraction has significant implications for decisions about management, for example, in terms of monitoring and controlling (Moench 2004, 88).
- Information asymmetry: Information is always limited and asymmetrically held by the parties of an exchange, here the users and providers of the resource system (North 1991). In particular, between the national or regional level authority, which in most cases is the monitoring agency, and that of polluters or abstractors, information asymmetry about the characteristics of groundwater is common. This must be considered in policy design since the transaction costs for monitoring pollution and abstractions may be prohibitively high. Moreover, knowledge is often used and misused by different stakeholder groups as a tactical resource in the bargaining process over issues, such as the benefits of privatizing water services (Conca 2006, 378).

Policies that Impact on Groundwater Governance

Similar to distinctions made by environmental economists (Stavins 2004), I classify three types of policy instruments: regulatory, economic, and voluntary/advisory.

- Regulatory or command-and-control policy instruments such as ownership and property right assignments and regulations for water use are compulsory.
- Economic policy instruments make use of financial (dis-)incentives such as groundwater pricing, trading water rights or pollution permits, and subsidies and taxes.
- Voluntary/advisory policy instruments are those that motivate voluntary actions or behavioral changes without fiat or direct financial incentives.

These instruments are ideal types and no policy option ever relies purely on one type of instrument (Stone 2002). The aim of these policies is to have an impact on governance structures. Governance structures are the organizational solutions for making rules effective; that is, they are necessary for guaranteeing rights and duties and their implementation when coordinating transactions. Almost every governance structure in the real world is a hybrid form somewhere between the polar cases of hierarchy and market. Various forms and combinations of governance structures are used to coordinate agri-environmental problems (Ménard and Klein 2004), and hybrids have been suggested as a possible way of managing common-pool resources, including complex and dynamic ecosystems such as transboundary water resources (Karkkainen 2005). Collective action, for instance, is a specific hybrid form of governance structure and of particular interest in managing common-pool resources like groundwater (Ostrom 1990). Cooperation in the water sector can even lead to spill over effects and better cooperation on conflictive political issues (Lopez-Gunn 2009).

Empirical evidence shows that it is very difficult to find and facilitate, with the help of policies, suitable combinations of governance structures for ensuring sustainable resource management. Every policy to be implemented encounters certain existing institutions. The diversity of groundwater management forms around the world are illustrated by, for example, Brentwood and Robar (2004), Giordano and Villholth (2007), Shah (2008), and Lopez-Gunn (2009).

Regulatory Groundwater Policies

Assigning disaggregated property rights and duties to groundwater creates incentives or disincentives for managing the resource. The following describes emerging trends in national groundwater legislation and regulatory provisions in the ongoing fight against depletion and pollution. A similar compilation of a variety of legislative approaches was made by Burchi and D'Andrea (2003) and provides many contemporary examples. Mechanisms for national groundwater legislation are often combined with market and voluntary/advisory policies.

Ownership Rights to Water and Land

In general, ownership rights to a physical entity include the following: (1) the right to make use of physical objects; (2) the right to alter them and derive income from them; and (3) the power of management, including that of alienation (Furubotn and Richter 2000, 77). For centuries, the owner of surface land was also the owner of the water under it. In general, this stage of unspecified property rights implies that the landowner can extract water without restriction. Many countries follow this tradition, for example, Spain (Utton 1982; Burchi and Nanni 2003, 228). In contrast, some Islamic schools of thought, such as Sunnism, distinguish between land rights and water rights: the digger of a well—whether on his own land or on unoccupied land—automatically becomes the owner of the well water as soon as digging is completed (Caponera 1992, 70).

Property Rights and Their Assignment

A crucial characteristic of groundwater governance is the difficulty in assigning effective property rights (Dalhuisen et al. 2000). Those involved may attribute value to a physical good because whoever has its rights enjoys certain benefits. However, its value may diminish if these rights are burdened by cost components. Schlager and Ostrom (1992, 250–251) generally divide property rights into access rights, withdrawal rights, management rights, exclusion rights, and alienation rights. These rights may be more or less well-defined, and how they are combined has an impact on the incentives of those involved to govern and manage "their" system (Ostrom 2003). When a system of groundwater rights is introduced, it is usually referred to as the right to abstract and the right of use, or access, and withdrawal rights, according to the Schlager and Ostrom classification. These rights are subject to conditions that determine how each is to be applied, for example, in terms of duration, locations for water abstraction and use, purpose of the use, rates of abstraction, specifications for water works, environmental requirements, fees and costs for possession of the right, records of transactions, loss or reduction of the right, suspension of the right, review of the right, and renewal of the right (Garduno et al. 2002–2006). For example, Iowa restricts the duration of groundwater abstraction permits to less than 10 years when aquifer capacity is uncertain (Burchi 1999; 58).

Statutory Vestment in the Public Domain

There is a trend by governments to control groundwater resources by declaring that they are a public domain (Burchi and Nanni 2003; Burchi and D'Andrea 2003). The resource is then regarded as being held by the state in trust for the public, as done, for instance, in France in 1992, in Italy in 1994, in Portugal in 1994 (Barraqué 2004), in South Africa in 1998, and in Argentina in 1967 (Burchi 1999, 58; Burchi and Nanni 2003, 231). Yet even when the state claims ownership rights to a body of groundwater, individual or collective users may nevertheless hold abstraction and use rights. This declaration turns the former owner into a user who must apply to the state for rights of water abstraction and use. A critical issue here is whether former owners of groundwater are entitled to compensation for such disenfranchisement, which is, according to Burchi and Nanni (2003), very unlikely. Yet there is a risk that the restrictions to a landowner's rights to groundwater are challenged in court and could result in complex judicial disputes (Burchi and Nanni 2003, 228).

Regulations for Use

Besides the critique of Kendy (2003) stating that the restriction of pumping does not save water tables from depletion, rather a decrease in water consumption would do, there is a trend to restrict the traditional landowner's water rights (Shah et al. 2001; Burchi and D'Andrea 2003; Burchi and Nanni 2003). This includes use and quantity limitations, drilling permits and licensing, use licenses, special zones of conservation, and reporting and registering requirements (Utton, 1982). The Sultanate Oman, for instance, is known for a strong and very visible hand of the state in groundwater governance (Shah 2008, 190).

In general, when drilling and well construction are done commercially, they increasingly fall under the scope of regulatory legislation (Burchi and D'Andrea 2003, 208). The water user may be obliged to obtain a permit or authorization before constructing a well or drilling a wellhole. In turn, the permit itself may be subject to conditions governing such factors as maximum depth or maximum abstraction rates. Especially in the case of large-scale, sophisticated facilities requiring external expertise and labor, groundwater legislation may also regulate the licensing of well-drilling contractors or may impose controls over the import of pumps and drilling equipment (Nanni et al. 2002–2006). Where pumping facilities are mostly on a small scale and constructed by the well users themselves, as in South Asia, these regulatory measures are hardly applicable (Shah 2008).

To protect groundwater against pollution, permits can be required either for the act of discharging waste into water or for continuing activities that result in the discharge. The latter is of course the more radical preventive approach (Burchi and D'Andrea 2003, 98). A licensing system for wastewater discharge can also be implemented. This type of legislation follows the "polluter-pays-principle" by which a polluter is charged for the amount of pollution he produces. However, this principle is very difficult to enforce due to the particular attributes of aquifers, for example, the time lag before pollution becomes apparent.

Land surface zoning as a policy instrument can be used for quantity control and quality protection of groundwater resources. For example, water administrators may pass laws creating special control areas where exceptional restrictions apply. Such areas may be resource conservation zones for the control of groundwater abstraction, or resource protection zones in areas where aquifers are highly vulnerable to pollution. Restrictions on crops, pesticides, and fertilizers are common in such areas to prevent them from leaching into the groundwater. Restrictions generally reduce land values and raise the question of a legal right to compensation payments. Laws governing such areas may be purely mandatory or may also be supported by voluntary policies involving education programs or the promotion of codes of good agricultural conduct. In the United States, Canada, and the European Union, zoning is a very common measure, especially for drinking water protection from nonpoint pollution sources such as nitrogen leaching (Burchi and D'Andrea 2003, 140). In contrast, in South Asia, the zoning system is only weakly enforced (Shah et al. 2001, 21).

A rather precautionary regulative measure is aquifer and land use planning. The management of water resources, including their protection from pollution, can be facilitated through long-term groundwater planning in order to ensure informed, forward-looking, and participatory decision-making. Such plans can provide for an integrated assessment of all involved factors. Burchi (1999, 63) describes water-planning systems in France where civil society participates in their formation and adoption and where such plans are legally binding and can only be challenged in the courts.

Conjunctive Use

The conjunctive use of aquifers and surface water resources helps optimize water resources for quantity and cost. Sahuquillo and Lluria (2003) describe two types: alternative conjunctive-use systems, where the targeted yield is obtained in dry years through increased pumping, and comprehensive conjunctive systems, which are related to artificial groundwater recharge and require more complex infrastructure. In order to receive the greatest benefit of a conjunctive-use system, both more advanced modeling of complex water systems and an integration of groundwater use into water resources planning are needed. Besides rules that positively affect the incentives for conjunctive management, strong political will is needed to implement such systems (Sahuquillo and Lluria 2003, 158; Rivera et al. 2005, 371). In India, for example, technical solutions have been developed for channeling monsoon river flows through earthen canals for the irrigation of wet-season crops while simultaneously recharging underlying aquifers (Road and Vidyanagar 2002). Such a practice naturally requires the cooperation of the respective administrative departments.

Economic Groundwater Policies

Economic policies may employ financial incentives and disincentives to change behavior in order to facilitate sustainable resource management. Of course there are many controversial views upon whether, when, and how water should be treated as a market good, including the political infrastructure for treating water as a marketed commodity (Conca 2006). When discussing shifting water to the so-called higher-value uses via market mechanisms, one has to be aware of the fact that in some countries market systems are largely ineffective due to corruption. The impacts of corruption are more extreme in developing countries, although the phenomenon is not limited to low- or middle-income countries (Plummer 2008). Corruption can be found in a range of interactions at all levels and in all aspects of the water sector, but it affects also the allocation between different uses and users. One type of corruption is when public servants abuse their power to extract small bribes, such as a water meter reader who offers to reduce a customer's bill in return for payment (Plummer 2008). Once the market system is distorted, economic policy measures are unlikely to be effective.

Direct and Indirect Groundwater Fees

Levying fees directly for water abstraction is a straightforward economic policy instrument. The fees may vary according to volume, area, location, and source. The crucial factor, however, is the number of clients. The costs of metering, serving, and monitoring millions of scattered small users would be prohibitive—even more so if the users have no incentive to comply (Shah 2008). In addition, administrative bodies in India, Pakistan, or Bangladesh are regarded as ill-equipped, inexperienced, and short of field staff (Shah et al. 2003, 3). However, the supervision of groundwater use has become more enforceable with the development of remote-sensing technologies, which make it possible to map crop distribution and to estimate actual evapotranspiration with high-resolution photographs.

Another solution proposed by Shah et al. (2003) is indirect pricing of groundwater by introducing a flat tariff for energy (electricity or diesel fuel), for example, the provision of a certain number of hours of electricity per day. This avoids logistical difficulties and transaction costs, and also circumvents the risk of strong farmer opposition associated with metering water. However, energy fees in many areas of the world are at present heavily subsidized.

Groundwater Markets

A water market is a set of arrangements that permit water rights (for abstraction and use) to be traded. The ability of water rights owners to exchange, lease, or sell their rights is essential for successful groundwater management (Blomquist 1992). In some water markets, rights can be sold and bought separately from land rights, for instance, in Colorado, Nevada, and Utah. An excellent working example of a groundwater market in Oregon is described by Lieberherr (2008).

Water markets cannot operate without stable, clearly defined, and enforceable water rights. Due to both costs and potential revenues, users can have incentives to trade rights and use water efficiently only if transferable pumping rights are clearly defined and limited (Blomquist 1992). In addition, there must be a requirement that water rights be put to effective and beneficial use (Solanes 1999, 73). Otherwise there is a negative effect on water transactions, water markets, and efficient water allocations. In the western United States, water rights transfers are increasingly considered as a policy alternative for encouraging the optimal use of scarce water resources through private reallocation (Solanes 1999, 76). To prevent overexploitation, control measures must be worked out and enforced to reduce the total volume of water rights over time.

In contrast to the water markets discussed earlier, in informal water markets such as those in South Asia, water sellers produce additional water to sell to others, rather than selling the water they would otherwise use themselves. In India, Pakistan, and Bangladesh, water markets are seen as tools to improve access to the resource pool by those who do not have their own source of irrigation water (Solanes 1999).

Subsidies and Taxes

Since electricity or diesel power is required to pump groundwater to the surface, there is a strong link between groundwater and energy. Instead of direct subsidies for water, farmers often receive electricity subsidies; this results in overuse of both energy and water in groundwater-irrigated agriculture. Annual groundwater withdrawal for agriculture in some of the most overexploited areas in India might be reduced by 12–20 km^3 simply by eliminating electricity subsidies (Mukherji and Shah 2005, 341). Heavy subsidies to the farming sector are also one reason for the collapse of many state electricity boards in India (Biswas 1999, 9). While it is legitimate to subsidize poor farmers to improve their livelihood, measures such as lump-sum payments to poor farmers will have a less detrimental effect on water resources than the allotment of subsidies for groundwater abstraction.

Another form of economic incentive lies in providing subsidies that encourage the use of more efficient irrigation technologies to achieve real water savings. Incentives to reduce agrochemical leaching are needed in order to control pollution from agricultural cultivation. Subsidies for fertilizers and pesticides can be re targeted. A further step might even be the introduction of an environmental tax on fertilizers and pesticides.

Voluntary/Advisory Groundwater Policies

In the following I will concentrate on voluntary policy instruments aimed at user participation in governing natural resources. In addition, participation can also be encouraged by economic instruments such as reduced water tariffs for group members. However, participation can also be enforced from the top down, as in Germany's water and land management associations (Wolff and König 1997).

Encouraging Local Self-Governance

Often the introduction of voluntary policies is associated with the decentralization of decision making. This, however, involves social and political trade-offs that need to be considered. Changed entitlements may imply more security for those who, before decentralization, had no information about their water resource and no voice in allocation issues, and less security for those who could always count on receiving their allocation from the central authority, whether by right, by payoff, or by influence (Kemper et al. 2007, 5).

Stakeholder and community participation is a hybrid governance structure that takes place at various levels. According to Ostrom (1990, 1992), we have to differentiate between appropriation problems (when, where, how, and how much to harvest) and provision problems (maintaining, recovering, or enhancing the productivity of a common-pool resource system). Whereas appropriation problems are local and can be solved by community collective action, the solutions to provision problems also involve regional and national governments (Schlager 2007). Cases in Southern California show how difficult such provision problems are to resolve (Schlager 2007, 147). In Orange County (one of the eight water basin examples studied), centralized governmental control of water is not required. A self-government regime has proven effective in reversing critical depletion of the aquifer and preventing its destruction through overextraction and sea water intrusion (Blomquist 1992).

Self-governance in groundwater management can be successful if it is embedded in other governance systems, that is, if it is coordinated with other organizations and if conditions for adaptability are provided (Lopez-Gunn 2009). In the latter case, water users must be provided with an institutionalized means for modifying watershed programs to meet variable water conditions. This situation is termed a "facilitative political regime" (Ostrom 1990, 137; Blomquist 1992, 335; Schlager 2007, 146). The Orange County, California, example shows how state officials acted as active facilitators of local management (Blomquist 1992; Smith 2004).

Important factors in developing countries are high population densities and multitudes of very small water users. In a successful collective action example in the Santa Clara Valley Water District, south of San Francisco, the total number of farmers is probably less than a thousand, whereas an area of comparable size in Asia would contain 100,000 farmers (Shah et al. 2001, 22). Still, there are successful cases of farmer-initiated water-user associations reported, for example, from India, including rules for collecting water fees and dealing with the community ownership of new wells (Kadekodi 2004, 265). It is a misconception that common-pool resource regimes based on local, self-governing institutions are applicable only to small groups of resource users. Rather, the key is a collective understanding of the scarcity of the resource and effective operational rules, as also shown by the Tampa Bay region in Florida. Here, a cooperative resource management system has evolved, which successfully serves a population of 2.1 million (Rowland 2000).

Institutional Aspects of Groundwater Governance

The preceding section provided a comprehensive review of current policies of national groundwater governance. The following is motivated by the multitier socio-ecological framework presented by Ostrom (2007), which provides us, like a guide, with a systematic classification of ecological and social information needed to understand complex systems of natural resource governance. Likewise, Shah's analysis of South Asia's water sector also draws on the socio-ecological background. Shah (2008, 152) introduces five types of institutional dynamics in relation to various aquifer conditions ranging from "atomistic individualism" to "cooperative gaming," the latter providing some opportunities for collective action. I also elaborate on the institutional aspects of groundwater governance from a socio-ecological view, in particular, from a synthesis of options and experience with national policies and the attributes of the resource and the resource system. From a socio-ecological perspective, this synthesis provides new insights into institutional aspects of groundwater governance. Comparable institutional aspects are raised by Solanes and Jouraviev (2006), who in their analysis of water institutions in Latin American and Caribbean countries highlight incompatibilities with existing institutional arrangements, counteracting macro economic policies, international agreements overriding national laws, a low level of trust in government bodies, imbalanced power of interest groups, preferences of external actors, and the values of ethnic groups.

Groundwater Governance Depends on Voluntary Compliance

Water users sometimes ignore or violate restrictions imposed on them. Therefore, voluntary compliance is a key issue (Pistor 2002; Burchi and Nanni 2003), since monitoring costs and enforcing national legislation may become prohibitively high, due to characteristics of the resource system and the high number of water users. In India, where the number of diesel and electrical pumps increased from 87,000 in 1950 to 12.6 million in 1990 (Burke et al. 1999, 40), groundwater laws would have to be enforced upon millions of farmers operating irrigation pumps throughout a vast countryside. This is almost impossible when voluntary compliance is missing.

Moreover, transferring new modes of governance, successful in other parts of the world, should be approached with caution. Such transferred laws can be enforced in recipient countries only if four premises are fulfilled: First, formal legal systems and organizational forms and institutions must respond to and foster demand. Second, there must be an alignment of formal norms with underlying social norms and beliefs. Third, the laws or institutions in question must provide solutions for actual conflicts and take the various interests behind such conflicts into account (Pistor 2002). Fourth, voluntary compliance implicitly assumes a certain level of common understanding and knowledge about the resource at stake. Otherwise, users will continue to ignore the new governance structures and will seek other solutions to their problems. The primary challenge for groundwater agencies in this regard is in communicating with a wide array of groundwater users to encourage sustainable use of the resource.

Considering California's groundwater management as an example, Blomquist (1992, 302) has shown that compliance with formal rules can be extraordinarily high. This is due to two factors: management programs were generally developed by the water users themselves, and they included some form of monitoring that made the actions of each user known to all fellow users. Each user's compliance thus depends on the compliance of the others. This feature is often discussed in combination with a system of graduated sanctions in which the participants themselves undertake monitoring and sanctioning and where the initial sanctions are surprisingly low (Ostrom 1992, 69). Monitoring can also be a by-product of other existing rules, as observed in rotating irrigation systems.

Groundwater Governance Must Take Tradition and Mental Models into Account

It is said that traditional local practices should not be ignored when new management schemes or technological innovations are implemented. Nevertheless, it happens. A typical example is found in parts of Eritrea, where a traditional system of protecting and allocating well water is established during drought. This system of informal rules is sustainable under historical abstraction regimes but is now threatened by a program of upstream dam construction that will alter the natural recharge regimes (Burke et al. 1999, 48). Another example of ethnic cultural values being a decisive factor for the success of management options is Chile, where the principle of individual water rights allocation has been waived for communities relying on community property (Solanes and Jouravlev 2006, 67).

Voluntary compliance with regulatory provisions is strongly linked with mental models, which when ignored leads to poor groundwater management. Traditions and religion shape these mental models. For instance, the basic principles of Islamic water law are still observed and strictly followed by the local population in Islamic countries (Caponera 1992, 68). In Muslim tradition, water is a public commodity, a gift from God that cannot be owned. Yet, Faruqui et al. (2001) found that Islam allows water providers to recover their costs. Although water itself cannot be sold because it is considered a social good and owned by the community, fees may be charged for the provision of water services. In Iran, for example, private water companies are allowed to charge prices amounting to the average total cost of providing water services. However, they must also provide 25 L of water per capita per day for free, as a "lifeline." Islamic law also sets penalties for those who do harm to others, thus opening the door for legal penalties against water polluters.

Unclear Administrative Responsibility and Bureaucratic Inertia Impede Groundwater Governance

The "problem of fit" occurs if the boundaries of a biophysical system, here an aquifer, do not match the jurisdictional areas of political and administrative structures responsible for managing this resource (Young 2002). In order to achieve the successful implementation of decentralized water resource management, the institutional arrangements have to be clearly defined and reasonably well matched with the aquifer system. Poorly defined boundaries may impair collective decision-making by including actors or communities who are not actually stakeholders in the particular resource system, or excluding others who have a stake (Ostrom 1990); both lead to prohibitively high coordination costs in terms of time and funds. A prominent question is the implication of nonlocal communities being involved, leading to powerful, nonresident players dominating the decision-making process (Blomquist and Schlager 2005). Studies of the implementation of river basin management in Europe, as required by the Water Framework Directive, found that historically deep-rooted structures, such as federal administrative and political systems in Germany, are likely to make basin management more difficult (Moss 2003).

Burke et al. (1999) have extended the problem of fit to social systems by emphasizing that biophysical boundaries and administrative boundaries must be in congruence with social boundaries as well. Since social and cultural variation is often as great as hydrogeologic or climatic variation, this may present an even greater challenge to the development of groundwater management systems. Blomquist and Schlager (2005) continue this discussion by arguing that the selection of boundaries is always a political act and even integrated watershed management has many trade-offs. Likewise, there are no ultimate boundaries. A change in social awareness can always lead to a necessary adaptation (Jarvis 2006).

The "problem of interplay" occurs when resource management requires the interaction of different levels of the political and administrative hierarchy (national, federal, regional, etc.) and/or horizontal interaction across different sectoral units and the related organizations (e.g., spatial planning, agriculture, or water protection) (Young 2002; Moss 2003). 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. In Mexico, for example, a multiplicity of overlapping and even contradictory legal requirements has been described (Biswas 1999, 9). Although aquifer management councils have been established which provide for self-governing and innovative solutions by water users, there is an unclear division of tasks and responsibilities between these councils and other administrative bodies (Wester et al. 1999).

Any administration that needs to implement new formal rules will show some reluctance when substantial changes in procedures are foreseen. This is understood as political and bureaucratic inertia, which is due, among other things, to the high transaction costs faced by civil servants (time, meetings, memos, etc.) in order to become acquainted with new policies and build new procedures for their implementation (Schleyer et al. 2006). In Eastern India, in Bangladesh, and in West Africa (Sonou 1997), for example, the governments' goal is still to bring about an agrarian boom through groundwater exploitation. However, policies have to change in response to new challenges: water management must now address substantive overexploitation and groundwater quality issues (van Steenbergen and Oliemans 2002). Inertia and a lack of information on the part of the authorities constitute a hindrance to administrations in making this transition (Shah et al. 2001, 20–29).

Conflict Resolution Mechanisms Are Important Elements of Groundwater Governance

Efficient and opportune conflict-solving mechanisms are critical for water governance (Solanes and Jouravlev 2006, 61). Many conflicts over water commence locally and escalate to an international level. Natural disasters such as droughts, in combination with very unstable political systems as in Somalia, obviously lead to local armed conflict over water access (Wax 2006). Yet, in general, the rhetoric over water wars is overwhelmed by the record of cooperation. There is an increasing evidence that water, under the right conditions, can act as a catalyst for cooperation (Delli Priscoli and Wolf 2009). Nevertheless, particularly at the local and regional scale, water professionals are increasingly being looked upon to serve as the role of mediators by all parties (Jarvis 2006). Without a third party, the parties that benefit from the status quo have no incentive for reaching a negotiated solution (Solanes and Jouravlev 2006). Another approach for conflict resolution is collaborative learning, which means that mutually focused thinking and productive talk could be effective as well. It should not be overlooked that consensus on particular water resource issues, such as boundaries for groundwater protection areas, requires patience and may take years to reach agreement (Jarvis 2006). Aquifer boundaries are always political in terms of who or what is in or out.

Political Economy Affects Groundwater Governance

When new water legislation is introduced, difficulties arise due to the social pressure placed on water users and their political associates to grant exceptions. This has a negative impact when resource management is controlled by rent-seeking stakeholders. In such cases, well-organized special interests promote self-serving policies in the absence of a transparent governmental and information system that would allow other stakeholders to counterbalance their influence (Burke et al. 1999, 52). Measures can be expected to meet strong resistance if they touch upon long-established relationships that involve corruption and opportunities for side payments. New measures that might change these interrelationships are thus strongly opposed or are circumvented by parties to the corruption. Individuals or communities that perceive they will suffer from a change defend the status quo, just as any change in power relationships where a loss of decision-making rights and rights to allocate funds is involved. Hamann (2005) refers to these issues as the problem of how to overcome the reluctance to alter the status quo. The latter may be intensified when additional funds are given to encourage local initiatives and self-organization (Schleyer et al. 2006, 128). In addition, the lack of objective data, for example, on extraction recharge estimates, enables the data to be used politically and provides grounds for manipulation (Moench 2004, 95).

All countries in South Asia have adopted parliamentary democracy. There is evidence that one consequence in these infant democracies is the politicians' inability to enforce measures that affect people's livelihood. Groundwater irrigators in Asia have emerged as a huge, powerful base of voters, and political leaders cannot ignore this fact when discussing energy subsidies or financial support measures for agricultural product markets (Shah et al. 2001, 21; Shah 2008, 142–148). Likewise, the registration of wells and supervision of well operation remain unrealistic in India or Pakistan. Thus, community acceptance and an understanding of complex natural relationships are necessary to ensure support for measures aimed at protecting groundwater.

Information Deficits Are Impeding Groundwater Governance

Groundwater data are often patchy, outdated, or inaccessible. Often there is a scientific uncertainty, for example, the extraction recharge estimates needed for policies based on the sustained yield approach, or the impact of human actions on the resource (Moench 2004; Braune and Xu 2009). Without understanding the complexity of the groundwater system, the irreversibility of groundwater depletion, and the necessity of precautionary protection, cooperation will be ineffectual. Even in Pakistan, which has based its agricultural boom on irrigation and has conducted many scientific studies on irrigation technologies and local management, there is an urgent need for the improved monitoring of groundwater levels and groundwater quality (van Steenbergen and Oliemans 2002).

This information deficit has four implications for groundwater governance: First, a common understanding of the operation and interrelationships of a management system is required for self-organization and public involvement (Ostrom 2000; Bruch 2005). Second, a prerequisite for voluntary compliance with groundwater regulations is public awareness. When knowledge about the danger of groundwater pollutants for personal health or the irreversibility of falling groundwater levels and loss of storage is inadequate, it is difficult to motivate people to change their behavior and refrain from otherwise profitable actions. Third, information-sharing and high-quality data are required for collaborative learning, proposed as a first step in conflict solutions as described earlier (Jarvis 2006). Fourth, a lack of information prevents administrations from taking the step from resource development to resource protection and management. In that respect, Moench (2004, 97) concludes that management approaches should rely more on the direct measurement of groundwater conditions such as primary data collected by water resource departments instead of relying on the scientific and monitoring data required for the concept of sustained yield.

Conclusions

There exist promising examples of regulatory, economic, and voluntary policy instruments to protect groundwater from pollution and depletion. When implementing a finely tuned balance among them, management deficits, which are aggravated by the complex resource attributes of water, can be reduced. Six aspects are relevant in framing groundwater governance systems from an institutional perspective: (1) voluntary compliance; (2) tradition and mental models; (3) administrative responsibility and bureaucratic inertia; (4) conflict resolution mechanisms; (5) political economy; and (6) lack of information. These are important for the design of national as well as transboundary groundwater governance.

No model of groundwater governance can be implemented in every location. What Kemper et al. (2007, 232) state for river basin management also applies for groundwater governance systems: there is no reason to believe that a particular style of management will perform well in diverse settings. To deal with the necessary institutional diversity, the governance of regional, national, or transboundary aquifers or rivers is increasingly based on multilevel solutions simultaneously operating at the local, regional, national, international, and intermediate levels (Finger et al. 2006; Paavola 2007). A network of actors, ranging from the private to the public sector, can potentially lead to more effective and more legitimate forms of groundwater governance (Lopez-Gunn 2009).

One further question is how to achieve the sustainable governance of transboundary aquifers. The institutional aspects highlighted in this review provide some hints as to what will be of relevance for transboundary groundwater governance. For instance, when boundaries are drawn among a larger territory to encompass a transboundary aquifer, the number of water users and the number of different stakeholders increase, as do the prevailing cultural and social differences. Regulatory agreements (including international agreements) must rely comparatively more on voluntary compliance and should be supported by public awareness campaigns. Moreover, it remains essential to recognize an even greater diversity of regional traditions and local rules-in-use. In addition, mechanisms for sharing information and acquiring homogeneous data must be improved between countries (Arnold and Buzás 2005; Ganoulis 2006; Van der Gun 2007).

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References

Arnold, G.E., and Z. Buzás. 2005. Economic commission for Europe inventory of transboundary ground water in Europe. *Ground Water* 43, no. 5: 669–678.

Barraqué, B. 2004. Ground water management in France: From private to common property. In *Managing Common Pool Ground Water Resources: An International Perspective*, ed. M. Brentwood, and S. Robar. Westport, Connecticut: Praeger Publishers.

Biswas, A. 1999. Water crisis: Current perceptions and future realities. In *Ground Water—Legal and Policy Perspectives*, ed. M. Salman, and A. Salman, World Bank Technical Paper No. 456, 1–12. Washington, DC: The World Bank.

Blomquist, W. 1992. *Dividing the Waters: Governing Ground Water in Southern California*. San Francisco, California: ICS Press.

Blomquist, W., and E. Schlager. 2005. Political pitfalls of integrated watershed management. *Society and Natural Resources* 18, no. 2: 101–117.

Braune, E., and Y. Xu. 2009. The role of ground water in sub-saharan Africa. *Ground Water* doi:10.1111/j.1745-6584.2009.00557.x.

Brentwood, M., and S. Robar, ed. 2004. *Managing Common Pool Ground Water Resources: An International Perspective*. Preface, ix–xiii. Westport, Connecticut: Praeger Publishers.

Bruch, C. 2005. Evolution of public involvement in international watercourse management. In *Public Participation in the Governance of International Freshwater Resources*, ed. C. Bruch, L. Jansky, M. Nakayama, and K.A. Salevicz, 21–71. Tokyo, New York, Paris: United Nations University Press.

Burchi, S. 1999. National regulations for ground water: Options, issues and best practices. In *Ground Water—Legal and Policy Perspectives*, ed. M. Salman, and A. Salman, World Bank Technical Paper No. 456, 55–68. Washington, DC: The World Bank.

Burchi, S., and A. D'Andrea. 2003. *Preparing National Regulations for Water Resources Management: Principles and Practice*. FAO Legislative Study 80. Rome, Italy: UNESCO and FAO.

Burchi, S., and M. Nanni. 2003. How ground water ownership and rights influence ground water intensive use management. In *Intensive Use of Ground Water: Challenges and Opportunities*, ed. R. Llamas and E. Custodio, 227–240. Leiden, The Netherlands: A.A Balkema Publishers.

Burke, J., M. Moench, and C. Sauveplane. 1999. Ground water and society: Problems in variability and points of engagement. In *Ground Water—Legal and Policy Perspectives*, ed. M. Salman, and A. Salman, World Bank Technical Paper No. 456, 31–52, Washington, DC: The World Bank.

Caponera, D.A. 1992. *Principles of Water Law and Administration: National and International*. Brookfield, Vermont: Balkema Publishers.

Chermak, J.M., R.H. Patrick, and D.S. Brookshire. 2005. Economics of transboundary aquifer management. *Ground Water* 43, no. 5: 731–736.

Conca, K. 2006. *Governing Water: Contentious Transnational Politics and Global Institution Building*. Cambridge, Massachusetts: The MIT Press.

Dalhuisen, J., H. De Groot, and P. Nijkamp. 2000. The economics of water: A survey of issues. *International Journal of Development Planning Literature* 15, no. 1: 4.

Delli Priscoli, J., and A. Wolf. 2009. *Managing and Transforming Water Conflicts*, *International Hydrology Series*. Cambridge, UK: Cambridge University Press.

Faruqui, N., A.K. Biswas, and M.J. Bino. 2001. *Water Management in Islam*. Ottawa, Tokyo: IDRC, UNU Press.

Feeny, D., F. Berkes, B.J. McCay, and J.M. Acheson. 1990. The tragedy of the commons: Twenty-two years later. *Human Ecology* 18, no. 1: 1–19.

Finger, M., L. Tamiotti, and J. Allouche. 2006. Introduction: Conceptual elements. In *The Multi-Governance of Water: Four Case Studies*, ed. M. Finger, L. Tamiotti, and J. Allouche, 1–42. New York: State University of New York Press.

Fischhendler, I. 2008. Institutional conditions for IWRM: The Israeli case. *Ground Water* 46, no. 1: 91–102.

Furubotn, E., and R. Richter. 2000. *Institutions and Economic Theory: The Contribution of the New Institutional Economics*. Ann Arbor, Michigan: The University of Michigan Press.

Ganoulis, J. 2006. A risk-based integrated approach for managing transboundary ground water resources. In *Overexplitation and Contamination of Shared Ground water Resources: Management, (Bio)Technological, and Political Approaches to Avoid Conflicts*, ed. C.J.G. Darnault, 355–373. Dordrecht, The Netherlands: Springer.

Garduno, H., S. Foster, Ch. Dumars, K. Kemper, A. Tuinhof, and N. Marcella. 2002–2006. Ground water abstraction rights. *Briefing Note Series Sustainable Ground water Management*, No 5. Washington, DC: The World Bank.

Giordano, M., and K. Villholth. 2007. *The Agricultural Ground Water Revolution: Opportunities and Threats to Development*. Wallingford, Oxon, UK: CABI.

Grafton, Q. 2000. Governance of the commons: A role for the state? *Land Economics* 76, no. 4: 504–517.

Hamann, R. 2005. The power of the satus quo. In *Adaptive Governance and Water Conflict: New Institutions for Collaborative Planning*, ed. J.T. Scholz, and B. Stiftel, 125–129. Washington, DC: Resources for the Future.

Jarvis, T. 2006. Strategies for ground water resources conflict resolution and management. In *Overexploitation and Contamination of Shared Ground Water Resources: Management, (Bio) Technological, and Political Approaches to Avoid Conflicts*, ed. C.J.G. Darnault, 393–414. Dordrecht, The Netherlands: Springer.

Kadekodi, G.K. 2004. *Common Property Resource Management: Reflections on Theory and the Indian Experience*. New Delhi, India: Oxford University Press.

Karkkainen, B.C. 2005. Transboundary ecosystem governance: Beyond sovereignty? In *Public Participation in the Governance of International Freshwater Resources*, ed. C. Bruch, L. Jansky, M. Nakayama, and K.A. Salevicz, 72–87. Tokyo, New York, Paris: United Nations University Press.

Kemper, K., W. Blomquist, and A. Dinar, ed. 2007. *Integrated River Basin Management through Decentralization*. Berlin, Heidelberg: Springer Verlag.

Kendy, E. 2003. The false promise of sustainable pumping rates. *Ground Water* 41, no. 1: 2–4.

Lam, W.F. 1998. *Governing Irrigation Systems in Nepal: Institutions, Infrastructure, and Collective Action*. Oakland, California: ICS Press.

Lieberherr, E.K. 2008. Acceptability of market-based apporaches to water management: An analysis of the Deschutes ground water mitigation program, http://hdl.handle.net/1957/8758.

Lopez-Gunn, E. 2009. Governing shared groundwater: The controversy over private regulation. *The Geographical Journal* 175, no. 1: 39–51.

Ménard, C., and P.G. Klein. 2004. Organizational issues in the agrifood sector: Toward a comparative approach. *American Journal of Agricultural Economics* 86, no. 3: 750–755.

Moench, M. 2004. Ground Water: The challenge of monitoring and management. In *The World's Water, 2004-2005*, ed. P. Gleick, 79–100. Washington, DC: Island Press.

Moss, T. 2003. *Das Flußgebiet als Handlungsraum: Institutionenwandel Durch die EU-Wasserrahmenrichtlinie aus Raumwissenschaftlichen Perspektiven*. Münster: LIT Verlag.

Mukherji, A., and T. Shah. 2005. Ground water socio-ecology and governance: S review of institutions and policies in selected countries. *Hydrogeological Journal* 13, no. 1: 328–345.

Nanni, M., S. Foster, C. Dumars, H. Garduño, K. Kemper, and A. Tuinhof. 2002–2006. Ground water legislation and regulatory provision. In *Briefing Note Series Sustainable Ground Water Management. No. 4*. Washington, DC: The World Bank.

North, D. 1991. Institutions. *Journal of Economic Perspective* 5, no. 1: 97–112.

Ostrom, E. 2007. A diagnostic approach for going beyond panaceas. *Proceedings of the National Academy of Sciences of the United States of America* 104, no. 39: 15181–15187.

Ostrom, E. 2003. How types of goods and property rights jointly affect collective action. *Journal of Theoretical Politics* 15, no. 3: 239–270.

Ostrom, E. 2000. The danger of self-evident truths. *Political Science and Politics* 33, no. 1: 33–44.

Ostrom, E. 1992. *Crafting Institutions for Self-governance Irrigation Systems*. San Francisco, California: Institute for Contemporary Studies Press.

Ostrom, E. 1990. *Governing the Commons: The Evolution of Institutions for Collective Action*. Cambridge, UK: Cambridge University Press.

Ostrom, V. 1962. The political economy of water development. *American Economic Review* 52, no. 2: 450–458.

Paavola, J. 2007. Institutions and environmental governance: A reconceptualization. *Ecological Economics* 63, no. 1: 93–103.

Pistor, K. 2002. The demand for constitutional law. *Constitutional Political Economy* 13, no. 1: 73–87.

Plummer, J. 2008. Introducing water and corruption. In *Global Corruption Report 2008. Corruption in the Water Sector*, ed. Transparency International, 3–15. New York: Cambridge University Press.

Puri, S. 2003. Transboundary aquifer resources: International water law and hydrogeological uncertainty. *Water International* 28, no. 2: 276–279.

Puri, S., and A. Aureli. 2005. Transboundary aquifers: A global program to assess, evaluate, and develop policy. *Ground Water* 43, no. 5: 661–668.

Puri, S., and H. El Naser 2003. Intensive use of ground water in transboundary aquifers. In *Intensive Use of Ground Water: Challenges and Opportunities*, ed. R. Llamas and E. Custodio, 415–438. Leiden, The Netherlands: A.A Balkema Publishers.

Rivera, A., A. Sahuquillo, J. Andreu, and A. Mukherji. 2005. Opportunities of conjunctive use of ground water and surface water. In *Ground Water Intensive Use*, ed. A. Sahuquillo, J. Capila, L. Martinez-Cortina, and X. Sanchez-Vila, International Association of Hydrogeologist Selected Papers No. 7, 371–384. Leiden, The Netherlands: A.A. Balkema Publishers.

Road, A.S., and V. Vidyanagar, ed. 2002. *Innovations in Ground Water Recharge. Water Policy Briefing 1*. Sri Lanka, Colombo: International Water Management Institute (IWMI).

Rowland, M. 2000. The evolution of two water resource management systems: Case studies of Tampa Bay and the Middle East. *Colorado Journal of International Environmental Law and Policy* 11, no. 2: 411–469.

Sahuquillo, A., and M. Lluria. 2003. Conjunctive use as potential solution for stressed aquifers: Social constraints. In *Intensive Use of Ground Water: Challenges and Opportunities*, ed. R. Llamas and E. Custodio, 157–175. Leiden, The Netherlands: A.A Balkema Publishers.

Schlager, E. 2007. Community management of ground water. In *The Agricultural Ground Water Revolution: Opportunities and Threats to Development*, ed. M. Giordano and K. Villholth, 131–152. Wallingford, Oxon, UK: CABI.

Schlager, E., and E. Ostrom. 1992. Property-rights regimes and natural resources: A conceptual analysis. *Land Economics* 68, no. 3: 249–262.

Schleyer, C., I. Theesfeld, K. Hagedorn, O. Aznar, J.-M. Callois, R. Verburg, M. Yelkouni, and J. Alkan Olsson. 2006. Approach towards an operational tool to apply institutional analysis for the assessment of policy feasibility within SEAMLESS-IF. Report 29 of the SEAMLESS EU Integrated Project under the 6th Framework Programme. Project No. 010036.

Shah, T. 2008. *Taming the Anarchy: Groundwater Governance in South Asia*. Washington, DC: Resources for the Future Press.

Shah, T., C. Scott, A. Kishore, and A. Sharma. 2003. *The Energy-Irrigation Nexus, Water Policy Briefing 10*.

Colombo, Sri Lanka: International Water Management Institute (IWMI).
Shah, T., A.D. Roy, A.S. Qureshi, and J. Wang. 2001. *Sustaining Asia's Ground Water Boom: An Overview of Issues and Evidence*. Bonn: German Development Institute and International Water Management Institute.
Smith, Z. 2004. Ground water: The U.S. experience. In *Managing Common Pool Ground Water Resources*, ed. M. Brentwood and S. Robar, 31–44. Westport, Connecticut: Praeger Publishers.
Solanes, M. 1999. Institutional and legal issues relevant to the implementation of water markets. In *Ground Water—Legal and Policy Perspectives*, ed. M. Salman and A. Salman, 1–12. World Bank Technical Paper No. 456. Washington, DC: The World Bank.
Solanes, M., and A. Jouraviev. 2006. *Water Governance for Development and Sustainability, CEPAL-SERIE Recursos Naturals e Infraestrutura No. 111*. Santiago, Chile: United Nations Publication.
Sonou, M. 1997. Low-cost shallow tube well construction in West Africa. In *Irrigation Technology Transfer in Support of Food Security*, ed. FAO, Water reports 14. Proceedings of a subregional workshop, April in Harare, Zimbabwe, 14–17. Rome: FAO.
Stavins, R.N. 2004. Environmental economics. In *The New Palgrave Dictionary of Economics*, 2nd ed, ed. L. Blume and S. Durlauf. London: Plagrave Macmillan Ltd.
Stone, D. 2002. *Policy Paradox. The Art of Political Decision Making*. New York, London: W.W. Norton &Company.
Theis, C.V. 1940. The source of water derived from wells: Essential factors controlling the response of an aquifer to development. *Civil Engineering* 10, no. 5: 277–280.
Usunoff, E. 2005. Water management issues related to aquifer intensive use. In *Ground Water Intensive Use*, ed. A. Sahuquillo, J. Capila, L. Martinez-Cortina, and X. Sanchez-Vila, International Association of Hydrogeologist Selected Papers No. 7, 309–318. Leiden, The Netherlands: A.A. Balkema Publishers.
Utton, A.E. 1982. The development of international ground water law. *Natural Resources Journal* 22, no. 1: 95–118.
Van der Gun, J.A.M. 2007. Sharing groundwater information, knowledge and experience on a worldwide scale. In *The Agricultural Ground Water Revolution: Opportunities and Threats to Development*, ed. M. Giordano and K. Villholth, 362–392. Wallingford, Oxon, UK: CABI.
Van Steenbergen, F., and W. Oliemans. 2002. A review of policies in ground water management in Pakistan 1950–2000. *Water Policy* 4, no. 4: 323–344.
Wade, R. 1994. *Village Republics: Economic Conditions for Collective Action in South India*. San Francisco, California: Institute for Contemporary Studies Press.
Wax, E. 2006. Dying for water in Somalia's drought. Washington, DC: *The Washington Post*. April 14.
Wester, P., B. Maranon Pimentel, and Ch.A. Scott. 1999. *Institutional Responses to Ground Water Depletion: The Aquifer Management Councils in the State of Guanajuato, Mexico*. Colombo, Sri Lanka: International Water Management Institute.
Wolff, P., and O. König. 1997. Germany's water and land management associations—performance determinants and problems. In *Deregulation, Decentralization and Privatization in Irrigation—State Functions Move to the Free Market*, ed. Association for Water Resources and Land Improvement (DVWK), Bulletin No. 20, 217–233. Bonn, Germany: Wirtschafts- und Verlagsgesellschaft Gas und Wasser.
Young, O.R. 2002. *The Institutional Dimensions of Environmental Change: Fit, Interplay, and Scale*. Cambridge, Massachusetts: MIT Press.