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Governance mechanisms for the sustainable use of groundwater in agriculture

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Summary

Groundwater may provide considerable potential to support food security in Sub-Saharan Africa - if managed and used sustainably. Against this background this study identifies policy instruments, management and governance mechanisms to promote the sustainable use of groundwater in agriculture, especially by small-holder farmers. For this, the study outlines common policy instruments and organisational structures for groundwater governance from the literature. It analyses challenges and lessons learned in implementing groundwater governance in case studies from China, India, Ghana and Spain. Based on this, the study concludes with recommendations on how to address common challenges in implementing sustainable groundwater governance and provides a checklist to support decision-making on risks and opportunities for engagement in groundwater irrigation by small holder farmers.

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List of abbreviations

AEP	Agro-environmental Plan
ALBERCA	Actualización de Libros de Registro y Catálogo
AMCOW	African Ministers' Council on Water
APFAMGS	Andhra Pradesh Farmer-Managed Groundwater Systems
APMIP	Andhra Pradesh Micro-Irrigation Project
PEAG	Plan Especial del Alto Guadiana
APWALTA	Andhra Pradesh Water, Land and Trees Act
ARYCA	Actualización del Registro y Censo de Aguas
AU	African Union
BGR	Federal Institute for Geosciences and Natural Resources
BMZ	German Federal Ministry for Economic Cooperation and Development
CAP	Common Agricultural Policy
CIDA	Canadian International Development Agency
CNY	Chinese Yuan
DC	Development Cooperation
ESIA	Environmental and Social Impact Assessment
FWS	Farmer Water Schools
GEF	Global Environment Facility
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit (German Development Cooperation)

GRIPP	Groundwater Solutions Initiative for Policy and Practice
GMC	Groundwater Management Committee
GWUA	Groundwater User Association
HU	Hydrological Unit
IDB	Irrigation District Bureau
IFPRI	International Food Policy Research Institute
IWMI	International Water Management Institute
KfW	Kreditanstalt für Wiederaufbau (KfW Development Bank)
MCM	Million Cubic Meters
NGO	Non-Governmental Organisation
NMMI	National Mission on Micro-irrigation
NMSA	National Mission for Sustainable Agriculture
NWDP	National Watershed Development Programme
OECD	Organisation for Economic Co-operation and Development
PEAG	Plan Especial del Alto Guadiana
RBA	River Basin Authority
RBO	River Basin Organisation
SCARP	Salinity Control and Reclamation Project
SDG	Sustainable Development Goals
SSA	Sub-Sahara Africa
UN	United Nations
WFP	World Food Programme
WMB	Water Management Bureau
WRC	Water Resources Commission
WUA	Water User Association

Executive Summary

Groundwater has played a major role in increasing food production since the 1970s, especially in Asia. In Sub-Saharan Africa, only 2% of the internally renewable groundwater resources are currently used (Shah et al 2020) - a great potential if used sustainably, in particular for semi-arid and arid areas with low precipitation and limited surface water availability. However, groundwater is a common pool resource, which is susceptible for depletion and degradation in the absence of effective governance mechanisms.

This study identifies management and governance mechanisms for the sustainable agricultural use of groundwater to formulate recommendations for the promotion of sustainable groundwater irrigation for small-holder farmers. For this, the study is based on reviewing relevant literature, four case study analyses and interviews with experts and practitioners from development organisations.

The analysis showed that, around the world, a number of policy instruments have been designed and implemented in order to make use of groundwater potential, on the one hand, and to prevent over-abstraction, on the other. Instruments deployed include informational (e.g., groundwater monitoring), capacity development, and regulatory (e.g., abstraction quotas, control of drilling licenses, closure of wells), and economic (e.g., tiered groundwater tariffs). Different organisations have been mandated or new institutional arrangements established to implement and enforce such instruments, ranging from government authorities at different levels to community-based organisations, such as farmer cooperatives or groundwater user associations. However, it is difficult to find good practice examples where groundwater resources are indeed being used in an equitable (secure access to smallholders) and sustainable (protected from overuse) manner. Instead, most case studies reveal considerable gaps in the existing governance frameworks as well as in their implementation and enforcement. Besides lack in human and institutional capacity for implementation, enforcement is often hampered by a top-down approach in introducing instruments, on the one hand, and intractability in political space to change policies providing perverse incentives for groundwater overuse (like energy subsidies for agricultural use), on the other. In addition, knowledge is usually insufficient to assess the actual and potential impacts of groundwater use on base/ environmental flow and on other users. This adds to the complexity of deciding on which instrument is the most promising.

Against this background, a pre-cautionary approach should be taken in promoting the development of groundwater for smallholder irrigation, and relevant governance mechanisms be carefully considered. The effectiveness of various existing policy instruments and governance arrangements depends not only on the natural setting (type of aquifer, agro-ecological conditions), but also on the given socio-economic context and existing governance system. Therefore, instruments and arrangements cannot easily be transferred from one case to another but need to be adapted to the given context. Nevertheless, the following recommendations can help to address common challenges in implementing groundwater governance frameworks:

- Establish a robust data base to inform groundwater development planning and governance decisions.
- Consider enforcement challenges in the design of policy instruments and implementation strategies, including those related to social and political implications.
- Strengthen human and institutional capacity for groundwater governance.
- Strengthen the role of local stakeholders in implementation
- Ensure cross-sectoral coordination in groundwater management.
- Take an integrated approach to promoting sustainable groundwater use for smallholder irrigation.

1. Introduction

Background to the study

The increasing pressures of population growth, climate change, and global food market uncertainties have intensified the food security challenges in many Sub-Sahara African (SSA) countries. Recent data reveals a concerning trend: more than 345 million people are facing acute levels of food insecurity in 2023 across 79 countries where the World Food Programme (WFP) operates, a figure that has more than doubled since 2020 (WFP, 2023). To address these challenges and in pursuit of the Agenda 2030's "Zero Hunger" goal (SDG 2), the African Union (AU) has outlined an ambitious course in its Agenda 2063. Aiming to raise agricultural productivity by 60 percent from its 2013 levels, the AU emphasises the need for increased development of irrigation, with groundwater-based agricultural irrigation emerging as a pivotal strategy.

Groundwater has been instrumental in boosting food production since the 1970s, particularly in Asia (FAO, 2020). Yet, in SSA, only 3 percent of agricultural lands are irrigated, with just 5 percent of that utilising groundwater (UN, 2022). Given that approximately 85 percent of the population lives more than ten kilometres away from a lake or major river, accessing surface water for irrigation is often challenging for many smallholder farms. Groundwater, on the other hand, may offer a more accessible and sustainable solution. It is widely distributed and can often be tapped just a few meters below the land surface. Especially south of the Sahara, shallow groundwater is often renewable, widely available, and can be accessed using simple and cost-effective technologies. These groundwater resources regularly replenish during the rainy season and, under suitable geological conditions, can even be artificially recharged. This makes them a prime candidate for sustainable use, provided appropriate safeguard measures are in place.

However, this potential has yet to be realised. The challenge now is to ensure that as we tap into this potential, we do not replicate the mistakes of other regions where over-exploitation has led to significant socio-economic and environmental repercussions. This underscores the pressing need for robust governance mechanisms that not only enable the effective development of groundwater but also secure its sustainable use and prevent over-exploitation. Enhancing groundwater resource governance is a critical factor for achieving the "Zero Hunger" goal (SDG 2) of the Agenda 2030 without compromising groundwater use for domestic water supply (SDG 6).

Against this background, the sector project on groundwater, implemented by the Federal Institute for Geosciences and Natural Resources (BGR), commissioned by the German Federal Ministry for Economic Cooperation and Development (BMZ), has been supporting Pan-African institutions like the African Ministers Council on Water (AMCOW) to unlock the potential of groundwater for socio-economic development, since 2018. The role of groundwater for irrigation has gained special attention and urgency, given the shocks on global food markets following the Russian war on the Ukraine and the recent drought periods in different parts of Africa. Therefore, BGR is currently leading different activities and studies to identify the groundwater potential for irrigation in Africa and to find pathways and mechanisms that promote its sustainable use for food security. By promoting the development of groundwater, the initiative not only aims to increase agricultural yields but also to support smallholder farms build resilience against climate-induced shocks, thereby contributing to the socio-economic stability of the region.

Aim and focus of the study

The primary aim of this study commissioned by BGR was to identify governance mechanisms that could ensure the sustainable agricultural use of groundwater for smallholder farms in SSA countries. Recognising that German Development Cooperation (DC) aims to support food security and overall resilience in the region, and in face of the risks related to uncontrolled use of groundwater, this study seeks to provide actionable recommendations on how DC could enhance groundwater governance to support these aims.

Delving deeper, the study contemplates the conditions that can either prevent or exacerbate the overuse of the groundwater resource in smallholder irrigation. The study investigates the array of instruments at the disposal of governments, and the challenges of implementing them with the goal of promoting sustainable groundwater use in smallholder agriculture.

For this, the study looks at the experiences of selected countries (China, Ghana, India, and Spain) and tried to get in-sights also in other countries. While the study could not identify cases without challenges and problems, it derives lessons learned on design and enforcement of governance arrangements. Examples from around the world offer valuable insights, but the study also remains vigilant of not only the bio-physical but also the socio-political circumstances to make governance effective. Based on this, the study provides recommendations on how groundwater governance can be strengthened through initiatives of DC, and highlights that this requires thorough integrated assessments and the design of context specific measures - which is anything but a trivial undertaking.

Methodology

To ensure a comprehensive and nuanced understanding, this study employed a mixed-methods approach. A thorough review of both primary and secondary literature laid the foundation, offering insights into existing governance mechanisms, their efficacy, and areas of improvement. Furthermore, expert interviews (Annex: list of interviews) were conducted to gather first-hand insights and perspectives. These interviews targeted stakeholders from German Development Cooperation entities, Non-Governmental Organisations (NGOs), and other experts in the field of groundwater governance and management.

Structure of the Report

Following this introduction, **Chapter 2** addresses the challenges of groundwater governance and management, emphasising its nature as an invisible common pool resource and its interplay with energy and agricultural policies. **Chapter 3** outlines the instruments and administrative levels of groundwater governance, introducing policy tools and discussing governance from national to local levels, supplemented by specific examples like Morocco's aquifer contracts. **Chapter 4** offers case studies from China, Ghana, India, and Spain, each analysed for success factors and relevance to the SSA context. **Chapter 5** delves into the complexities of implementing groundwater governance, highlighting challenges from policy to institutional levels. The report concludes in **Chapter 6**, with generic not country-specific recommendations for German Development Cooperation and, lastly, provides a checklist containing decision-relevant points for a DC engagement.

2. Challenges in groundwater management

Groundwater shows a number of characteristics that turn its governance and management particularly challenging. The risks of unsustainable management leading to over-exploitation and externalities are therefore high. Externalities may include negative consequences on neighbouring wells, on adjacent stream flows and ecosystems, and on the future availability of water supplies for growing populations (OECD, 2015). Some of these risks also exist in surface water irrigation, and although they do not apply to the same extent but in variations, the differences are not absolute but rather in degree. The following paragraphs summarize common challenges in groundwater management.

The bio-physical characteristics of groundwater obscure sustainable management of the resource. Groundwater systems are characterised by an aquifer's capacity to store water ('storage coefficient') and the rate at which the water flows through an aquifer ('transmissivity'). However, defining the borders of an aquifer (the resource's domain) and the users' domain abounds with uncertainties regarding aquifer recharge areas, discharge characteristics, and its interrelationship with surface water bodies. Due to the fact that replenishment periods are long and the provenance of groundwater generation is not always clear, overuse and pollution is usually not immediately perceptible (the complexity and time lag inherent in many aquifer flow regimes cause these regimes to become 'decoupled' from the causes and effects of interventions). The effects of human interventions may, therefore, become evident only after a considerable time lag.

A consolidated data base to inform management decisions does often not exist. The above-mentioned hydro-geological characteristics influence the magnitude of the groundwater management and governance challenges. Providing a consolidated data basis to inform management decisions requires considerable scientific, technical and administrative efforts, and associated costs. Therefore, the information basis for groundwater management is often insufficient. This is especially true for SSA countries, where geological data is available in some parts, but data on groundwater levels and flows is largely unavailable.

Groundwater systems are invisible common pool resource systems with a large number of users. The use of groundwater is characterized by rivalry and high costs of excluding non-sanctioned users (e.g., illegal well drillers, individuals using more water than assigned by water permits). Each individual's use subtracts resource units which are then no longer available for others. In this respect, one user may potentially affect other uses depending on the transmissivity and recharge rate of the aquifer in question. Exclusion costs are high because of the size of aquifers, and the number of users that may extend to thousands and millions of individuals. While it is an advantage of groundwater that access points are decentral, it increases costs of monitoring and enforcement. If not governed effectively, the accumulated utilisation rate may exceed the limit of the resource, and may result in a Tragedy of the Commons.

The subtractable nature of the resource flow requires access rules (well drilling, individual use shares) and rule-ordered allocation procedures to make optimal and fair use of the resource. Without established and enforceable rules, the right to use would be gained through its capture by those who can afford high investments and operation costs.

Groundwater management is interconnected with the management of resources governed by other sectors. Governing the behaviour of groundwater users is even more complicated because it does not only depend on (ground-) water policies but is closely interconnected with other sectors' policies such as energy/electricity, land use planning, forestry, and of course, agricultural policies. Low subsidized energy costs create incentives to overexploit the resource, and this also applies if the cultivation of water-intensive crops is promoted through agricultural and trade policies. Large-scale changes in land use can have substantial long-term effects on groundwater recharge and quality, and thus on groundwater availability.

3. Instruments and administrative levels of groundwater governance

The challenges summarised in the previous section clearly show that sound groundwater governance is necessary in order to prevent, or at least minimise, the externalities associated with uncontrolled groundwater use (e.g., sinking groundwater tables resulting in higher pumping cost that not all users can afford, eventually groundwater depletion and knock-on effects in stream depletion, with repercussions on surface users and related ecosystems.

There are numerous definitions of groundwater governance. However, for the purpose of this study we adopt the definition provided by Villholth et al. (2018):

> *Groundwater governance is the framework encompassing the processes, interactions and institutions, in which actors (i.e., government, private sector, civil society, etc.) participate and decide on management of groundwater within and across multiple geographic and sectoral levels.*

Box 1 below provides further definitions of components of groundwater governance that are further addressed in the following sections and throughout the study, i.e., policy instruments, organisational structures, and governance systems.

Governance with the aim to support the sustainable use of groundwater by smallholders has to address three different but largely interlinked fields of action:

- **Governance and management of groundwater resources**. The issue in this policy field is how to regulate competition that exists between different groundwater users with the aim of achieving socially environmentally and economically sustainable use of the resource through design and implementation of relevant policy instruments and organisational structures.
- **Promoting the use of groundwater for smallholder farms**. The aim here is to provide incentives and support smallholders in switching from rain-fed agriculture to irrigation, or to complement surface irrigation with groundwater.
- **Governance and management of groundwater irrigation systems**. This governance field addresses questions of collective action and social arrangements for investing in infrastructure, operation and maintenance of the system, and sharing and distributing the abstracted water, and financing all of these tasks.

The focus of this study lies on the sustainable management of groundwater resources/ aquifers. The promotion of smallholder irrigation is not examined in detail in this study, because this policy field is very similar to promoting surface water irrigation by smallholders. The governance of irrigation systems is clearly distinct from the problem of managing an aquifer (the shared resource), and is not further discussed in this study.

Box 1: Definition of terms

Policy instruments: specific instruments developed by government authorities or other mandated agencies to implement policies and influence behaviour of farmers and private commercial farm enterprises (Howlett, 1991, Bouwma et al., 2015). These could be grouped under legislative/regulatory; economic/fiscal, planning, cooperative and information/communication-based instruments (Bouwma et al., 2015).

Organisational structures: either spontaneously emerging or cautiously designed in a given context to effectively implement policies and specific policy instruments to achieve specific goals, i.e., sustainable development, use and management of groundwater resources (Williamson, 1979; Hagedorn, 2015). Organisational structures can be state-centred, such as national or local authorities, or community-centred, such as water user associations, or a combination of both, and they may include private businesses such as drilling companies.

Governance system: a system of policies and instruments, organisations mandated, institutional arrangements, processes and specific actor constellations that legislate, plan and manage activities (towards societal goals, or public goods). Institutional arrangements in a governance system further define the delegation, distribution, or sharing of power related to decision-making and implementation.

3.1 Policy instruments to enable sustainable use and prevent over-abstraction

As mentioned above, efforts to promote the (increased) use of groundwater resources for smallholder irrigation, governance arrangements will have to address two different aspects: (i) the exploration and expansion in groundwater use where policies and instruments are needed to support smallholder irrigation, and (ii) the control and regulation of water use to prevent over-abstraction. While this study focusses on the second, namely the aspect of preventing over-use, Table 1 summarises instruments commonly applied to promote groundwater irrigation.

Reviewing formal policy and legislation in Sub-Saharan African countries, Chokkakula and Giordano found that "groundwater does not figure prominently in strategies for agricultural development. Instead, government-supported irrigation development is heavily biased in favour of surface water, which receives government budget allocations regularly" (2013: 792). As a consequence, groundwater has not yet been exploited to its potential for irrigation in many countries in Sub-Sahara Africa. However, pockets of overuse exist, and instruments are implemented to reverse over-abstraction (Bruns, 2021: 630).

Table 1: Instruments to promote groundwater irrigation by smallholders

Policy field	Promotion instruments
Land-related issues	Secure land use-rights (under modern or customary law)
Groundwater irrigation- related issues	Improve well drilling services, support business development of drilling companies Subsidies for infrastructure and technology Exemptions for small groundwater users (no well licenses, no permits)
Agricultural intensification issues	Access to agricultural inputs (seeds, technology, fertilizer) Access to credits (low lending rates; collateral other than land) Subsidies (cost-sharing) for individuals and/or user groups for pumps (manual, mechanized, electric, solar) Fuel subsidies (diesel, electricity) Availability of local staff to manage groundwater irrigation systems, among other issues
Marketing / trade issues	Favourable conditions for marketing equipment (tariff exemptions of import duty on agricultural machinery; low taxes for equipment) Availability of equipment in proximate locations; access to repair facilities

Source: Chokkakula and Giordano (2013).

This chapter presents a variety of well-known policy instruments that have the potential to prevent, or reverse, overexploitation of the respective groundwater resources (see Table 2). Such instruments are commonly applied in combination and can either target the demand side (e.g., water quota, tiered water pricing) or the supply side of groundwater (e.g., the substitution of groundwater by other sources, and by enhancing infiltration and recharge), and can either address groundwater use directly or indirectly (e.g., through land or energy use). For a detailed discussion of instruments see Molle and Closas (2017) and OECD (2015).

We distinguish between five categories:

- A first category of instruments is **regulatory** in nature that aim at preventing or reversing over-abstraction of aquifers. One sub-category addresses the control and number of new wells and could target well drillers or irrigators, while another sub-category focuses on water abstraction by existing wells. State-ordered regulatory measures face information constraints that prevent targeted and effective regulation. However, regulations may not necessarily come as state-ordered, but could be the result of collective decisions made by a community of users. Regulatory instruments, be they direct or indirect, require monitoring and enforcement efforts.
- A second category, **economic**, **fiscal** instruments, either provide incentives or impose sanctions to control the behaviour of groundwater users. Again, economic approaches to incentivise user behaviour may be decided by state authorities but also by other authorised agencies, such as e.g., river basin organisations (RBO), and, again, could be the result of collective decisions made by a community of users. Economic schemes can lead to efficient outcomes but may be associated with high transaction costs, and socially unequal outcomes.
- A third category are **planning** instruments of diverse kind: Water management plans aim at the protection of water bodies, the conservation of groundwater resources, and they may consider supply-side and demand-side efforts to support the sustainable use of groundwater within watersheds. Water allocation plans review how much water is available, considering environmental flow requirements and the existing and potential demands on which individual water-use permits depend. Land-use plans are the central instrument for nature conservation and landscape management, and may limit land and water use by zoning off specific areas. The plans mentioned are prepared by public authorities, with varying degrees of public participation, and varying degrees of binding force for both state and civil actors.
- A fourth category are **cooperative agreements** which are concluded between members of e.g., Groundwater Irrigation Cooperatives and Groundwater User Associations, but also between multiple stakeholders (the aquifer contracts in Morocco are a special form). Cooperative agreements of this kind include rules on setting up the respective organisation (voting, delegation), its goals and mandate, and rules-of-use including those that aim at preventing or reversing overdraft. Collective management schemes are intrinsically adapted to local circumstances but depend on the participation and commitment of users.
- A final category is **information**, **communication** instruments that provide information to stakeholders concerned on e.g., characteristics of the aquifer, the rate of utilisation, use-permits assigned, new technologies, agronomic practices, and on national strategies, and development and risk scenarios.

Table 2: Instruments to promote the sustainable use of groundwater, preventing over-abstraction

Instruments	Measures to be taken
1 Regulatory instruments	**Control number and expansion of wells** • Licensing well drillers • Rules for well spacing • Backfill illegal wells • Restrictions for deepening of wells • Buy out and ban new wells • Designation of prohibition zones where drilling is not allowed **Control abstraction by existing wells** • Permits for groundwater users • Quota prescribed not to impact the resource base and environmental flows • Ban on water-intensive crops (compensation payments required)
2 Economic, fiscal instruments	Water pricing policies (water resources extraction charges, volume-based water charges) Subsidies for improving water-use efficiency (land levelling, water-saving technologies), and for cultivating drought-resistant crops Subsidies for new technologies (pumps, irrigation) Differential energy pricing (electricity, diesel)
3 Planning instruments	Water resources management plans, annual water allocation plans Land-use plans, including zoning (e.g., groundwater protection zones) National sector and cross-sectoral policies (water, agriculture, energy) and strategies
4 Cooperative instruments	Multi-stakeholder aquifer contracts Agreements between members of groundwater cooperatives and groundwater user associations
5 Information, communication instruments	Provide information to users on characteristics of aquifers, the rate of utilisation and use-permits assigned Information on national strategies (agriculture, energy, water) and development scenarios

3.2 Different levels and forms of governance

Groundwater governance takes place at different administrative levels. The overall objectives for resource development and corresponding policy and legal frameworks for groundwater management, as well as general principles on the division of public and private rights and responsibilities, are usually set at the national or sub-national level. Depending on the political administrative structure of a state, mandates for resource governance and management are set at either the national or sub-national level which also decide on policy instruments and organisational solutions.

Actual implementation, monitoring and enforcement of policy instruments usually takes place at the local level, but some governance processes may also take place at intermediate levels of administration. Local organisations may also be tasked to design locally specific policy instruments, such as tariff structures, allocation rules etc. Table 3 below summarises governance issues which are commonly decided either at the national/sub-national or the local level.

Table 3: Typical groundwater governance issues at different administrative levels

Administrative levels	Governance issues
National/ sub-national level	General framework for groundwater governance and management, principles and guidelines for designing and implementing policy instruments, and organisational structures, including e.g., • nature of property rights (private or public, tenure linked to land or not), rules for licenses and permits and conditions attached to both (such as duration, withdrawal quantity, cancellation) • allocation of resources between different sectors (agricultural, urban/domestic, etc.), and rules that regulate situations where not all users and not all agricultural users can be served • principles for economic instruments (prices, subsidies, trade controls) • governance mandates at various levels of administration (subsidiarity, decentralisation, devolution) • stakeholder participation • collection and management of knowledge and information
Local level	Implementation of national/sub-national governance frameworks on the ground comprising, • the design of locally specific instruments, including water allocation plans, monitoring and enforcement • the establishment of local level organisational structures and mechanisms for participation and conflict resolution • local data collection

At all administrative levels, but especially at the local level, there are multiple types of organisational structures for groundwater governance, ranging from state-centred to community-centred. Most common are, however mixed forms, such as cooperative multi-actor approaches and co- management schemes (see Molle and Closas, 2017) for a detailed discussion of the different organisational structures).

In **state-centred governance systems**, design, implementation, monitoring and enforcement of policy instruments fully falls within the mandate of public authorities and other government agencies that act within administrative or catchment boundaries. However, experience has shown, that purely state-centred approaches often face resistance of water users and thus challenges in enforcement. Instead involving communities in groundwater governance, such as self-regulation or voluntary programs undertaken by users, organised in water user associations or agricultural cooperatives, have shown to be more effective in regulating groundwater use on the ground (Molle and Closas, 2017).

There are, however, very few examples of purely **community-centred approaches** where local communities take sole responsibility for the sustainable use and protection of their groundwater resources. Examples are Qanats managed by local communities, which are traditional underground channels used to transport water from an aquifer. In Iran, for instance, water user associations known as *mirabs* are responsible for the operation and maintenance of qanats. They resolve disputes, and collect fees for maintenance and repair. However, community-based governance and management has its limits: systems can collapse if internal allocations rules are not or cannot be enforced (see Box 2). They can be prone to elite control and corruption, and may be undermined by individual 'exit strategies' such as drilling private wells. Despite these challenges, community-centred governance can play a crucial role in managing groundwater resources, particularly in contexts where state capacity is limited.

Usually, groundwater governance involves sharing of governance mandates between governmental agencies and resource users in **co-management schemes,** as decision-making processes in groundwater governance usually span various scales, constituencies, and organisations (Molle and Closas, 2017). This collaborative dynamic was aimed for, for example, in Jordan, through the Highland Water Forum, an initiative designed to foster cooperation between the government and local communities in managing water resources. However, the Forum's potential was left unrealised due to multiple intertwined factors, including changes in political priorities at ministerial level, economic actors and limited involvement of large farmers (Oberhauser, Hägele, and Dombrowsky, 2023; Hussein and Eichholz, 2020). Some of the challenges in implementing co-management schemes can also be seen in Morocco, where aquifer contracts have been established that involve both the state and multiple stakeholders (see Box 3). An important aspect is finding the right balance between state control and user autonomy in managing groundwater resources. While too much state control can lead to resistance from users, too much user autonomy can lead to over-abstraction or inequitable access.

Box 2: Punjab's experience with community tube well groups

The establishment of community tube well groups in Punjab, Pakistan, took place in the context of the Salinity Control and Reclamation Project (SCARP) where deep tube wells provided vertical drainage in (saline and) freshwater areas to lower groundwater levels and to provide additional water for irrigation.

In Punjab's vast irrigated areas, groundwater pumped with tube wells has been fed into distributary canals to be used for irrigation purposes. In the early 1990s, the ministry decided to transfer SCARP tube wells to community tube well groups to reduce the fiscal burden resulting from operation and maintenance costs. The transfer to communities was favoured over private, because higher economic gains and improved equity due to higher utilisation factors were expected. Community tube wells would benefit small farmers, and curb the anarchical and inefficient growth of private wells.

In order to make the transfer to communities attractive, the Punjab Government discontinued monetary incentives for installing private wells, and offered, instead, subsidies for communities. For access to subsidies, farmers must join a community tube well group. The groups are obliged to operate and maintain the wells out of their own resources. Water-use rights are restricted to group members and relate to the farmers' share of initial contributions. In addition, the Agricultural Development Bank of Pakistan commissioned credits to farmers for tube well installations: the bank set the minimum land size for mortgages at more than 2 hectares, but did not consider loans to either cooperatives or community groups which was later on changed. Afterwards, loans were granted at 13 to 14 percent interest for a term of 10 years, with one-year grace period, if farmers deposit their passbooks as collateral.

Farmers who wanted to establish a community tube well group faced a legal obstacle: the water users association (WUA) ordinance (1981), the basic document for the establishment and registration of farmer organisations until 1997, did not foresee tube well groups, but associations at watercourse level. The WUA ordinance requires a minimum membership of 51 percent of eligible water users on a respective watercourse for registration. However, it was decreed that if 30 percent of WUA members apply for tube well drilling and subsidies, and accept the obligations, a tube well group could be established.

As a result, more than 2,200 community tube well groups were established. Apart from the monetary incentives provided, farmers appreciated a regained water supplied by the then decommissioned SCARP tube wells. The areas where that happened were short of surface canal water, and small farmers cultivating less than 5 hectares regarded groundwater as a supplementary source of about 60 percent of irrigation water.

An assessment made by Latif & Masih (2000), showed that one quarter of the original group members did not receive water due to some farmers' monopoly position. Furthermore, tube wells were not professionally operated, and water distribution along the canals was not fair – a widespread phenomenon common in many surface irrigation systems.

Source: Scheumann and Memon, 2003.

Box 3: Morocco's Aquifer Contracts: an innovative collective management approach

Aquifer contracts in Morocco are voluntary agreements between the government and multiple stakeholders that aim at regulating and improving the management of groundwater at the local level. It encourages stakeholder participation and allows them to take responsibility within a negotiated contractual framework. This type of decentralized engagement is embedded in a broader river basin management framework in order to ensure consistency between the objectives and actions implemented across the different management levels. Aquifer contracts should overcome ineffective central, top-down regulation and control measures resulting from high transaction costs to monitor and control the numerous and diffuse groundwater abstraction points.

The first aquifer contract in Morocco was introduced in 2006/07 for the Souss aquifer because it has seen significant falls in groundwater levels that are largely attributed to over-exploitation of groundwater, and it lies in a river basin that is affected by an overall water deficit. In 2013 an inter-ministerial notification, signed by the ministers of agriculture, interior and water expressed political support and provided guidelines for the establishment of aquifer contracts. In 2014, a national workshop on the management of groundwater resources again put aquifer contracts at centre stage. After signing, responsibility for implementation was transferred to the River Basin Authority.

One of the strengths of the Souss aquifer contract was the number and breadth of stakeholder organisations that were involved.[1] However, complex negotiations were necessary to design the agreement. Six parts of the agreement are framed as specific bilateral partnership agreements, and some of the parties signed only selected specific partnership agreements that advantaged them. For example, the farmers' union only agreed to decreases in cultivated area after the inclusion of the plan to regularise some illegal wells.

"The negotiation and implementation of the Souss Aquifer Contract has faced a number of limitations:

- A lack of consensus on the central problem. Some stakeholders did not agree that groundwater was being over abstracted, but rather saw the problem as one of a lack of resource allocation from the central state. Reliable data were missing such as monitored water abstraction rates.
- A lack of consensus at ministerial level about what measures to take. For instance, various ministries did not agree that water fees should be increased, or that specific areas should be protected from further groundwater abstraction.
- Reliance on supply-side solutions: the aquifer contract relied on the supply of additional surface water to substitute for reducing groundwater abstraction, but this meant a lengthy infrastructure program, which was delayed due to budget constraints, and these delays were used by farmers' associations as a reason to postpone installation of groundwater abstraction water meters.
- Small farmers were less well represented in the contract. By contrast, the larger scale farmers were well organised into cooperatives and associations, and could use the contract to further their vested interests. Conflicts between large- and small-scale farmers predated the contract, and were not directly addressed or ameliorated by the contract measures.

[1] The Souss-Massa-Draa River Basin Authority, the Souss Massa-Draa regional government, three presidents of regional councils in the river basin, Office National de l`Electricité et de l`Eau Potable, the national public water utility, the Federation of Associations of Users of Agricultural Water, the Chambers of Agriculture of Taroudant-Agadir-Tiznit, the Professional Association of Well Drillers of Souss, and two national research institutions.

- At the same time when increased water user fees were implemented, farmers also received subsidies, which largely negated the desired effect of the increased water fees to conserve water.
- And above all, the agreement is voluntary, and the River Basin Authority has low enforcement capacity, so that non-compliance was not dealt with effectively."

Source: Closas and Villholth, 2016; Houdret and Heinz, 2022.

4. Case studies

In this chapter, we present approaches of groundwater governance and management. As a basis for selecting cases, we screened a vast body of literature on groundwater irrigation, and decided, finally, in favour of China, Ghana, India, and Spain because of their diverse aquifer characteristics, and because they stand for promising – but not perfect – approaches.

The studies have different foci: while the in-depth desk studies China, India, and Spain deal with attempts to control overuse, the Ghana study stands for a country in which individual initiative and entrepreneurship of farmers promoted small-scale groundwater irrigation without official support. In one or the other way, these approaches are exemplary not only for the selected countries, but represent typical attempts to cope with overexploitation (Ghana is an exception). A final criterion was the availability and accessibility of literature on which all country studies rely (no field research).

Table 4: Case studies in brief

Country / region	Aquifer characteristics	Utilisation rate	Groundwater Governance / Management
China **Minqin and Guazhou Counties, North China Plain**	Multi-layered aquifer system Upper Aquifer: coarse sand, unconfined, 30-50m thick Lower Aquifer: fine sand, confined, flows from mountains to basin centre	Overused due to agricultural demands	**Regulatory and economic instruments**: Water Quota System and Well Drilling Permit System (Minqin County), Tiered Water Pricing (Guazhou County) **State-cenred, co-management:** GWUAs in Minqin County implement well closure, quota system and smart card readers
Ghana **Upper East Region, North Ghana**	Basement complex, consolidated and sedimentary rocks Shallow, low storage, moderate transmissivity Low annual production Recharge between 4-13 percent of annual rainfall	Currently no over-abstraction	**Regulatory instruments**: Water Resources Commission Act 522 (1996), Water Use Regulation Law (2001), Drilling License and Groundwater Development Regulations (2006) **Community-centred** local governance through customary land tenure, farmer-led groundwater irrigation practices
India **Andhra Pradesh, Southern India**	Alluvial (28 percent), Hard Crystalline Rock (31 percent) Deep alluvial: high yield and storage Hard crystalline: shallow, low storage, common in semi-arid Southern India Recharge in rainy season (Jun-Oct), rapid decline in dry season (Nov-May)	Overused due to agricultural demands	**Regulatory instruments**: Model Groundwater Bill (1970, 2017), Andhra Pradesh Water, Land, Trees Act (APWALTA, 2002), National Water Policy (2012) **Informational instruments**: Farmer Water Schools, Gaming approach **Co-management**: Andhra Pradesh Farmer-managed Groundwater Systems Project (2003-2013) promoted community management and hydrological monitoring, and Farmer Water Schools for knowledge sharing
Spain **La Mancha, south-central**	Limestone (Western Mancha) extends to ~5,500 km² with notable storage	Overused due to agricultural demands	**Regulatory, economic, informational instruments**: Water Law (1985) introduced concessions, well registration initiatives and abstraction census; Emergency regime for over-exploited aquifer introduced water quotas, later complemented by compensation payments and government buy-back schemes **Co-management:** GWUAs with limited management mandate captured by interest groups

4.1 Case study North China Plain

The China study presents a case where increased agricultural water demands in an arid climate led to groundwater over extraction, and where the state invented regulatory and economic instruments to reduce water consumption. While a quota system was successfully implemented with the support of local groundwater organisations, the introduction of tiered water prices was hampered by faulty design of the tariff system, and the self-interests of the local bureaucracy.

4.1.1 Aquifer characteristics and groundwater utilisation in the North China Plain

The North China Plain, encompassing Minqin and Guazhou Counties, features a complex hydrogeology with a multi-layered aquifer system including shallow and deep storage aquifers. The upper aquifer, primarily composed of coarse sand, is unconfined, with its thickness varying between 30m to 50m. Conversely, the lower aquifer is confined and predominantly consists of fine sand. The water tables' depth ranges from 2 to 10 meters, with groundwater flow mainly directed from the mountainous regions towards the basin's centre (Aarnoudse et al., 2016).

In both counties, small-scale farming depends on irrigation because of the arid climate (low rainfall, high evaporation), and on easily accessible groundwater because surface water supply has not been reliable.

Historical records indicate that pumping activities commenced in the early 1970s and increased post the late 1970s. Over the following decades, they caused a decline in groundwater tables, particularly in the downstream areas of the rivers: Minqin is located downstream of the Shiyang River, and Guazhou downstream of the Shule River. The situation has been further exacerbated by a decreased recharge in downstream areas of the Lake District of Minqin. Thousands of irrigation wells have been drilled, and groundwater extraction far exceeded the recharge. As a result, groundwater levels had dropped so much (between 10m to 30m in Minqin) that wells had dried out with significant negative effects on crop production. In the East Lake region, for instance, growing water scarcity, severe salinisation of soils and desertification of land have driven over 32,000 individuals to migrate within ten years, and caused a decline in the number of farming communities (Aarnoudse et al., 2012).

4.1.2 Governance approaches and the institutional arrangement for monitoring and implementation

These problems prompted a revision of the Water Law at the national level in 2002. The Law allowed to implement strict regulations in areas with severe overuse. In Minqin County, water administrations introduced a license procedure for drilling new wells and a **quota system** to re-allocate water resources, and in Guazhou, **tiered water prices** were supposed to incentivise farmers to reduce the amount of water used in irrigation. In both counties, and country-wide, these measures were accompanied by the introduction of smart card readers to better monitor groundwater abstractions (see Box 4).

Box 4: Smart Card Readers

In the early 2002, water meters and smart card readers were introduced to improve monitoring. Smart cards readers are connected to pumps, and by swiping the card, the pump turns on. If the pumped volume exceeds the water account (which is digitally registered on the card), the pump turns off automatically. The card (hence, the water account) can be reloaded by local water officers of the Irrigation District Bureaus. The introduction of this technology provided local authorities with a tool to monitor groundwater usage by farmers.

The technology is designed to be compatible both with volumetric groundwater pricing and quota regulation.

4.1.3 The Water Quota System in Minqin County

The Well Drilling License was already enacted in 1987 by the Water Management Bureau of Minqin to regulate the drilling of new groundwater wells with little effects. In 1990 a Provincial Plan (“Save the Oasis”) was launched to reduce annual groundwater use to 300 MCM before the year 2000. But “despite the clear target, no effective policy measures were implemented” and abstraction accounted 400 MCM (Arnoudse et al., 2012:1216). Furthermore, the local water administration took a bold step by closing 3,000 wells out of 7,000 between 2007 and 2009. Compensations were paid to the well-owning farm group to compensate for the negative effects on their farms. This action, encapsulated by the local slogan "Close the wells, reduce the farmland," targeted wells especially at the desert's edge, and encouraged the abandonment of the surrounding land.

Following the revision of the national Water Law 2002, that urged regulation in groundwater overdraft areas, the Shiyang River Basin Management Plan was officially launched in 2007. The plan comprised a clear allocation target, i.e., to reduce groundwater use by almost 80 percent. While the River Basin Authority (RBA) coordinated activities, the Water Management Bureau of Minqin, the Irrigation District Bureaus (IDB) and the Water User Associations (WUA) were mandated to implement the water quota system. Importantly, career opportunities of local water officials were linked to the envisaged allocation target.

Concurrently, to provide a reliable water supply for farmers, surface water inflow to Minqin was augmented by channelling additional water from the Yellow River Basin, combining abstraction limits with an enhanced surface water supply. Then, the quota per capita system was gradually implemented and became effective in 2010 (Aarnoudse et al., 2017). The per capita quota is calculated in a very restrictive way to reduce the farmers’ groundwater use (for details on the calculation method, see Aarnoudse et al., 2017: 923). To monitor and ensure adherence to these quotas, smart card readers were installed at pumping installations, allowing farmers to pump water up to designated limits (Aarnoudse et al., 2012).

While quotas are calculated per person, the quotas are administered per farm group by the local Irrigation District Bureaus in which they are assisted by the boards of Water User Associations (WUA). Each village has a WUA and each household officially became a WUA member. WUAs are mostly identical with the existing village committees, plus farm group leaders. WUAs have the responsibility to record the exact number of members per farm group in order for the Irrigation District Bureaus to exactly calculate the quota per farm group. At farm group level, staff of the WUAs take over water distribution according to the pre-determined quota. Groundwater fee per hectare (actually a cost recovery fee) has to be paid to the Irrigation District Bureaus prior to the start of the irrigation turns, and an electricity fee for pumping costs to the electricity provider.

The water quota system has successfully reduced groundwater use in irrigation in Minqin County because local water authorities had a strong motivation (career opportunities) for achieving the allocation target as determined in the Shiyang River Basin Management Plan.

4.1.4 The tiered water pricing system in Guazhou County

In 2005, responsibility between the management of surface and the management of groundwater was split. While local government administrations and its Water Management Bureaus at the prefecture and county levels continued to be responsible for groundwater management, the management of surface water was transferred to River Basin Authorities. This shift also meant that surface water fees were now collected by independent RBAs and that Water Management Bureaus lost its source of revenue to them.

In 2007, the water administration of Guazhou County decided in favour of implementing tiered water pricing as an incentive system to curb groundwater withdrawals. However, there were no clear reduction targets. The 2007 system introduced charges based on consumption, with rates set at CNY (Chinese Yuan) 0.01/cubic meters for the initial 100,000 cubic meters per well, and CNY 0.02 above 100,000 cubic meters. While the tiered water prices aimed to stimulate water conservation by charging a low rate for an initial consumption block and a higher rate for subsequent use, its practical application was challenging for, at least, two reasons: first, some farm groups had more wells under their control than others for similarly large areas to be irrigated. Pumping from more wells than the neighbour farm group meant, households had more water available at a low price (they did not have to exceed the 100,000 threshold). Second, electricity and water prices were charged and collected at the farm level as one rate, and there was no clarity on how much to pay for groundwater per cubic meter. It is therefore not surprising that post-implementation data showed varied responses among farmers. Specifically, 40 percent of the surveyed households reported that their groundwater use per unit of land had remained unchanged over the years 2003-2013; another 40 percent stated that their groundwater use had increased.

The decision of the water administration of Guazhou County to implement the tiered water pricing system coincided with a change of mandates, and subsequent financial consequences: The Water Management Bureau lost its source of revenue when it was decided that surface water fees have to be paid to the river basin authority. Aarnoudse et al. (2017) assume that local water officers might have been interested in keeping farmers' use at elevated levels to assure their revenue from groundwater fees.

4.1.5 The role of county water administrations and local user organisations in groundwater governance

Groundwater governance is not strong on the national but on the local-county level. It is the counties' water management bureaus that decide which instrument to use. The Water Management Bureaus have been actively involved in implementing and enforcing the water quota system and the tiered water pricing system together with the Irrigation District Bureaus (both supported by the introduction of smart card readers).

In Minqin, WUAs covering groundwater management issues have been instrumental in implementing the water quota system. WUAs were established as a component of a broader water-policy reform by the government. The Water Management Bureau of Minqin should arrange for the establishment of local organisations in each village, and it became mandatory for every household to join as an official member. The structure of the WUA board is primarily based on existing village committees, with Farm Group leaders to ensure representation from various agricultural factions.

The reform authorised WUAs to perform key functions such as selecting wells for closure, issuing water permits per households, overseeing the smart card system and above all, enforcing the per capita water quotas in order to adhere to overall water allocation targets. However, WUAs operate in a narrow scope for decision-making: once Irrigation District Bureaus had defined the limits of wells per village, WUAs selected them; per capita allocation targets were determined by the local water administration, WUAs enforced them.

With the inception of WUAs, the Water Management Bureau of Minqin could directly interact with local groundwater institutions, and could enforce regulatory prescriptions with their assistance (Aarnoudse et al., 2012). However, in Guazhou County, Water User Associations did not play a role in implementing the tiered water pricing system.

Table 5: Regulatory instruments and organisations mandated

Legal and regulatory instruments	Organisations mandated
Water Law (2002 Revision) urged regulation in overdraft areas	**Ministry of Water Resources**, national authority **River Basin Authorities** coordinate activities related to River Basin Management Plans **Water Management Bureaus** at county level **Irrigation District Bureaus** **Water User Associations** at village/sub-village level act as intermediaries between local water administration and farm groups
Licenses for Well Drilling (1987) and Water Quotas (2010) implemented in Minqin	Managed by **the Water Management Bureau of Minqin County** and **Water User Associations**
Tiered Water Pricing (2007) implemented in Guazhou	Managed by **the Water Management Bureau of Guazhou County**

4.1.6 Lessons learnt

Both counties have witnessed significant groundwater stress due to pumping activities that began in the early 1970s. This historical trend has urged authorities at county level to introduce instruments such as a water quota system, and tiered water pricing. Both instruments aimed at the reduction of groundwater use in small-scale irrigated agriculture, and were supported by the introduction of smart card machines. The instruments were not equally successful: groundwater use decreased in Minqin county, but increased in Guazhou county.

However, it is not entirely clear why one instrument worked and the other did not. Nevertheless, there are at least some relevant factors that can be named:

In Minqin, the quota system was part of a River Basin Management Plan, in Guazhou it was not backed up by clear targets formulated in a water allocation plan.

In Minqin County, the reduction in groundwater use can be attributed to the measures enhancing the supply of surface water for irrigation. Furthermore, water quotas have been linked to a rewarding system for local water officials once they achieve allocation targets. And finally, WUAs were instrumental in implementing per capita quota, and provided a means of control over users.

In Guazhou County, the economic incentive of tiered water pricing did not materialise because of the faulty design of the tariff system. Furthermore, it was hampered by dis-incentives that confronted the local Water Management Bureaus with a loss of revenues when surface water fees were re-directed to the River Basin Organisation Authorities. The expanded use of groundwater, on the other hand, guaranteed them a source of income.

The cases show that success does not only depend on the implementation of a specific instruments, and even less on the introduction of smart card machines (even though these facilitate monitoring), but on the overall institutional arrangements, in the case analysed, on the incentives/dis-incentives provided to local water officers.

4.2 Case study Upper East Region of Ghana

In those regions of Ghana where shallow groundwater irrigation is widespread, traditional authorities and local communities govern access to and use of groundwater resources based on customary (land) rules. There, the development of shallow groundwater resources for dry-season irrigation has been initiated by smallholders who are producing staple crops and vegetables for household consumption and urban markets. Irrigation has increased their households' incomes significantly if compared with those not practicing irrigation (Laube, 2015; Namara et al., 2011), and decreased rural-urban migration. It has been an important strategy to adapt to changing climatic conditions (Laube et al., 2011).

4.2.1 Aquifer characteristics, and potential for development in the Upper East Region

In Ghana, the occurrence of groundwater is linked to three geological formations: the basement complex, consolidated sedimentary formations underlying the Volta basin, and sedimentary rocks (Agodzo et al., 2023). In the Upper East Region, groundwater is utilised in the Anayare and Atankwidi catchments which are sub-catchments of the White Volta River bordering Burkina Faso. There, temperatures are high, and a single rainy season exists from May to October with an average annual rainfall of 900 mm. The Upper East Region has a reasonably high recharge rate of 4 to 13 percent rainfall. Aquifer depth is shallow with low storage and moderate transmissivity; well yields are generally low.2

Over the past decades, annual groundwater production in the Volta basin through boreholes, hand dug wells, and piped systems has increased substantially, reaching an estimated 88 MCM/year, giving approximately 44 percent of the population improved access to groundwater" (Martin and Van de Giesen, 2005: 239).

Early hydro-geological assessment studies came to the conclusion that the present production in the relatively dry northern areas of Ghana should not be expected to have any significant impact on the water balance, and that dry-season irrigation could be expanded 14- to 18-fold (Martin, 2006; Namara et al., 2011: 20-21; Obuobie et al., 2013; Anayeh et al., 2013). Results of a hydro-geological assessment study funded by the Canadian International Development Agency (CIDA) confirm that "the annual recharge estimated indicates that less than 2 percent of recharge from rainfall is being abstracted annually. Over-abstraction may occur in some localised areas though."3 The most recent assessment states that groundwater irrigation can be increased with little risks of overexploitation, even in the face of climate change and variability (Dittoh, 2020: 19).

However, in an unpredictable environment with long dry seasons and dry spells, water levels dropped, for instance in 2006, and had negative impacts on yields and income (Laube et al., 2011; Laube, 2015), but recovered in the following years.

4.2.2 Farmer-led development and use of shallow groundwater for dry-season irrigation

The construction and use of wells of various sizes (i.e., depth and width) for irrigation is very common throughout Ghana wherever shallow groundwater is available. This is especially prevalent in the three northern regions and south-eastern coastal strips. In the mid-1990s, hundreds of peasants in the catchments of the Anayere and Atankwidi rivers started to harvest shallow groundwater from wells for irrigating vegetable gardens. Farmers use environmental indicators to locate suitable sites for digging wells, and transfer of local

[2] Http://www.wathi.org/ghana-water-resources-profile-usaid-swp-august-2021 (accessed on 24 June 2023).

[3] Http://www.wrc-gh.org/water-resources-management-and-governance/ground-water-management/ (accessed on 24 June 2023).

knowledge across communities allows to define suitable time when to dig and to determine the source and timing groundwater recharge (Kwoyiga and Stefan, 2018).

There are several types of shallow groundwater irrigation in the region as well as throughout Ghana, depending on hydro-geological as well as on economic and financial factors (see Box 5).

Box 5: Types of shallow groundwater irrigation in Ghana

Seasonal shallow wells are used by farmers in areas with high water tables in low-lying areas, often along river banks, on riverbeds, in swampy areas, or close to poorly functioning formal irrigation schemes. Farmers produce vegetable during the dry season, and cultivate staple crops such as maize, sorghum, and millet in the wet season. Depth of seasonal shallow wells ranges from 1 to 5m depending on the level of the water table and the technology used for lifting water. Simple tools like bars, axes, and hoes are used for digging. A rope is tied to a bucket and the loose soil is collected and pulled out of the well until the water table is reached.

Permanent shallow wells are developed closer to the homestead or even in the living compound, near urban centres, and in fields away from homesteads. These wells are lined with cement, or are unlined, and well depth ranges from 1 to 14m depending on the groundwater level. Simple manual tools are used to construct the wells. The output of these wells is rather low, and water is usually lifted manually (rope and bucket, rope pump with bucket), and sometimes with motorised pumps. Farmers may have a number of wells to minimise labour required for irrigation. These wells are used throughout the year mainly for vegetable farming, domestic use, and livestock watering.

Source: Namara et al., 2011: 20-21.

4.2.3 Governance by statutory law and formal institutions alongside with customary rules and traditional authorities and communities

In Ghana, the law on water is one of pluralism, i.e., a mix between customary and statutory laws and regulations (Sarpong, 2008: 3). According to statutory law, water resources are regulated by the Water Resources Commission (WRC) Act of 1996 and the Water Use Regulations of 2001 which rule that “the property in and control of all water resources is vested in the President on behalf of, and in trust of the people of Ghana” (Section 12 of WRC Act 522). Hence, there is no private ownership of water, and permits defining use-rights must be granted by those authorised, namely the WRC. However, some users are exempted from applying for water-use permits (see Table 6).

Officially, shallow groundwater schemes are characterised as informal if the area irrigated is not greater than 0.5 hectares; if farmers use simple structures and equipment, and if investments are small and funded by farmers (Kwoyiga and Stefan, 2018). Also, the Drilling License and Groundwater Development Regulations (2006) allow exemptions for communities and individuals who construct hand-dug wells for domestic water supply (Pavelic et al., 2012). The Irrigation Development Authority (1987) under the Ministry of Food and Agriculture is mandated to develop and manage surface irrigation projects (reservoirs, irrigation network). Groundwater is not seen to be IDA’s responsibility, and groundwater irrigation is not specifically targeted in any irrigation policy statements. This picture does not change if one looks at the district level: District Authorities only support the development of groundwater resources for domestic supply: their Agricultural Offices’ mandate does not include irrigation; hence, irrigators do not benefit from the provision of agricultural inputs like fertilisers and seedlings, and from services targeting on-farm water management. To conclude:

Informal irrigation does not receive the same state support as formal and large-scale commercial surface irrigation schemes, and "even subsidies on inputs given to rainfed farmers do not extend to dry-season production" (Dittoh, 2020: 14).

At the strategic level, no official support was provided for these informal (smallholder) systems until 2018. The Agenda for Transforming Ghana's Agriculture (2018-2021) intended to promote enhanced water management in rainfed agriculture on 3,000 hectares until 2021 (Ministry of Food and Agriculture, January 2018: 46). However, it is not clear whether these goals of the Ministry of Food and Agriculture have been achieved.

At the local level, local authorities continue to govern access to and tenure of land, and, because water rights are rooted in customary land rights (riparian doctrine), also access to and use of (ground-)water resources.[4] Under customary law, water is considered a common (public) good, vested in stools, communities and families, and not subject to individual appropriation. It is the earth priests that are the custodians of land: they grant access to land and groundwater for dry-season farming. Landownership is communal, and individual use does not translate into ownership; individuals (families) only enjoy usufructuary rights to water. However, as Sarpong mentions, "no customary rules were developed or evolved to address matters such as (…) irrigation" (2008: 4).

Kwoyiga specifies that "access to land for such purpose (shallow groundwater irrigation) is usually obtained through negotiations with people who own pieces of land near suitable groundwater locations. Individual farmers who are fortunate to own land at such locations easily put them to use" (Kwoyiga, 2019: 403). If no land is available, one approaches relatives, in-laws, neighbours or friends: "…most household heads owning irrigable land are willing to share their land during dry season because they usually do not have the necessary capacities of labour and capital to farm the land under their control" (Schraven, 2010: 122-3).

Traditional authorities and communities argue that the official regulations (WRC Act, Water Use Regulations) are unconstitutional because the Ghanaian Constitution (1992) would recognise the existence of common law (Sarpong, 2008). Their claims would not be recognised although local communities still regard local authorities as 'owners' of land and water resources (Agyenim and Gupta, 2010: 347).

No one is allowed to trespass on another irrigators' land and access their groundwater structure without consent. If farmers practicing shallow groundwater irrigation face scarcity of water, they negotiate with others farmers: "Influenced by social bonds or sense of togetherness, irrigators, however, sometimes help one another by granting access to water in their wells" (Kwoyiga, 2019: 408).

However, the studies reviewed do not provide information on how access among those using one well is regulated when groundwater levels dropped due to insufficient rains and poor infiltration, and when lowering wells is not possible.

[4] According to Sarpong, it is not clear "as to whether or not customary law treats groundwater as part of land so as to render same capable of being owned by an individual who owns the land under which it is situated" (2008: 4).

Table 6: Regulations of (ground-)water resources

Legal instruments	Content
Statutory rules	
Constitution of Ghana 1992	The Constitution recognises the existence of common law, i.e., traditional authorities are the 'owners' of land and water resources; customary land is vested in stools, skins, and land-owning families.
Water Resources Commission Act 522, 1996 Water Use Regulation Law (Legal Instrument, LI 1692), 2001	Both legal instruments rule that "the property in and control of all water resources is vested in the President on behalf of, and in trust of the people of Ghana", and permits must be granted by those authorised. Users are exempted from the permit requirement if water abstracted by mechanical means does not exceed 5 litre/sec, if water abstracted is used in subsistence farming, and if the area to be irrigated does not exceed one hectare (Regulation 10).
Drilling License and Groundwater Development Regulations (LI 1827), 2006	A drilling license is required for monitoring and abstracting water.
Irrigation Development Authority Regulations (LI 1350), 1987	IDA is mandated to develop and manage irrigation projects, and to provide e.g., water management services to formal irrigation and large-scale commercial schemes.
District Assemblies District Agricultural Offices	Districts invest in drinking water infrastructure and irrigation (small dams, dugouts). Services of the districts' Agricultural Offices are not provided to informal irrigation schemes.
Customary rules	
Local governance based on customary rules (traditions)	Water use-rights are rooted in customary land tenure (riparian doctrine). Land is communal and granted to individuals, families, and clans. Earth priests are the custodians of land, and grant access to land and indirectly to groundwater, while chiefs would be engaged in settling disputes. Access to groundwater is based on contributions to the construction and maintenance of wells.

Source: van Edig, Engel and Laube, 2002; Agyenim and Gupta, 2010; Kwoyiga, 2019

What are the constraints to expand shallow groundwater irrigation? - According to Dittoh's study "Assessment of the Farmer-Led Irrigation Development in Ghana" (Dittoh, 2020) for Water Global Practice issued by the World Bank Group, the aquifer system in the dry northern areas of Ghana is sufficiently recharged to allow further development of groundwater resources. Martin and van de Giesen mention that "these problems (of over-exploitation and a decline of the water table) are usually caused by low transmissivities unable to sustain a yield large enough to match the pumping rate and should not be expected to have regional impacts" (Martin & van der Giesen, 2005: 245). Obuobie et al. (2013) who assessed the potential in two areas of north-eastern Ghana concluded that groundwater irrigation could be expanded 14- to 18-fold.

So much for the positive side. Barriers are many, one major being political because groundwater irrigation is not specifically targeted in any irrigation policy statements nor do public institutions address and support shallow groundwater irrigation by smallholders. The list of constraints to efficient development and management of water resources (not only groundwater) is long: understaffing, low technical capacity, limited funding and unreliable, insufficient hydrological and water quality data would hinder planning and management. These all affects the WRC's ability to manage and monitor water use permits.[5]

Dittoh (2020) also mentions factors beyond administrative bottlenecks such as: availability of land suitable for irrigation; availability of labour for the labour-intensive irrigation; impediments due to the local land tenure system; lack of capital and official support (subsidies to invest in shallow groundwater irrigation); lack of extension services (crop diseases, on-farm water management), and finally, constraints of the market(ing) system.

4.2.4 Discussion and recommendations

Groundwater resources in the region have not been overexploited although changing rainfall patterns have sometimes created stress on dry-season irrigation practices. Schraven assumes that scarcity of land and labour, and the use of low-tech for digging wells as well as for applying irrigation water has prevented overuse (Interview Schraven), alongside with constraints created by hydro-geological features (if, e.g., groundwater layers cannot be tapped by hand-dug wells).

Customary authorities have supported agronomic improvements such as the use of groundwater for irrigation. Hence, customary authorities and customary land tenure are not per se insurmountable barriers to rural development (see Derbile (2012) for the role they play in managing community-based surface irrigation systems). Consequently, one needs to acknowledge the role traditional authorities can play in promoting livelihood strategies which nevertheless require official support – and this concerns on-field water use and access to financial services among other issues.

What one can see here; it is not so much a customary common property regime on (ground-)water but on land: access to groundwater is free if one has access to land. It is the allocation of land, and not (ground-) water, that is regulated by traditional authorities (the riparian doctrine applies). In case of conflicts between farmers over access to groundwater, if several farmers draw water from the same well, resolution of conflicts is a matter for them. There are no local (customary) rules that address scarcity issues, and that guide the collective of users how to balance allocations if not all demands could be accommodated (it is not clear, anyway, if overuse is caused by abstractions of the many wells existing). There are few, if any, direct, preventive rules related to water abstractions, one being that 'No drilling is allowed on sacred grounds!'.

Under the given circumstances (low-tech lifting devices, the small size of the land cultivated), the existing rules to groundwater abstractions are sufficient. However, if high-tech technologies (e.g., solar pumps) are invented, and if demand increases, regulatory instruments, such as water-use permits would have to be implemented to balance demands and avoid the overuse of the resource.

[5] Http://www.wathi.org/ghana-water-resources-profile-usaid-swp-august-2021 (accessed on 24 June 2023).

4.3 Case study Andhra Pradesh India

Over the last five decades, policies led to an exponential expansion of groundwater extraction in India. Lack of effective governance mechanisms to promote sustainable use of groundwater have led to over-exploitation and degradation of groundwater. In hard crystalline rock aquifers, the Andhra Pradesh Farmer-Managed Groundwater Systems (APFAMGS) promoted capacity development tools for collective monitoring of groundwater aquifers which led farmers to make decisions for efficient use of water. Further, game-based experiential learning tools were piloted to promote rules for water sharing in these water scarce regions. While the efforts have succeeded in promoting sustainable groundwater use behaviour among the project participants, its long-term sustainability is contingent on effective adaptation of the capacity development tools to the local context and integration into agricultural extension systems.

4.3.1 Groundwater development and aquifer characteristics

In India, 65 percent of irrigation supply is sourced from groundwater extraction, which is a result of an exponential increase in irrigation wells (open wells and tube wells) from 0.15 million in 1960 to nearly 20 million in 2000 (Shah, 2009). Policies that favoured the distribution of affordable irrigation pumps, subsidised agricultural inputs such as seeds, fertiliser and electricity have led to this massive expansion of groundwater irrigation (Briscoe and Malik, 2006). The massive development of water infrastructure (also surface water) was not sufficiently accompanied by an improvement in the governance of water resources and water services (ibid), leading to over-exploitation and degradation of groundwater resources. While the links between subsidised inputs, especially electricity, and groundwater decline are debated in literature, these policies have had differential impacts on different types of aquifers in India.

Alluvial aquifers and **hard crystalline rock aquifers** constitute 28 percent and 31 percent, respectively, of the total aquifer systems in India. While the deep alluvial aquifers with higher specific yield and storage are not immediately affected by declining groundwater under the currently subsidised (100 percent) electricity regime, shallow aquifers with low storage capacity underlying most of the semi-arid Southern India are likely to be depleted by the ongoing declining trends (Sishodia et al., 2016). The groundwater levels in these aquifers are recharged during the rainy season (June to October) and decline quickly as a result of pumping during the dry season (November to May). Therefore, the dynamics in this aquifer system mean that there cannot be a continuous long-term decline of groundwater as the shallow water table recharges with good rainfall. Groundwater aquifers are crucial for adapting to climate variability and change in the rainfall dependent semi-arid tropics. However, low storage capacity and yield of the aquifers and increased dependence on groundwater is leading to frequent well failures. The impact of an ineffective governance regime has been significant in the shallow hard rock aquifers as this has led to a quasi-open access regime providing perverse incentives for over-extraction of scarce groundwater resource.

4.3.2 Governance approaches for sustainable groundwater use and management in the hard rock aquifer regions

In India and Andhra Pradesh, groundwater conservation, use and management behaviour at different levels are all affected by a complex web of formal and informal rules. Table 7 provides a list of key policy instruments, which have an impact on groundwater management. With regards to the formal rules, the Constitution of

India empowers the federal states to regulate groundwater resources through appropriate regulatory/administrative and economic instruments or through further empowerment of communities to manage the groundwater resources that they use. However, the government of India provides the broader institutional framework by formulating and enacting policies and Acts for regulating and developing water. Besides these directives, the central government also provides support for states to adapt and implement national policies and legislations. Studies have shown that there is a wide variation across states in adopting and implementing the Model Groundwater Bill, 1970, and its subsequent revisions (World Bank, 2010). For example, the bill provides for establishing and empowering state groundwater management agencies and regulations targeting large groundwater users. Only a few states have established such an agency, and if, without sufficient capacities to discharge the regulatory and development functions as foreseen by the Model Groundwater Bill.

Table 7: Formal institutional framework governing groundwater in India and Andhra Pradesh

Policy instrument	Aim and mechanism of governance
Model Groundwater Bill, 1970, Model Groundwater (Sustainable Management) Bill 2017 (latest) *Regulatory*	The first and successive Model Bills stipulate the establishment of a central authority for groundwater development and management, as well as regulating the use of groundwater through control of drilling wells. The 2017 Bill extends the doctrine of 'public trust' to groundwater, just as for surface water, dispelling the hitherto popular view that groundwater is a privately-owned resource linked to the rights to land above the aquifer. It further gives groundwater regulation a strong orientation of environmental protection, where any foreseeable environmental damage resulting from prospective use of groundwater needs to be prevented.
National Watershed Development Programme (NWDP), 1994; later Integrated Watershed Management Programme (IWMP) *Technological, capacity development and economic*	Watershed development is a supply-side intervention for augmenting the aquifer recharge by reducing the run-off through soil conservation measures. Community members adopt these measures on private and communal lands, thereby increasing the percolation of rainwater to recharge the aquifer. The 1994 landmark guidelines and subsequent revisions streamlined most of the rural development programmes in the country to subsidise soil and water conservation measures. Managed aquifer recharge is another supply-side intervention which focuses on similar technical measures through capacity development measures at community level.
Andhra Pradesh Water, Land, Trees Act (APWALTA), 2002 *Regulatory*	APWALTA is a comprehensive legislation enacted by the then Government of Andhra Pradesh to regulate the use of groundwater though mandating the registration of existing wells and ensuring a minimum distance between wells through mandating permissions to be issued by a competent authority for digging new wells.
National Water Policy, 2012 *Regulatory*	Recognises that groundwater is currently being over-exploited and states the need for managing groundwater as a common property resource and regulating its use through regulating the use of electricity by using separate electric feeders for groundwater pumping for irrigation.

Andhra Pradesh Micro-Irrigation Project (APMIP), 2003; National Mission on Micro-Irrigation (NMMI), 2010; National Mission for Sustainable Agriculture (NMSA), 2014 *Technological and economic*	Micro-irrigation is a technological intervention where central and state governments promote the adoption of drip and sprinkler irrigation technologies by subsidising the costs of installation by 40 to 90 percent in order to deal with impending water scarcity for irrigation and to improve the water-use efficiency in agriculture.
Andhra Pradesh Farmer-managed Groundwater Systems (APFAMGS) Project, 2003 – 2013 *Capacity development, technical and informational instrument*	APFAMGS project promotes community management of groundwater resources through development of capacities of communities to collect and analyse data to understand the dynamics and status of groundwater in the aquifers from which they withdraw. The newly co-generated knowledge is supposed to trigger local collective action for sustainable management of groundwater by making informed choices of crops and irrigation technology and frequency based on crop water requirements.

Supply-side instruments are principally technological interventions adopted either collectively at an aquifer or micro-watershed level by members of a community, or individually on private farmlands. These include soil conservation technologies, which also reduce runoff and enhance infiltration of water into the ground. The watershed development/management and managed aquifer recharge projects across different states have contributed to the enhancement of groundwater availability. The costs for soil and water conservation measures on private and common lands that increase the supply of groundwater are subsidised by either central or state governments. While these efforts were successful in achieving their aims of improving the groundwater resource base, their long-term sustainability depends on the equitable and efficient use of the groundwater, which often falls out of the purview of these instruments.

Demand-side instruments primarily include regulatory measures that aim to control the drilling of new wells, rather than controlling the volumes of water withdrawn from the aquifer. These instruments are typically enforced in a top-down manner by groundwater agencies of respective states, where such Acts are enacted. The Government of Andhra Pradesh (which included the present-day Telangana state) introduced a progressive legislation called Andhra Pradesh Water, Land and Trees Act (APWALTA) in 2002, which required farmers to register the existing tube wells and receive permission to drill new tube wells. However, this regulatory instrument failed to achieve the desired result. A study observed that 66,000 new individual agricultural electricity service connections were granted in reality, while permissions were granted for only 2,500 new wells during the year 2005-06 (Sishodia et al., 2016). Further, central and state governments subsidised micro-irrigation systems to improve water-use efficiency. Some of the main constraints that led to the low-scale adoption of micro-irrigation technologies are lack of knowledge on crop water requirements, lack of capacity building in technology transfer programs, inadequate access to water or water storage structures, and disincentives due to low or zero pricing of energy and water for irrigation (Nair and Thomas, 2023).

Besides these targeted instruments, a number of sectoral development and regulatory policies have an impact on groundwater availability and use. The subsidised agricultural inputs, including free electricity, although targeted to benefit small and marginal farmers, had in fact negative impacts on them. Majority (90 percent) of the small and marginal farmers do not own irrigation wells and where they own, they ran dry due to the competitive drilling of tube wells in which they cannot participate due to lack of resources (Kumar et al., 2013; Fosli, 2014). The National Water Policy of 2012 states that groundwater "needs to be managed as a community resource held, by the state, under public trust doctrine to achieve food security, livelihood, and equitable and sustainable development for all". However, the governance structure for groundwater in India has so far failed to establish groundwater as a common property resource.

4.3.3 Community-based approach to sustainable use and management of groundwater

The failure of the regulatory instruments has led to experimentation with informal and participatory groundwater management in different parts of the country, either supported by federal states, or through bilateral or multilateral funding support. One such initiative was the Andhra Pradesh Farmer-Managed Groundwater Systems (APFAMGS) in the hard rock aquifer districts of the federal state of Andhra Pradesh. The approach involved **informational and capacity building** instruments for promoting a participatory management regime for a hydrogeological unit (Reddy et al., 2021). The initiative was funded by several bilateral and multilateral agencies (Royal Netherlands Embassy of India, FAO and Global Environment Facility (GEF), in seven districts of the erstwhile Andhra Pradesh state. Following the projects closure in 2013, there were attempts to sustain and upscale the initiative. The core capacity building component of the project focused on mobilising the communities of groundwater users to organise themselves into groundwater management committees (GMC) at the village level and all the GMCs in villages sharing an aquifer into hydrological units. In total, 555 GMCs were established and networked across 63 aquifers or hydrological units (World Bank, 2010).

The APFAMGS project-initiated Farmer Water Schools (FWS) based on a participatory approach to sharing of information and collective learning. About 10,000 famers attended 300 FWS, organised fortnightly over a span of five years in the project region. During the FWS, farmers were trained to understand the groundwater dynamics in their villages as well as in the entire hydrological unit. The farmers trained in the FWS then became volunteers for participatory hydrological monitoring, where they created and shared an understanding on groundwater dynamics in their community by fortnightly monitoring of water level in 2,026 observation wells, collection of rainfall data from 190 rain gauge stations and measuring well discharge from 700 observation wells. The volunteers maintained the records of hydrological monitoring and shared the information with other community members through public viewing. Further, based on the knowledge on water availability for each season, farmers collectively made crop plans for dry and wet seasons. Impact studies showed that although the project emphasised only on improving water use efficiency, and did not impose any restrictions on crop choices, farmers tended to diversify towards less water-intensive crops voluntarily with an aim to minimise risk (World Bank, 2010; Reddy et al. 2021).

The information and capacity development tools for groundwater monitoring were successful in promoting efficient water use to some extent. However, in the absence of any **rules for water-sharing** between well-owners and non-well-owners, sustainability of these approaches is questioned (Bruns and Meinzen-Dick, 2022). One reason behind the uncertainty of long-term success of APFAMGS lies in the project's exclusive targeting of well owners, who constitute less than half of the farmers. In absence of arrangements that treat **water as a common property resource**, there is a danger of jeopardising the benefits of such targeted community-based efforts. Without access to water for irrigation, the non-well-owning farmers lack incentive to contribute to collective conservation efforts for recharging the aquifers. Further, the social regulation on restricting new wells will be ineffective, as non-well-owners tend to dig their own wells increasing the frequency of well failures.

One of the innovative methodological approaches applied for promoting rules for water-sharing was through **'game-based experiential learning'** to solve the social dilemma situations of groundwater management in APFAMGS villages by the NGOs, Foundation for Ecological Security and Jana Jagriti (Meinzen-Dick et al., 2018; Falk et al., 2023). This approach combined information-based tools of groundwater monitoring with framed field experiments simulating farmer-participants' crop choices and their impacts on aquifers (Meinzen-Dick et al., 2016). The results of the games indicate that farmers cooperate in making their crop choices, in light of knowledge on the impacts of choices on the groundwater resource. Assessment of learning effects of the game, both immediately after the game and after a year, indicate that farmers who participated in the games are more likely to engage in coordinating the selection of crops leading to the conclusion that such game-based learning approaches do have the potential to shape mental models of groundwater users (Falk et al., 2023). Similar learning effects of the games as observed in the Indian cases were reported in the selected Meki River catchment of Ethiopia (ElDidi et al., 2023). Despite the demonstrated "proof of concept" for the game-based tools, social learning and possible spill-over effects from game participants to larger community seems to be challenging. To have a larger-scale impact, tools need to be localised and embedded into the regular capacity development mechanisms such as by involving the agricultural extension agencies. Although, the new approach in isolation may not be a panacea, in combination with other tools such as groundwater monitoring tool and crop water budgeting tools and accompanied capacity development efforts, this can trigger social regulations for more sustainable groundwater management at the aquifer level.

The success of this initiative based on experiential learning is further attributed to the commitment and efforts of the implementing NGOs, which had a long-term presence in the region. However, the long-term success and sustainability of such an initiative still hinges upon the incentives provided by the current energy and groundwater governance regimes as well as pricing policies favouring water-intensive crops (Reddy et al., 2021).

4.3.4 Lessons learned for community-based governance of groundwater

Community-based groundwater management: The APFAMGS model in India proves that enabling communities with appropriate capacities to generate and use information on groundwater dynamics is effective in nudging farmers towards judicious groundwater use based on collectively generated scientific evidence on groundwater dynamics. This does not depend on altruistic collective intentions and equity considerations, rather on individual risk minimisation through diversification to non-water intensive crops. This model is especially suitable for hard rock shallow aquifers, which have similar dynamics of depletion and replenishment due to low storage capacities.

Coordinated approach for groundwater development: The APFAMGS project developed capacities for understanding the groundwater dynamics. However, farmers need knowledge and resources for adoption of improved cultivation and irrigation technologies and practices. For example, diversification towards low-water intensive and high remunerative crops requires knowledge on cultivation practices, crop water requirement and critical irrigation stages as well as availability of inputs such as seeds, fertiliser and efficient irrigation technologies. Therefore, design of new community-based irrigation schemes should consider the capacities of agricultural extension services by including coherent components for capacity development.

Capacity development methods for social learning: Further, innovative approaches to develop capacities of communities to design and enforce rules for groundwater use under a common property rights regime need to be included in the design of new groundwater development interventions. The game-based experiential learning tools prove to be complementary to other tools for capacity development of communities for groundwater management. While there is potential for these tools to create an impact on behaviour, the learning modules need to be adapted to the local context and integrated into the local extension mechanisms so that they are used on a regular basis for effective social learning.

Coherent policies to improve synergies in the groundwater-energy-food security nexus: The tools for groundwater monitoring and game-based experiential learning led to choices of less water-intensive crops grown and efficient technology/practice of irrigation in the study areas. However, its long-term sustainability in promoting adoption of sustainable groundwater use is also contingent upon the incentives provided by the energy and agricultural (input subsidies, price support and public procurement of crops) policies. Therefore, efforts must be made within the scope of the development intervention, to influence policy makers to avoid/ minimise trade-offs resulting from policies of water, energy and food sectors.

Integrating supply- and demand-side measures of groundwater management: Measures for augmenting the supply of groundwater resources such as watershed development programmes need to include efforts to develop capacities of communities for making crop choices and adopting efficient irrigation technologies that promote rational and efficient use of water. Inclusion of non-well owners is crucial for the sustainability of community-based groundwater management initiatives.

4.4 Case Study La Mancha region Spain

The Mancha region, located in south-central Spain, showcases the intricacies of groundwater management in agriculturally intensive areas facing serious environmental degradation. The example of the Western Mancha Aquifer is paradigmatic due to the variety of policy tools implemented at various political and administrative levels. At the national level, the transformative 1985 Water Law shifted groundwater rights from private hands to public control. The example shows, however, the challenges in enforcing such a fundamental shift, highlighting the need to accompany such measures with sufficient institutional and financial resources. Introduction of abstraction quotas in the Western Mancha Aquifer demonstrated the political sensitivity of top-down regulatory instruments and the need to accompany such measures with sound compensatory measures and other incentives. It also demonstrates the challenges of monitoring and enforcing policy instruments such as abstraction quotas. While Groundwater User Associations exist in the Western Mancha Aquifer, the example shows that they also need to be equipped with necessary authority and sufficient resources. Otherwise, their contribution to groundwater management is easily reduced to lobbying for powerful user groups.

4.4.1 Aquifer characteristics and groundwater use in La Mancha

As a critical hub for agriculture and groundwater-dependent ecosystems, the La Mancha region in south-central Spain grapples with the multifaceted challenges of groundwater governance and management. Situated within this region is the Western Mancha Aquifer, a pivotal component of the Upper Guadiana sub-basin that is part of the larger Guadiana River Basin shared between Spain and Portugal.

Set against a climate characterised by hot, dry summers, brief winters, and an average annual rainfall of 415 mm, the La Mancha Region's groundwater dynamics are shaped by the intricate network of rivers, wetlands, and aquifers. The region's subtle topography, combined with its distinct geological features, leads to a less pronounced surface drainage system, underscoring the connection between its surface and groundwater resources (Custodio, 2002). Four primary aquifer systems stand out: Western Mancha, Campo de Montiel, Sierra de Altomira, and Mancha de Toledo.

The Western Mancha Aquifer is particularly notable for its vast expanse, covering approximately 5,500 km², and its significant groundwater storage capacity. The aquifer is characterised by limestone and is highly permeable due to fistulation and karstification. Its renewable resources vary between 200 MCM/year during dry spells and 500 MCM/year in wetter periods, with the Guadiana River Basin Plan providing a more conservative estimate of 260 MCM/year. This abundant groundwater also feeds important wetlands, notably the Tablas de Daimiel, an international Ramsar protected wetland and a National Park. Between 1980 and 1997, extensive water-table drawdowns not only escalated water costs but also diminished the springs initiating the lower Guadiana River and disrupted the subterranean flow to the Tablas de Daimiel wetland, significantly reducing its flooded area from 1,800 hectares in the 1960s to as little as 15 hectares in 2009 (Closas and Molle, 2016).

The Western Mancha Aquifer also holds socio-economic importance as groundwater-fed irrigation has played a crucial role in the economic development of La Mancha. The tail end of the 1970s marked a transformative period as the Western Mancha aquifer was intensively exploited to transition the region from predominantly dry-farming territories to irrigated lands (Closas, Molle and Hernández-Mora, 2017). The most notable change was the shift towards irrigated vineyards, especially during the 1990s and 2000s. This was partly linked to specific funds for the modernisation of agriculture and EU subsidies paid for the cultivation of vine (Closas and Molle, 2016).

In the Western Mancha, there was a significant increase from 30,000 irrigated hectares in 1973 to 130,000 ha by 1989. This intensive groundwater use led to many wells drying up by the late 1980s, sparking what was termed a "pumping war". Abstractions rose from 150 MCM/year for the period 1960 to 1976, to 600 to 700 MCM/year in the late 1980s. Particularly in the Western Mancha Aquifer, from 1980 to 1995, the annual extraction rates consistently exceeded its natural recharge capabilities. This imbalance resulted in a yearly water level drop of 1 meter throughout the 1990s (Closas and Molle, 2016; Lopez-Gunn, 2003).

4.4.2 Transition from private groundwater rights to public domain: the 1985 Water Law

Groundwater abstraction rights in Spain were linked to landownership and thus considered private property since the 1897 Water Law. The rationale behind this was to promote agricultural and economic growth through private investments in groundwater development in regions like La Mancha. Existing wells only had to be registered starting from 1934, but many users did not follow the respective decree. As Spain underwent broader political and socioeconomic shifts in the 20th century, concerns about sustainable water management, equitable distribution, and environmental conservation began to take centre stage. The 1985 Water Law was born out of these concerns and marked a critical transition of water and groundwater rights from private ownership to the public domain. The law stipulated that the state, through River Basin Authorities (RBA), would regulate and control groundwater abstractions by requiring concessions for all new users (except for wells under 7,000 m3/year). Recognising the historical establishment of private groundwater rights, the law aimed to transition these rights into concessions, following a predetermined transitional phase. Existing well owners were presented with two distinct pathways to register their rights during the 3-year window provided by the law:

1. Secure a "private water right" for a 50-year duration until 2035 through registering it in the Registry of Public Waters. After this period, they would be given priority by the state to receive an administrative concession, allowing them to continue extracting groundwater. This pathway was essentially a bridge to move from a private right to a more formalised, state-recognised concession after the 50-year period.
2. Maintain the private right indefinitely by registering it within the Catalogue of Private Waters. Theoretically, the incentive to register groundwater historical rights in the Catalogue was to offer a form of 'administrative protection' by the state. However, many groundwater users were uncertain about the exact benefits and protections this registration would afford them.

The apparent contradiction between the 50-year transitional phase and the indefinite right through the Catalogue arises from the law's attempt to avoid compensation payments. Despite these provisions, the uptake was not as expected due to various reasons, including lack of clear information from the state and mistrust from groundwater users towards the RBA that was mandated to issue water rights. Moreover, the law's implementation was fraught with administrative challenges in the registration process, as it culminated in a surge of permit applications on the last day of the registration period in 1988, placing immense pressure on the Guadiana RBA.

To address these challenges and streamline the registration process, the government introduced two sequential national programs: ARYCA (Actualización del Registro y Censo de Aguas) in 1994 and ALBERCA

(Actualización de Libros de Registro y Catálogo) in 2002. Still, within the Western Mancha aquifer, of an estimated 40,000 wells, only 17,000 had been registered with the Guadiana RBA by 2008, revealing 52,408 hectares of unauthorised irrigation (Closas, Molle and Hernández-Mora, 2017).

Table 8: Groundwater governance instruments in the Mancha Region

Policy instrument	Contents and implementation responsibility
1985 Water Law *Regulatory instrument*	National Law transitioned groundwater rights from private ownership to the public domain. Mandated state regulation and control of groundwater abstractions. Established River Basin Authorities responsible for overseeing the registration process and ensuring groundwater abstractions complied with legal requirements.
Emergency Abstraction Regime *Regulatory instrument*	Imposition of strict groundwater abstraction quotas. Guadiana RBA introduced and enforced the emergency measures, including the quota system.
Agro-environmental Plan (AEP1 and AEP2) *Economic instrument*	Compensation payments for farmers willing to reduce groundwater use. Guadiana RBA designed and implemented the plan.
Special Plan for the Upper Guadiana Basin (Plan Especial del Alto Guadiana [PEAG]) *Economic instrument, communication instruments*	Public purchase of private groundwater abstraction rights and concessions through a 'public water bank'. The acquired rights would be transferred to farmers without legal water rights or to other priority uses. Outreach and education programs, promotion of water-saving technologies and practices to incentivise farmers to reduce groundwater abstraction. Guadiana RBA designed and implemented the plan.

4.4.3 Abstraction quotas as part of emergency regulatory regimes for overexploited aquifers

Additionally, the 1985 Water Law empowered the state to declare specific aquifers as overexploited, leading to the implementation of emergency measures. In response to the significant over-abstraction in the Western La Mancha Aquifer, the state initiated a series of measures under the emergency regulatory regime. One of the central measures was the imposition of strict groundwater abstraction quotas. Other measures under the emergency regime included the prohibition to drill new wells and the freezing of new groundwater abstraction concessions.

The Guadiana RBA introduced the initial quota system in 1991 (i.e., System 1), with the general quota set at 4,278 m^3/ha/year. This quota was modulated according to the size of farms: smaller farms (up to 5 ha) were allowed to use the full quota whereas larger farms were only granted significantly lower volumes of groundwater per hectare (Closas and Molle, 2017). However, as the aquifer continued to deplete, the Guadiana RBA implemented Quota System 2 in 1994. This new system established a universal maximum pumping quota of 2,000 m^3/ha across all crops and users. Vine cultivators were allocated a slightly lesser quota of 1,500 m^3/ha. These quotas were subject to annual adjustments, contingent on evolving climatic conditions and water requirements. Sanctions ranging from EUR 3,000 to EUR 30,000 per farmer were put in place for violations of the maximum quotas (López-Gunn, 2003). However, groundwater abstraction limitations were only imposed on those users with wells registered in the Registry of Public Waters or in the Catalogue, as illegal wells were officially unknown of. Moreover, the Guadiana RBA lacked human capacity to fully enforce sanctions for illegal wells and excessive abstractions (Closas and Molle, 2017). The logistical complexity and high costs of enforcing regulation due to the large number of independent users, posed a challenge for enforcing the quotas. Despite the use of remote sensing and meters, constantly monitoring what was happening on the ground proved to be beyond the capacity of the public administration.

4.4.4 Compensation payments other support measures for farmers

In face of significant political resistance in the farming communities resulting in the illegal drilling of wells on the one hand and demands for compensatory measures, on the other, the first Agro-Environmental Plan (AEP 1), was set up in 1992. The goal of AEP 1 was to reduce total groundwater abstractions from the Western Mancha aquifer to 240 MCM/year, by compensating farmers willing to reduce groundwater use. National funds as well as European funds under the Common Agricultural Policy (CAP) were used to support the compensation payments. Since the compensation payments were high as compared to the income losses resulting from reduced water abstraction imposed by the quota system, farmers responded positively. Especially larger farms could benefit from considerable compensation payments. Water abstraction in the Western Mancha and Campo de Montiel aquifers was reduced by 60 percent by 1997. However, indeed, the set-up resulted in European funds being used to pay farmers for merely complying with the quota regime. In response to a request from the European Commission, the AEP regime was substantially modified in 2003 and payments were hence significantly reduced. This resulted in a lack of interest from farmers and the end of the programme in 2005.

In 2008, a Special Plan for the Upper Guadiana Basin (Plan Especial del Alto Guadiana (PEAG) was approved after years of negotiations and changing governments with different priorities (see Closas and Molle, 2017). The PEAG foresaw the public purchase of private groundwater abstraction rights and concessions through a ‘public water bank’ (López-Gunn et al., 2013). The acquired rights would be transferred to farmers without legal water rights or to other priority uses. For example, water rights were bought from farmers irrigating mainly cereals and allocated to economically more productive crops, such as vine. For this to happen, potential recipients had to declare their illegal wells. This was particularly relevant in the Western Mancha aquifer, where no new concession could be granted under the emergency regime. The PEAG also outlined complementary measures to incentivise and support reduced water abstraction, including as well as outreach and education programs, and the promotion of water-saving technologies and practices.

However, the PEAG was only partially implemented due to shifts in political priorities and reduced funding. Moreover, the effectiveness of the public buy-back scheme was obscured by irregularities in its implementation. While it was intended to reduce water abstraction by those farms that sold their water right, indeed it was found that more than 80 percent of the rights purchased by the state had not been used for more than five years. There was also insufficient monitoring of actual water abstraction after the selling of water rights.

4.4.5 User participation in groundwater management in La Mancha

Spain has a long-standing tradition of user (mainly farmer) participation in surface water management. The 1985 Water Law reaffirmed this practice and granted water users (irrigators, hydroelectricity users and domestic water users) active presence and voting rights in the formal decision-making structure of RBAs. However, groundwater user communities are much rarer in Spain. The 1985 Water Law requires the establishment of groundwater user associations (GWUA) as part of emergency regimes for aquifers declared over-exploited. Most GWUA in Spain, however, emerged out of users' self-interest, e.g., to avoid state-led introduction of an emergency abstraction regime and as a response to general mistrust towards RBAs and state led aquifer management (Lopez-Gunn, 2012). Based on cultural, social and historical context, there are two main types of groundwater user communities in Spain: those established under public law and those established as private associations of individual users with private rights (such as well societies or irrigation cooperatives). Both are entitled to carry out aquifer monitoring and control of abstractions together with RBAs (Closas and Molle, 2016).

Yet, the operationalisation of GWUAs encountered certain impediments. While conceptualised as instruments of sustainable groundwater governance, they lack the mandate, management capacity and financial means to fulfil such tasks. Moreover, their focus was occasionally diverted by the pronounced influence of established farming unions. Historically, these unions have held considerable influence in agrarian regions such as La Mancha. Over time, some began to shift focus towards lobbying activities that predominantly benefitted large-scale agricultural operations. This redirection often manifested in advocacy for increased groundwater abstraction quotas and other policies that, while beneficial in the short term, potentially compromised the overarching goal of sustainability.

GWUAs in the Western Mancha Aquifer region were formed predominantly along municipal boundaries following the 1987 provisional declaration of over-exploitation. They relied on municipal governments, agricultural chambers of commerce, and farmer unions for administrative and organisational support, leading to significant influence from established farming unions. The 'General Community of Irrigators of Aquifer 23' was established in 1996 to oversee the Western Mancha Aquifer, as a compulsory measure following the definitive declaration of over-exploitation of the aquifer in 1994. It integrates the 20 GWUAs from the municipalities, representing 17,000 farmers in the aquifer region. Establishing the General Community was characterised by rivalry among the different GWUAs in the region. Moreover, according to Lopez-Gunn (2012), there is considerable mistrust between the Guadiana RBA and the user communities in the Western Mancha Aquifer region. All these factors limit their role in implementing groundwater governance at the local level.

4.4.6 Insights and lessons from groundwater governance in La Mancha

Above all, the sheer size of the Western Mancha aquifer, combined with the multitude of its users, made co-management a daunting task. The example of Spain demonstrates the difficulties in changing from a private property regime in which water abstraction rights are connected to land property to a system where water is considered to be in the public domain and where access is granted by concessions. Registration of the huge number of existing wells turned out to be a logistical challenge highlighting the considerable time and financial resources that should be foreseen for such an undertaking. Moreover, the mandated RBA was not equipped with the human and institutional capacity to manage the process, nor monitoring and enforcement of compliance.

Experience with abstraction quotas in the Western Mancha Aquifer demonstrate that top-down introduction of restrictions naturally provoke resistance from users. They therefore involve high political costs and require sufficient political will. The costs of monitoring were also found to be much higher than expected and despite the use of remote sensing and meters monitoring and enforcement of abstraction limits proved to be beyond the capacity of the RBA (Closas and Molle, 2016).

Compensation payments for reduced groundwater abstraction helped reduce groundwater abstraction and could support the introduction of abstraction quotas. However, the La Mancha example shows that farmers interest in such payments were limited to instances where farmer could generate economic benefit. Further, they need to be designed in a way that benefits are not skewed in favour of large water users.

Public buy-back schemes of groundwater rights may be opportune to transfer groundwater abstraction rights to economically more valuable uses or to allocate water for the environment. However, they need to be backed by strong monitoring capacities in order to ensure that they do not lead to reactivation of dormant water abstractions.

GWUAs were expected to play a supportive role in groundwater governance and management, acting as intermediaries between the state and individual groundwater users. However, the lack of devolution of management powers, and the GWUAs' limited financial capacity prevented them from taking on such mandates. This demonstrates that GWUAs need active support from the River Basin Authority. Moreover, the influence of farmer unions and their engagement in policy lobbying, raised concerns about their long-term efficacy in addressing the groundwater challenges of the region (Closas, Molle and Hernández-Mora, 2017; Closas and Molle, 2016).

5. Conclusions for setting up and implementing effective groundwater governance regimes

Literature review, country study analysis and interviews with actors from German Development Cooperation and German non-governmental organisations have revealed multiple challenges in designing effective policy instruments and governance arrangements for groundwater development and use - and even more so in implementing and enforcing them. The most common challenges in setting up and implementing effective groundwater governance regimes are summarised in the following paragraphs:

Natural characteristics of groundwater complicate design, monitoring and enforcement of instruments. Due to the invisibility of the groundwater resource and its complex interlinkages with surface water, the scientific-technical task to determine its extent and availability is challenging. Furthermore, information on the irrigation potential is often inaccurate and sometimes exaggerated, while the needs of aquatic ecosystems are often not known or not taken into account. Moreover, data on the number of existing wells (legal and illegal) and water-use rights (informal and formal permits or concessions) granted, as well as the amount of water actually abstracted, are often not available or unreliable. This complicates assessing the impacts and the upper limits of groundwater use, and hence the targeted design of policy instruments to prevent over-abstraction. Monitoring is a challenging issue because of the many extraction points, so is enforcement of the conditions attached to drilling licenses and groundwater-use permits (see case studies from Spain, India, and China). The reasons for incomplete data and knowledge bases are not always technical, but sometimes also politically motivated, and hence difficult to solve.

The effectiveness of instruments depends on the social and governance contexts at the national and local level. It is therefore difficult to directly transfer governance arrangements from one location to another and the idea that clear attributable effects can be expected from one instrument or the other would be misleading. In one county, abstractions quotas were expedient because water authorities could rely on local user associations in implementing them, and because water quotas have been linked to a rewarding system for local water officials once they achieve allocation targets. In the other county, water authorities opted for tiered water prices but their implementation was hampered by faulty design and dis-incentives provided to local Water Management Bureaus. Abstraction quotas were expedient in one case, in the other it was tiered water pricing (see case study North China). Efforts to put all groundwater rights under the same status by transforming historical water rights into concessions, as it was foreseen by the 1985 Water Law in Spain (see case study La Mancha), or into a permit-based system as it was done in Zambia (Scheumann and Phiri, 2018), shows that the success of these policy instruments hinges on conflicts between traditional and modern land tenure systems, hence conflicts between 'modern' and traditional authorities. It is therefore impossible to make general statements as to which instruments are best suited to prevent or reverse overuse. Moreover, it often is not just the choice of a specific instrument, or even the mix of instruments, that counts, but also the strength and competence of the actors involved, the commitment and leadership of agents of change, and whether they can effectively implement, and monitor, the instruments of choice.

Human and institutional capacity for monitoring and enforcement is insufficient, particularly at lower levels of governance. The existence of regulatory tools and other policy instruments does not guarantee that the government or implementing agencies actually avail of the necessary resources and capacities to enforce or implement them, nor that users will apply or abide by them. One indication of this are the many illegal and/or unregistered wells that can be observed in many countries. This is often referred to as the monitoring and enforcement conundrum. A key issue is whether the respective decision-making units, be they governmental or non-governmental and community-based, have the technical skills as well as the administrative and financial resources to enforce rules. Indeed, this seems to be the far bigger problem than the lack of hydro-geological data.

Social and economic implications of policy instruments hamper their acceptance and enforcement. While subsidies have positive distributive effects, bans, quota and the closure of registered and unregistered wells negatively affect the respective users, and thus often cause resistance from those affected. Due to their social and economic implications, decisions on instruments to either promote or regulate groundwater use may rather come about as a result of political pressure from interest groups, than due to their potential in regulating resource use. Moreover, as a consequence of the political economy of existing resource use, corruption and by-passing of formal rules may indeed overrule formal provisions, which makes it even harder to assess their effectiveness in advance.

It is much easier to gain support for increasing the supply of water and decide on subsidies, than to control demand for water, hence water abstraction. Nevertheless, even if supply side approaches are confronted with less resistance from the user side, they require significant infrastructure investments, and coordinated action between sector institutions. Demand side approaches, on the other hand, may have to be complemented with compensation schemes, as they have been introduced for example in Spain and China (see case studies above). In Tunisia, harsh social and economic effects were cushioned, by first closing unregistered wells of large groundwater consumers that had significant impact on water tables, while allowing smaller scale unregistered use to continue during a transition period. Environmental and Social Impact Assessment studies may be one instrument to assess impacts and identify compensation measures. However, their value as a planning tool depends on the quality of baseline data, and on their status in overall decision-making procedures (political landscape).

Insecure land and water tenure of smallholders obstruct the promotion of groundwater irrigation as well as sustainable groundwater management. In order to create incentives for smallholders to invest in groundwater, water tenure systems, either modern or customary, must provide security for investments in land and water infrastructure (wells, pumps, irrigation distribution infrastructure).

Access rights to groundwater are either closely linked to land-use rights (land-cum-water, for instance in the Northern region of Ghana) or dissociated from land. The conversion from one legal form to the other (i.e., from private water rights to water use-permits under the public domain doctrine) is a complicated, conflictual undertaking (Spain, Zambia). The rationale behind this change is to enable the regulatory body to respond flexibly to changing water availability and demand patterns. Permits are better suited to be adapted to situations of scarcity than water rights, since their specifications such as duration, revocation, modification, allow a more flexible approach than individual entitlements which are infinite and inflexible. However, in a number of Sub-Saharan African countries smallholders do not have to apply for permits (*de minimis rights*), meaning that their use rights are not formally registered. This means that monitoring is difficult, and if legally not recognised, they are unprotected in times of water scarcity or conflict over resource use.

The establishment of local groundwater organisations, and their participation in performing governance, is a complicated task. Experiences with Water User Associations of surface irrigation systems reveal that their performance hinges on conditions such as whether all users in a command area are members; whether management is professionally organised (which in turn depends on the farmers' financial endowment); and, above all, whether they have the authority to enforce policy instruments. It must also be emphasised that there are great differences in the nature of local user organisations and the role they can and, above all, are allowed to play: local groundwater organisations in China effectively enforced well closure and water quotas. However, these organisations were less focussed on enabling participatory user involvement but rather an 'extension' of the government apparatus. The Spanish Groundwater User Associations on the other hand had a limited management mandate and were thus easily hi-jacked by strong interest groups. The experience with Morocco's multi-stakeholder aquifer contracts (see Box 3) also shows that it is difficult to reconcile the interests of all stakeholders, and that incentives are needed for those who are sceptical to participate. And even then, the stakeholders concerned could not agree on a common goal, nor on the measures to be implemented to reverse overuse. The result is a non-binding, not enforceable agreement.

Efforts to promote groundwater irrigation on the one hand, and to prevent over-use on the other, are uncoordinated, creating trade-offs. Energy subsidies for the agricultural sector, for example, may accelerate irrigation development but also accelerate aquifer depletion, as was apparent in the case studies from India, Spain and China. In many parts of the world, instruments to better regulate water extraction have only been introduced when impacts of over-use had become urgently apparent. Policies and instrument for promoting irrigation and those for preventing over-use have not been introduced in a harmonised manner, creating trade-offs between the two goals. This also stems from the fact that they concern different policy fields (agriculture vs. water/environment) and often fall within the mandate of different actors. Efforts to regulate land use in the recharge area of an aquifer, for example, requires coordinated action between water and agricultural/ forest authorities, and eventually with nature protection. Uncoordinated national policies (agriculture, irrigation, water, energy) lead to inconsistent, and even contradictory overall development strategies being adopted.

Lack of extension services and inadequate access to financing hamper efforts to promote groundwater irrigation by smallholders. The use of groundwater in smallholder agriculture has the potential to contribute to food security, increased income and job creation. However, it should be clear that using groundwater for irrigation is only one factor among others that determines whether these goals can be realised. Farmers switching from rainfed to irrigation may not have the necessary expertise and skills, which may result in excessive water consumption and over-abstraction of aquifers as well as in poorly operated infrastructure and loss of investments. Diversification towards low-water intensive but nevertheless high remunerative crops requires knowledge on cultivation practices, crop water requirement as well as on the availability and affordability of inputs such as seeds, fertiliser and irrigation technologies. Others factors are e.g., access to credits, agricultural inputs, and knowledge about water-efficient agricultural practices and technologies. While the first factors mentioned raise questions on whether smallholder farmers have the financial means, and on governments' support policies, the last one refers to capacity development and agronomic and irrigation extension services for farmers. However, agronomic and irrigation experts at village level and in local administrations are lacking, and support for groundwater user associations to manage groundwater irrigation schemes is insufficient.

6. Recommendations for German Development Cooperation

6.1 Recommendations

The following recommendations refer to the challenges identified in the previous chapter, and these in turn are based on a review of existing documents and analyses, on in-depth studies (China, Ghana, India, and Spain), and on the experience of experts.

However, it should be clear that the recommendations are of a general nature and do not take specific contexts into account. They abstract from the political constitution of countries, from their administrative peculiarities and, above all, from the respective political circumstances and political power plays. That is why no general statement can be made here on how governance structures should look like, and in particular on the role that local stakeholders should play - they must be adapted to the context and situation of Sub-Saharan African countries. Nevertheless, the recommendations address common challenges in implementing governance frameworks that promote the sustainable use of groundwater in agriculture.

Establish a robust data base to inform groundwater development planning and governance decisions. In order to design policy instruments that govern the sustainable us of groundwater for smallholder irrigation in a targeted manner, information is needed on the groundwater resource base, the agro-ecological conditions, on water-use permits assigned, on registered and unregistered wells, as well as on the actual utilisation rate.

- ➔ Ensure a thorough assessment of the real irrigation potential. This not only depends on available renewable groundwater resources, but also on the needs of groundwater dependent ecosystems and agro-ecological conditions.
- ➔ Develop human capacities for data collection as well as for setting up and maintaining databases
- ➔ Make use of local knowledge and develop capacities of local stakeholders in data collection
- ➔ Promote cooperation and establish mechanisms for data exchange between different sectoral agencies, such as those responsible for agricultural development, irrigation management, issuing drilling licenses, and environmental protection

Consider enforcement challenges in the design of policy instruments and implementation strategies, including those related to social and political implications. Decisions on instruments should be pragmatic, consider what conditions are required that make implementation likely, and whether these conditions are met, or can be met in the long run.

- ➔ Analyse existing groundwater governance arrangements (covering e.g., legal, administrative aspects) to identify strengths and weaknesses. This should include an analysis of existing land and water tenure arrangements (formal and informal water-rights systems), and how they are related to each other. A thorough analysis of the political economy of groundwater use should be the basis to design policy interventions and reforms
- ➔ Assess the social and political implications (e.g., on informal groundwater use rights) of instruments to be introduced, consider how these may complicate enforcement, and develop compensation if farmers suffer economic losses. Environmental and Social Impact Assessments are one tool to identify social implications
- ➔ Carry out thorough analyses of human and institutional capacity for implementation and enforcement
- ➔ Design policy instruments that are adequate and easy to monitor and enforce – and combine them with compensatory measures, as appropriate, to balance social impacts
- ➔ Complement the design and introduction of policy instruments with a clear strategy of how and by whom these will be implemented and enforced
- ➔ Carry out communication and awareness raising campaigns and engage relevant stakeholder groups in the process of designing groundwater governance instruments to increase political will and stakeholder support, and to facilitate a shared understanding of the groundwater situation and problems
- ➔ Promote access to data for the public and relevant stakeholders in order to increase transparency, strengthen accountability and create trustful relations

Strengthen human and institutional capacity for groundwater governance. The administrative units, which by mandate perform key functions of groundwater governance at all levels, need clear mandates and skilled personnel to perform their diverse governance tasks.

- ➔ Establish or strengthen institutional structures to fulfil the various necessary mandates for sustainable groundwater governance
- ➔ Assign clear mandates to different actors in groundwater governance and establish mechanisms for communication and coordination to ensure a coherent approach across different levels of administration and different aspects of groundwater governance
- ➔ Assess gaps in and implement training programmes to develop human capacities related to all necessary governance tasks
- ➔ Strengthen capacities in developing and deploying technical solutions to support groundwater governance

Strengthen the role of local stakeholders in implementation: Local stakeholders (e.g., municipalities, village councils, local groundwater cooperatives and water user associations) can effectively contribute to sustainable groundwater governance in a variety of ways.

- ➔ Assess existing local stakeholder structures, such as local authorities, groundwater user organisations, farmer associations, traditional authorities, that already hold or could take on mandates in groundwater governance
- ➔ Strengthen existing or establish new local structures for sustainable groundwater governance, and assign clear roles and responsibilities for groundwater governance tasks
- ➔ Assess the financial basis of local structures, and consider additional income sources if water user fees are not sufficient
- ➔ Promote national/regional policy frameworks that strengthen local authorities and/or stakeholder organisations
- ➔ Establish mechanisms to promote cooperation between authorities, communities, farmers and other stakeholders, and take account of economic, political imbalances between these groups
- ➔ Develop human, financial and institutional capacities at the local level for the adoption, operation, maintenance and repair of technologies to support monitoring and enforcement

Ensure cross-sectoral coordination in groundwater management. In order to strike a balance between diverse goals of sectoral agencies, and to avoid, or at least minimise inconsistencies and trade-offs between strategies and related policy instruments, coordination across relevant sectors is required, especially across the water, agriculture, energy and environmental sectors.

- ➔ Assess coherence among relevant sectoral policies and governance frameworks and address inconsistencies, in particular between those administrations that are mandated for promotion of irrigation (ministry of agriculture, or irrigation) and prevention of over-use (ministry of water resources/ environment)
- ➔ Identify opportunities to increase cross-sectoral communication and coordination, and establish cross-sectoral working groups, liaison officers, or coordination meetings
- ➔ Raise awareness across sectors about the potential trade-offs and risks in groundwater management to increase political will to implement management strategies and policy instruments that do not contradict each other
- ➔ Support authorities to develop a national groundwater irrigation strategy, promote and support the establishment of integrated groundwater management plans that define development goals related to use and protection, identify risks and ways to address them

Take an integrated approach to promoting sustainable groundwater use for smallholder irrigation. To realise the irrigation potential of groundwater, farmers need secure land and water-use rights, access to crucial services such as access to credits and agricultural inputs, access to knowledge of suitable farming practices and crops, water-efficient irrigation practices.

- ➔ Create incentives for smallholders to switch from, or complement rainfed agriculture with irrigation, e.g., through financial support and capacity development mechanisms, as well as providing access to inputs such as seeds, fertiliser and efficient irrigation technologies
- ➔ Ensure that land tenure and water tenure systems provide security for investments by farmers
- ➔ Strengthen agricultural extension services with agronomists and irrigation experts
- ➔ Promote the establishment of training centres (or farmer schools) to improve farmers' skills in water use on farm level, crop-water requirement, selection of suitable crops, operation and maintenance of irrigation systems
- ➔ Raise awareness of farmers about the need for sustainable groundwater use, e.g., through communication campaigns or innovative game-based experiential learning tools that inform farmers about groundwater dynamics and vulnerability

6.2 Checklist for German Development Cooperation with regard to risks in sustainable groundwater use and opportunities in groundwater governance

Careful consideration of the following questions can support decision-making on risks and opportunities for engagement in groundwater irrigation by small holder farmers.

Knowledge about the resource

- ✓ Is the availability of groundwater resources identified, and how reliable are these data?
- ✓ Is the demand for groundwater resources known?
- ✓ Is the groundwater utilisation rate known, and is the potential for agricultural use identified (along with overall agro-ecological conditions)?
- ✓ What are the characteristics of the aquifer in question (especially with regard to storage capacity and transmissivity)? Does abstraction affect other users? What is the risk of overuse?

Existing regulations and policies

- ✓ Is there an abstraction limit (a cap) that reflects in situ requirements (groundwater-dependent wetlands) and sustainability limit (a buffer)?
- ✓ Are regulations (emergency plans) foreseen for drought/ scarcity situations?
- ✓ Is there a national plan/program that promotes smallholder irrigation, and, if, what are the contents and who is in charge of its implementation?
- ✓ Are there restrictions on groundwater use, and, if, what instruments are used to achieve this, and are these effective?
- ✓ Are there effective mechanisms for monitoring and enforcing these instruments, with clear and legally robust sanctions?
- ✓ Are social, economic and environmental impacts of instruments assessed, and are compensation measures foreseen?
- ✓ Are groundwater entitlements legally defined, and how are those of smallholders secured (have the groups legal entitlements or individual farmers)?

Existing institutions, coordination and support mechanisms

- ✓ Do farmers have access to credit services, among other issues, and are they supported by e.g., extension services (agronomic, irrigation)?
- ✓ Are there mechanisms to coordinate activities between the relevant authorities (e.g., agriculture, water, irrigation) to achieve policy coherence?
- ✓ Do land tenure systems (modern and customary) provide security for smallholders to invest in irrigated agriculture?
- ✓ Are responsibilities/mandates clearly defined across administrative levels?
- ✓ What local organisations exist, and what functions do local organisations have vis-à-vis state administrations and farmers?
- ✓ Do local organisations receive support in how to manage groundwater irrigation systems and implement instruments?
- ✓ Have these units (state, user organisations) the necessary human and financial capacities, and the authority to fulfil these functions?

Overall performance and problems

- ✓ What does the governance arrangement look like, and what are its deficits/ weaknesses?
- ✓ What kind of conflicts exist and how are they managed?

7. Annex: List of interviewees

Date	Name	Organisation, Position	Country experience
April 2023 written statement	Walter Huppert	Retired, formerly GTZ senior expert	South America, Africa, Middle East
27. Juni 2023	Benjamin Schraven	Freelance (formerly DIE)	Ghana
5. Juli 2023	Christiane Ehringhaus	KfW, Senior Sector Economist – Agriculture & Rural Development	General
5. Juli 2023	Dirk Wenzel	KfW, Technical expert	Kenya, Ethiopia
5. Juli 2023	Thomas Brehler	KfW, Technical expert	Egypt, Jordan
5. Juli 2023	Jens Moedinger	KfW, Technical expert	Morocco, Tunisia, Algeria
13. Juli 2023	Tobias Godau	GIZ, Programme Manager (formerly BGR)	Tanzania, Zambia
28. Juli 2023	Philipp Günther	Bischöfliches Hilfswerk MISEREOR e. V., Referent Water	Sahel region, Zimbabwe
28. Juli 2023	Sabine Dorlöchter-Sulser	Bischöflichen Hilfswerk MISEREOR e. V., Referent Rural Development	Africa
2. August 2023	Manfred Matz	GIZ, Programme Coordinator for Water Projects in Tunisia	Tunisia
7. August 2023	Andreas Müller	GIZ, Specialist, Competence Centre 4D20, Forest, Biodiversity, Agriculture	Niger
8. August 2023 written statement	Ingrid Jacobsen Stig Tanzmann	Brot für die Welt, Referentin Ernährungssicherheit, Klimawandel und Landwirtschaft	General
6. September 2023	Elisabeth van den Akker	GIZ, Technical Coordinator of the German Cooperation Agriculture and Food Sector	Mali, Ethiopia
6. September 2023	Charlotte Wilczok	GIZ, Technical Advisor in GIS, Remote Sensing, Agroecology, Monitoring & Evaluation	Mali

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