Chapter 13
Improving Water Management in Pakistan Using Social-Ecological Systems Research

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Abstract High quality research informed by systems thinking can contribute to positive outcomes in complex, dynamic situations related to managing natural resources such as water. This chapter refers to social-ecological systems thinking to identify characteristics of high quality transdisciplinary research that makes a lasting impact. We primarily draw on lessons from a four-year research for development project that focused on learning how to improve groundwater management in Pakistan. Uncontrolled and unmonitored use of groundwater for irrigation has resulted in declining water levels in parts of Punjab, Sindh and Balochistan. The project sought to address this by developing and supporting professional relationships among groundwater managers from government agencies, university researchers and farming communities. Six in-depth case studies, two from each province, enabled groundwater monitoring capacity, and understanding of the social and economic aspects of water use, to be developed together. Stakeholder forums ultimately developed as platforms for co-learning and collaborative planning around on-farm interventions and mobile applications. In this chapter we present the background literature that informed us, and what we did. We also reflect on what could be improved in similar future projects. We note the constraints of short term project funding on this type of collaborative learning based project, and highlight where structured and consistent investment in water resources planning is required. We also suggest that projects such as this would be improved by incorporating ecological perspectives alongside technical, social and economic aspects.

Keywords Transdisciplinary research · Systemic co-inquiry · Groundwater management · Capacity building · Co-learning

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13.1 Introduction

High quality research informed by systems thinking can contribute to positive outcomes in complex, dynamic situations related to managing natural resources such as water (Christen et al. 2019). To create positive change in such contexts requires building capacity for learning at societal scales (Pahl-Wostl et al. 2008) and a managerial capacity to be adaptable to that learning and to constantly changing circumstances (Allen et al. 2011). This chapter identifies characteristics that constitute high quality research that engages and enhances capacity of social actors to learn and adapt. We primarily draw on our recent experience leading a four-year research for development project, funded by the Australian Centre for International Agricultural Research (ACIAR) as a collaboration between Australia and Pakistan, and focused on how groundwater management in Pakistan can be improved (https://www.aciar.gov.au/project/LWR-2015-036). Henceforth we refer to this as the Improving Groundwater Management Project.

The chapter draws on ideas associated with social-ecological systems research as an aid to understanding and articulating the underlying causes affecting groundwater management. Consideration of social-ecological systems explains why our research project was needed, and what kind of practice changes can make a positive difference. Here we explain that a social-ecological systems approach to research is interdisciplinary, transdisciplinary, and involves co-inquiry and interventions. We conclude by echoing the concluding point of the second chapter of this volume. Specifically, we argue that a key aspect to advance research to improve water resources management in Pakistan is to improve understanding of how investment in water resources information systems, groundwater management, basin planning, water resources institutions, and water-related ecological outcomes can contribute to enhanced development outcomes for Pakistan.

13.2 Why Water Management in Pakistan Needs Improving: Groundwater as a Case Study

Agricultural, urban, and industrial development in Pakistan is concentrated in the Indus River plain. The Indus Basin is water-stressed and has long been recognised as facing a pending water crisis. Demand for water in all sectors is growing – the major user of surface and groundwater is irrigated agriculture. In Punjab's agricultural areas about 50% of irrigation depends on groundwater, and about 20% in Sindh. This development has been driven by a combination of poor access to surface water, increased cropping intensities, and policies to encourage groundwater use to reduce waterlogging. The uncontrolled and unmonitored use of groundwater for irrigation has resulted in declining water levels in the eastern doabs of Punjab, southern Punjab and parts of Sindh, where groundwater is exploited from shallow freshwater lenses. It has also led to declining water levels in the irrigated lands of Balochistan, where using groundwater is often the only option for agriculture.

When designing the Improving Groundwater Management Project, we took the view that research aiming to improve groundwater management is best undertaken in collaboration with groundwater users and managers. Our strategy to cement this collaboration involved using six in-depth case studies across three provinces of Pakistan: Balochistan, Punjab and Sindh (Fig. 13.1). In the case study areas within Punjab and Sindh, groundwater is primarily used as a supplement to the surface water supplied through the Indus Basin Irrigation System (IBIS), while irrigators in the case study areas of Balochistan are almost totally dependent on groundwater due to the low and highly variable rainfall patterns they experience.

The project team consisted of researchers from Australia partnering with staff from universities, provincial water management agencies and national and international research organisations in Pakistan. A foundational objective of the research project was to develop a shared understanding among the project team and those with whom we collaborated of the groundwater situation, and the need for improved management. One aspect of co-developing this shared understanding involved team

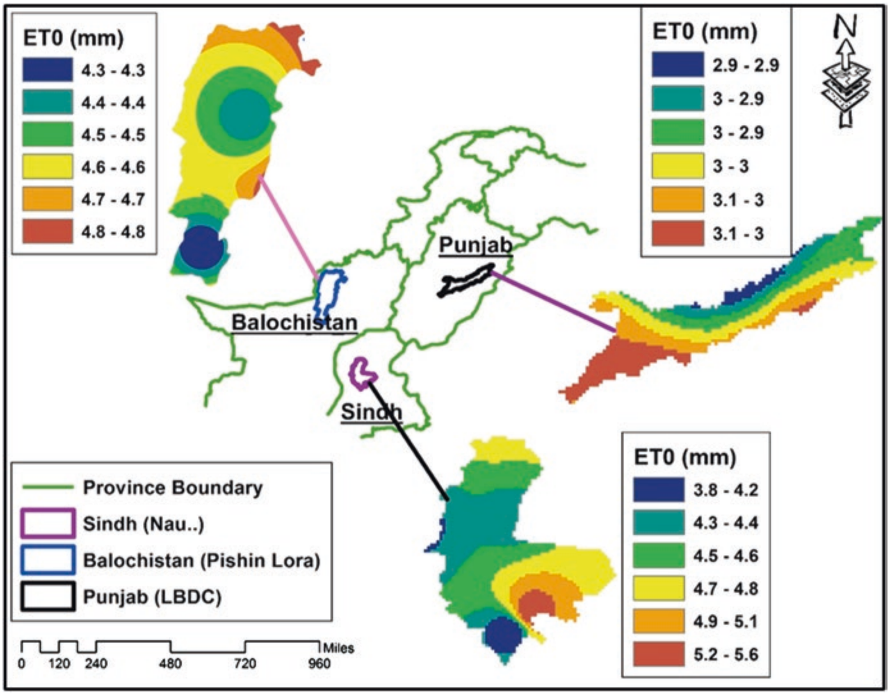

Fig. 13.1 Map displaying location of case study areas (Kuchlagh and Pishin Lora sub-basins in Balochistan; 1R and 11L distributaries in the Lower Bari Doab Canal (LBDC) command area in Punjab; and Malwa and Chiho distributaries in Shaheed Benazirabad and Naushahro Feroze districts respectively in Sindh). ET0 is a measure of evapotranspiration, the amount of water loss from plants and soil

members collaborating to review the literature related to groundwater use and management for agricultural production in Pakistan (Mitchell et al. forthcoming). This was followed by extensive engagement with groundwater users and managers in the case study areas through participatory rural appraisals and the formation of stakeholder forums. The following two sub-sections summarise key themes emerging from the literature review to help understand ecological and social impacts of groundwater use related to the project's case study areas.

13.2.1 Ecological Impacts

Literature exploring ecological impacts from groundwater use and management in Pakistan is very limited. Most examples we found would be better defined as being broadly 'environmental' impacts; i.e., they describe how impacts on the natural environment are affecting society and the economy. Our most focused search, in March 2017, used the Scopus database and Google Scholar search engine and the names of our potential case study locations: "Pishin Lora" (Balochistan), "Bari Doab" (Punjab), and "Nawabshah", "Khairpur" and "Naushshro Feroze" (Sindh). These searches revealed a predominant research focus on social aspects among the groundwater relevant literature involving Pishin Lora, in particular a focus on exploring awareness and understanding of the causes of groundwater depletion (Ashraf and Routray 2013; Jilani and Khair 2014), and its impacts (Kakar et al. 2014). This was also the emphasis of the literature involving the Lower Bari Doab Canal command area, where spatial variation (Basharat et al. 2014), groundwater quality (Basharat and Tariq 2013) and potential for groundwater recharge (Basharat and Basharat 2019) also received attention. It was only our potential case study areas for Sindh that yielded research related to what could be described as 'environmental', but this was mostly focused on concerns for local populations and crop production in relation to arsenic and other heavy metal contamination of groundwater (Baig et al. 2011; Brahman et al. 2016; Rabbani et al. 2017).

At a broader scale, beyond those studies specifically related to our case study areas, there were also more studies related to environmental impacts of groundwater use focused on Sindh than the other two provinces, and most of these studies also highlighted concerns related to contamination of groundwater from heavy metals (Haq et al. 2005; Siddique et al. 2012; Alamgir et al. 2016). These aspects were also the predominant focus of Punjab-based studies (Ullah et al. 2009; Khattak et al. 2012). While there have been some studies documenting decline in water levels and water quality of internationally important wetlands (Ramsar sites) (Khan et al. 1996; Mastoi et al. 2008), including dammed reservoirs in Sindh (Kazmi et al. 2006), there has been very little, if any, reference to groundwater use and management. However, there were some studies that identified community benefits arising from conservation of wetlands and mangroves (Khan et al. 1996, 2014; Rasool et al. 2002). There is also a growing recognition that saline intrusion in the Lower Indus Basin Aquifer results from overuse of groundwater (Chandio and Lee 2012) and reduced outflows from the Indus River (IUCN 2003; Kamal et al. 2012). Our conclusion is that there is currently insufficient research to improve our understanding of how groundwater use is impacting the ecology and ecological assets of the project's case study areas, as well as of Pakistan more broadly, and how an improvement of these assets can in turn offer improvements for society.

13.2.2 Societal Impacts

While it is evident that development of irrigated agriculture across Pakistan has raised productivity and profitability of the agricultural industry as a whole, it is apparent that is that the way groundwater is being used and managed exacerbates existing social inequalities across the three provinces (Mitchell et al. forthcoming). This theme came through most clearly in the literature related to groundwater use for irrigated agriculture in Balochistan, which has received significant academic attention (van Steenbergen 1995; Mustafa and Qazi 2007, 2008; Khair et al. 2015; van Steenbergen et al. 2015). In particular, the longitudinal study led by van Steenbergen articulates the classic common pool resource dilemma being experienced in Balochistan due to a 'socio-institutional void' – or lack of effective management. This 'socio-institutional void' was described by van Steeenbergen (1995) when the 'groundwater rush' was in full swing, and the lack of any government-led or informal community-led institutional responses represented what he described as a wild west 'frontier' problem with a predictable outcome: groundwater over-exploitation.

Access to groundwater in Pakistan is usually tied to land ownership, with no restrictions imposed, and no cost to the farmer apart from the costs of extraction. Extraction is generally through small tube-wells – the bores used to pump groundwater, consisting of a long tube drilled into the ground and sunk to a depth below the water table. Tube-well owners have exclusive rights to the groundwater, and have no restrictions on selling their groundwater to other farmers, which benefits wealthier farmers over smallholder farmers and tenants (Meinzen-Dick 1996). Such easy access to groundwater in Balochistan created a boom time 'apple economy' for farming families, especially during the 1980s and 1990s, when returns were four to five times better than previously achieved (Khair et al. 2015). Yet Balochistan remains the most impoverished and least developed province in Pakistan, with an annual economic growth rate of 2.5% compared with a national growth rate of 4.4% for the period 1999–2000 to 2014–2015, and per capita income almost half the national average (Pasha 2015). The apple growing bonanza led to a massive increase in the number of tube-wells, and this in turn led to depletion of aquifers (van Steenbergen et al. 2015), with groundwater levels dropping by 2–5 m annually (Khair and Culas 2013). This situation had been predicted by van Steenbergen (1995), who warned of consequences of the socio-institutional void. No initiatives were taken to reverse the trend, and depletion of aquifers continued, despite the costs of drilling and pumping from ever greater depths (van Steenbergen et al. 2015).

The impacts for farmers in the Kuchlagh sub-basin of Balochistan have been well detailed by van Steenbergen et al. (2015). Many farmers were forced to sell their land and migrate, or lease land to survive. For those who retained their land, the scarcity of water and costs of extraction meant most had to abandon their apple orchards or remove the trees to be replaced with low water consuming crops. Some farmers sold their groundwater to private truck owners to be on-sold for domestic household use, especially given the massive population increase due to influx of migrants escaping the conflict in Afghanistan. The unfolding situation being described is reminiscent of a 'desakota'-like rural to urban transformation, where livelihoods based on agriculture become subsumed by the need to find other ways of making a living (van Steenbergen et al. 2015, citing Desakota Study Team 2008). Not only does this situation create a profound shift away from a sense of community towards individual competitiveness, but it also exacerbates the extent of inequality between rich and poor.

In the Indus Basin irrigation command areas of Punjab and groundwater dependent areas of Sindh, the situation is different from that in Balochistan, but the resulting groundwater over-extraction also exacerbates existing social inequalities. A large canal network to carry surface water was established by the British initially to protect against crop failure, but is now extensively used for increasing agricultural production (Narain 2008). The canal water is low cost but insufficient, so groundwater is accessed by farmers via tube-wells to supplement it. Groundwater levels are usually highest closer to the main canals of the command areas, meaning farmers whose lands are located at the tail-end of canal distributaries have deeper groundwater and greater extraction costs than those whose lands are located at the head of canals, as was found to be the case for the Lower Bari Doab Canal command area of Punjab (Basharat and Tariq 2015). It is also the tendency that wealthier farmers own land at the head of canal distributaries, and the extent of inequality across the Pakistan rural landscape is compounded by existing socio-political dynamics of land ownership, tenancy and dependency (Tagar et al. 2016). While surface water allocations are regulated by provincial governments, local power dynamics often mean that wealthier farmers living near the head of distributaries have greater access to surface water supplies, with many distributaries running dry at the tail-end, especially in southern Punjab and across the Indus delta areas of Sindh (personal observations – see, for example Mitchell et al. [2020] – though Shah et al.'s [2016] efforts to validate such observations with analysed data paint a more complex picture; also see Anwar and Ul Haq [2013] for an analysis of inequity along the length of a canal). The resulting increased dependency on groundwater at tail-ends inflicts a greater cost burden on farmers, increases rates of depletion, and results in groundwater of decreasing quality being used, with associated salinisation and lower productivity of the land for these farmers (Latif 2007; Latif and Ahmad 2009; Basharat 2012; Punthakey et al. 2015). Variations in access to both surface and groundwater feed a vicious cycle that exacerbates existing inequalities.

13.2.3 Causes: A Social-Ecological Systems Analysis

The literature review provided some context, but developing a shared understanding of the need for improved groundwater management also required ongoing dialogue among the project team and our other collaborators on what is driving the situation causing the adverse social and environmental impacts described above. This dialogue sought to avoid focusing only on the visible events and symptoms by ongoing inquiries seeking to understand underlying causes for the observed phenomena. Over time, such a dialogue both reflects and influences the system of interest. Here, we take stock of where our understandings have reached as a result of the dialogue, and we apply a social-ecological systems framing to articulate underlying causes of systemic issues as co-evolving dynamics between the biophysical and social worlds (Folke et al. 2005, 2016).

As Fig. 13.2 demonstrates, an examination of underlying causes can include investigations into patterns and processes of human behaviour, and how the natural environment responds. In the groundwater for agricultural use context, such an examination will often focus on resource users – those humans directly farming the land and using water for productive benefit. This often results in farmers being blamed for the observable events and symptoms of groundwater depletion, waterlogging, and the effect of the use of poor water quality on crop production. The simplistic narrative of assuming farmers are either unaware, or unwilling to change, can result in calls for 'education', greater regulation and incentives to modify the behaviours of irrigators.

There are other, however, more systematic aspects that drive the patterns and processes resulting in the observable phenomena. Systems and structures have

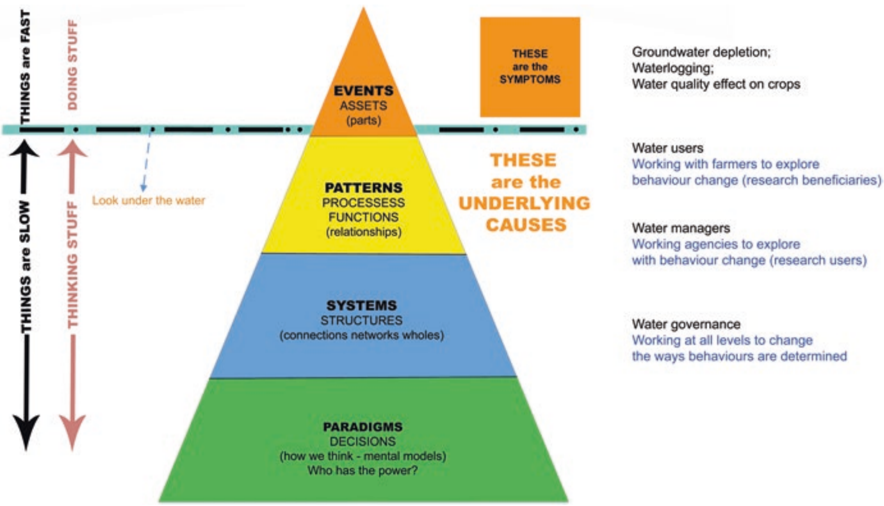

Fig. 13.2 Understanding underlying causes from a systems perspective using an iceberg metaphor. (Image adapted from that used by Paul Ryan, Australian Resilience Centre, with permission)

developed and reified over time to influence whether and how those directly managing the land and water can adopt practices that use resources more sustainably, and with less adverse impacts on society and the environment.

Systemic change is needed if Pakistan is to use groundwater in a way that approaches sustainable development, i.e., "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" where the concept of needs focuses particularly on "the essential needs of the poor, to which overriding priority should be given" (World Commission on Environment and Development 1990, p. 87). This classic articulation of sustainable development emphasises that its pursuit involves both sustaining the environment and challenging social injustice. There is a social justice dimension to achieving sustainability, especially because of the poverty trap for those eking out a living through further degradation of the marginal lands where they are forced to live (Dobson 1999).

Reflecting on the above led our project development team to a critical realisation. Transformation cannot occur by focusing solely on behavioural change among water users. Rather, it is imperative to work with those responsible for managing water and its use to explore how behavioural changes at the system level can lead to more sustainable use of resources. Equally important was to put learning and adaption at the heart of the project, such that project members and participants were supported to be co-researchers as much as possible.

In the groundwater management context of Pakistan, our Improving Groundwater Management Project went beyond merely having academic institutions as project partners. The project team has benefited from having formal partnership relationships established with provincial irrigation departments as water managers (the project's intended next users of the research outputs), as well as a set of co-inquiry case studies with irrigator communities as water users (the project's ultimate intended research beneficiaries). How this collaborative, multi-player project worked is described in the next section.

13.3 Contributing to Improved Water Management Using the Practice of Social-Ecological Systems Research

The approach of social-ecological systems research has been explored more in theory than in practice (Walker and Salt 2012; Sellberg et al. 2018). Its conceptual origins are in understanding change in ecological systems and the application of adaptive management (Holling 1973, 1978). Significant advances in the approach came with realisations that ecological dynamics generally evolve as interactions with changes in social systems (Berkes and Folke 1998), and that the approach is fundamentally about embracing change – both adaptation and transformation – through processes of active adaptive management (Folke et al. 2005). These advances were in part driven by the work of Ostrom (1990) based on her investigations into groundwater management as “governing the commons”, which in turn led to the need for adaptive governance as a change in paradigm (Dietz et al. 2003). It is also interesting to note that one of the earliest applications of the approach involved an investigation to understand the underlying causes driving change of an Australian catchment affected by waterlogging (Walker et al. 2009). There is also a large body of research in cybersystemics (e.g. Ison 2016) exploring ways to facilitate transformation within institutions for more just and adaptive governance, for example Blackmore et al. (2007).

While the Improving Groundwater Management Project was not framed as social-ecological systems research, the approach informed its origins so that it became a project with integrating leadership from both the biophysical and social sciences. The project’s design thus offers guidance for how social-ecological systems research can be effectively put into practice. At the core of the social-ecological systems concept is that it involves interdisciplinary research, i.e., pursuing a shared research objective by actively traversing and enabling learning and growth across academic disciplinary boundaries (Tress et al. 2005). We would also assert that for social-ecological systems research to have practical influence, it needs to go beyond interdisciplinarity to become transdisciplinary, i.e., to develop and pursue a shared research objective with actors in society (such as land managers and other stakeholders), by “unsettling the distinction between research providers and research users” (Mitchell et al. 2017, p. 2). For transdisciplinary research to become an effective process of learning through active adaptive management requires intervening in the systems being studied (Midgley 2003) through co-inquiry with those who are part of these systems (Foster et al. 2019; Allan et al. 2020). Reflection on practice is also essential (Stringer et al. 2006) to enhance learning and identify what could be improved. The following sub-sections use this framing for how to deliver high quality social-ecological research to critically evaluate the research performance of the Improving Groundwater Management Project.

13.3.1 Interdisciplinary Research: Building Partnerships Across Disciplines

13.3.1.1 What We Have Been Doing

The core of the Improving Groundwater Management Project involved the development of groundwater management tools and options that would have the potential of improving livelihoods for farming families. Delivering on this objective would require, at the very least, expertise in hydrogeology (for the development of groundwater management tools and options) and agricultural economics (to explore how these tools could influence farming family livelihoods). The project relied on the development of both groundwater and socio-economic models, and regular efforts to integrate them as they were developed, so that their inputs and outputs were informed by each other’s inputs and outputs.

The project's overall aim, however, involved building capacity of managers and practitioners, which required research strategies informed by the social sciences. As further described below, in the case of groundwater management tools and options, the priority was that these be developed with intended research users – the provincial irrigation departments – to ensure they had the capacity to use and further develop the tools and options after the four-year project had concluded. In addition, as these tools and options are meant to inform and influence groundwater use behaviour, their further use and development is best achieved by irrigation department staff working in collaboration with groundwater using community representatives and a broader array of service providers with whom these communities work. The provincial department staff were developing their own capacity with technical experts and research beneficiaries simultaneously, and were thus in a key position to benefit from as well as facilitate learning. The research strategies adopted were thus influenced by social learning theory, which involves challenging assumptions about how society functions, and where "ideas and attitudes learned … must diffuse outwards to wider social units or communities" (Reed et al. 2010, p. 4; and see Steyaert and Jiggins 2007; Faysse et al. 2014).

13.3.1.2 Suggested Improvements

On reflection, the Improving Groundwater Management Project's understanding of the issues and their underlying causes could have benefited from greater integration with environmental science expertise to offer additional appreciation for how the groundwater situation has emerged as a result of interlinking social and ecological dynamics. The ecosystem services framework, such as that used to define the provisioning, regulating, cultural and supporting service roles provided by wetlands (Millennium Ecosystem Assessment 2005; Finlayson et al. 2011), offers one approach to exploring these interactions for resource management contexts. Restoring and maintaining the health of the environment and water related ecosystems is also a priority set out in Pakistan's National Water Policy. Future research and capacity development would need to incorporate environmental objectives to support improved management of freshwater ecosystems and, in particular, the benefits that ecosystem services bring, often free of charge, to local people (Finlayson et al. 2019).

Similarly, developing a shared understanding of how the groundwater situation being faced can be articulated as a challenge for sustainable development can be informed by the growing body of literature that explores integration using the United Nation's Sustainable Development Goals (Stafford-Smith et al. 2017; Velis et al. 2017), including that which specifically promotes multiple use of aquatic systems and their resources (Lynch et al. 2019) and the impacts of climate change (Pittock et al. 2019).

13.3.2 Transdisciplinary Research: Building Partnerships Between Researchers and Research Users

13.3.2.1 What We Have Been Doing

The organisation that funded the research, ACIAR, encourages research that creates and maintains genuine partnerships. Its core business is to ensure research is developed collaboratively with partners in the countries with development needs that it seeks to support as part of the country's overseas aid program (ACIAR 2018). Key to the strategy is to secure co-investment with partner organisations, which it primarily achieves through in-kind contributions of these partners' staff time.

Because our project sought to have groundwater management tools and options developed as a collaborative activity in each province, securing staff time commitments from researcher and research user organisations to work in collaboration with each other has been essential. For example, the Punjab Irrigation Department (PID) committed both senior-level and middle-level professional staff to work with academics from the University of Agriculture, Faisalabad to develop the groundwater model for the Lower Bari Doab. Examples of collaboration include PID sharing its groundwater monitoring data, and working with researchers to enhance its collection of that data. Similarly, in Sindh, early career academics at Mehran University of Engineering and Technology took the lead in working with officials at the Sindh Irrigation Department (SID). This collaboration has resulted in the two organisations co-investing in further groundwater modelling training programs to disseminate that capacity more broadly across SID. A comparative dearth of groundwater monitoring data availability in Balochistan meant collaboration there has focused on co-investment to drill monitoring bores and install loggers in the project's case study areas. An added benefit in this case is that decisions involving these monitoring bores were undertaken in collaboration with the communities as intended beneficiaries, members of whom made the space available and built protective structures. Balochistan Irrigation Department staff have also benefited from having their GIS skills improved.

As a project team, our efforts to build a transdisciplinary approach have thus gone beyond establishing partnerships with research users. Core to our strategy has been to nurture ongoing partnerships between university researchers and government staff and their respective organisations and ensure mentoring and training was available where needed. These and other collaborations developed and were supported by occasional gatherings of the whole project team – traversing provinces, organisations, discipline areas and social hierarchy. These events, while complicated and costly, provided space to share and develop new framings of situations, and to build confidence and trust in the team network. The collaborative relationships between the community, irrigation departments and academic institutions has, for example, facilitated the uptake of EC meters to monitor groundwater quality and a desire to improve water management practices.

13.3.2.2 Suggested Improvements

Our transdisciplinary strategy was intended to have been informed by an institutional analysis. However, this research activity did not proceed due to difficulty accessing the necessary resources and expertise to deliver the analysis we were proposing. Institutions include the rules, norms and strategies shaping decision-making by individuals and organisations (Scott 2014). A critical institutional analysis undertaken with social actors as research partners can identify institutional arrangements that are performing well, as well as those that are not delivering well according to the purpose we would seek from them (Cleaver and de Koning 2015; Clement et al. 2017). The approach facilitates social learning towards institutional designs that can more effectively deliver on, for example, sustainable groundwater development and use.

A four-year project inevitably imposes limits on what can be achieved. We were aware from the outset that our project would focus on improvements to groundwater management (principally the realm of hydrologists and water managers – Mukherji and Shah 2005), rather than being able to influence governance arrangements (about how people in society share power with governments in decision-making and program delivery – Stoker 1998) related to groundwater. Research that would investigate and intervene in groundwater governance arrangements was seen as beyond the scope of the project.

13.3.3 Co-inquiry and Interventionist Research: Building Partnerships Between Researchers, Research Users and Research Beneficiaries

13.3.3.1 What We Have Been Doing

Co-inquiry is a deliberative research process to institutionalise collaborative action by research providers and users as a community in response to the complex situations they are navigating. It relies on iterative social learning as the means to improve outcomes (Foster et al. 2019). In our case, the actions undertaken as a collaboration among researchers, research users and research beneficiaries used the methodology of intervention: purposefully co-creating change in the system being studied (Midgley 2003). Such collaborative action with social actors in the case study areas was championed and facilitated by academic team members as a form of participatory action research (Fals Borda 2006; Woodward and Hetley 2007), drawing on support from collaborative evaluation, reflection and sense making (Enfors-Kautsky et al. 2018) as the case study co-inquiries evolved.

The process of co-inquiry began with a series of participatory rural appraisals (Chambers 1994; Allan and Curtis 2002) in our proposed study areas to identify communities to collaborate with, establish partnerships and networks, learn about the situation and identify problems to be addressed, secure local stakeholder ownership and benefit, and establish pathways for their inclusion in determining case study research activities, design and outcomes. These activities identified six case study communities to work with, based partly on biophysical and spatial criteria, and partly on community potential and willingness for involvement. The activities led to the local establishment of stakeholder forums for each case study with representation from the community, farmer organisations, non-government organisations, irrigation departments, agricultural extension and on farm water management units and local agribusinesses. Each stakeholder forum held a workshop to determine collaborative research actions.

The workshops were used to investigate four potential interventions with the project team:

1. Improving use of a range of monitoring tools, such as data loggers and EC meters, to enhance co-learning among irrigators, extension agents and researchers about issues and potential solutions associated with groundwater use and management.
2. Accessing the new groundwater modelling information that shows trends in groundwater levels and quality over time, and explores scenarios related to changed pumping regimes and future climatic conditions.
3. Using a mobile App and web-based tool developed by the project team to record information from tube-wells, including water levels and quality, and to access other land and weather information that can inform decision-making.
4. Accessing social and economic data created and analysed by the project team to offer information, guidance and generate discussion with case study communities about their future pathways for agricultural development, resulting in more detailed decision-making and associated justification for on-farm interventions to be investigated, such as to trial high efficiency irrigation methods in the Balochistan case studies, low water use crops in Punjab, and raised bed and integrated farming in Sindh.

Action plans were developed at each workshop, and are currently being implemented. The COVID-19 pandemic has extended the length of time for the project team to be engaged with communities on these action plans, but has also undermined opportunities for interaction and co-inquiry.

While formal action plans are an example of direct outcomes for irrigator communities as intended research beneficiaries, many of the outcomes of developing habits of learning together are less direct and tangible, but no less important. One outcome is the creation of new shared operating spaces among participants of the Improving Groundwater Management Project team, outside of this actual project. These spaces allow for faster development and implementation, such as when a new project from a national partner was established in record time in Balochistan because of networks developed among multiple agency staff and farmers.

These new operating spaces have provided opportunities for women to share in inquiry and design of future actions. The stakeholder forums are deliberately inclusive, driven and supported by strong female project members from universities and NGOs. The stakeholder forum activities have showcased women's involvement in learning and planning for water management. For example, at a stakeholder forum in Sindh, female councillors were included in deliberating on options, bringing local expertise that might otherwise have been missed.

A Representative Agricultural Pathways (RAPs) framework was introduced to the stakeholder forums in Punjab as a means to explore future scenarios building on information provided by the groundwater and socio-economic models. The RAPs framework is developed on the premise that both biophysical and socio-economic drivers are essential components of agricultural pathways. Its methodology is based on capturing plausible farm-level improvements as climate change and other impacts such as water scarcity affect the future of farming operations. By exploring shared visions, it enables a farming community to consider and adopt new adaptation strategies. Using the RAPs methodology with stakeholders also allowed the identification of climate change scenarios that would benefit both the farming community and the operational responses of the Punjab Irrigation Department.

In Sindh, the involvement of the Sindh Irrigation Department from the outset has resulted in improved knowledge across the Sindh-based team of groundwater issues, as well as enhanced team capacity for groundwater modelling. Appreciation of the importance of diffusing this knowledge and capacity has, for example, led to partner co-funding of training programs for staff in the Sindh Irrigation Department.

In Balochistan, the irrigation department has collaborated with researchers and the provincial agriculture extension department, who together have been active in co-inquiry and engagement with the irrigator community. This enabled decisions on where to site monitoring bores to be made jointly with the community, and ensured their assistance in safeguarding and learning from the bore and loggers.

13.3.3.2 Mobile Application "Apna Pani" for Groundwater Data Collection and Visualisation

Apni Pani (our water) is a mobile application which is used to collect and report groundwater depth and water salinity (EC) data (Fig. 13.3). Through this application, users are able to monitor their groundwater. They can also access daily agro-meteorological data from world weather online (temperature, wind speed and humidity) to help them in their daily/seasonal operations such as input applications (pesticide and irrigation). Groundwater and meteorological data are integrated into another mobile and web-based application – *Apna Farm*. *Apna Pani* and *Apna Farm* applications are easy to use and provide up-to-date data, offering improvements on other available applications (e.g. NASA 2020). Moreover, groundwater use can be better managed as users can get information on when there is a need for further irrigation and how much water is needed (Patel 2018). *Apna Farm* can be accessed at http://mriazkhan.com/aciar/dss/ and provides data on land characteristics, enabling users to compute multiple crops' water requirements. Such data can inform decision-making about which crops to grow in relation to the on-farm surface and groundwater situation (Fig. 13.4). The following data are provided:

Fig. 13.3 Data reported by users of *Apna Pani* mobile application

- Current weather conditions.
- Soil properties data including soil organic matter, potassium, pH, phosphorus, and EC.
- Crop profitability.

The information provided by *Apna Pani* and *Apna Farm* also provide the potential for the practice of co-inquiry to continue beyond the life of the project. Their use is being currently championed by younger members of farming families as well as extension agents. Together with shared understanding of future pathways for agricultural development, farming communities are better placed to consider ongoing adaptations in practice in discussion with extension agents and others with expertise and experience in irrigation and on-farm water management.

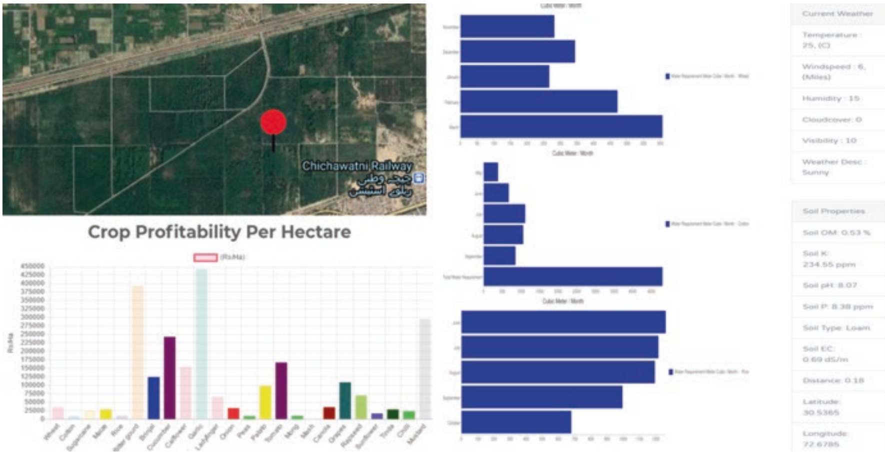

Fig. 13.4 Computing crop water requirements for multiple crops and accessing weather, soil and crop profitable data for optimal decision-making

13.3.3.3 Suggested Improvements

The project's mission of establishing the means for ongoing co-inquiry is to have farming families seen as having a particular set of expertise that is just as important as the expertise offered by extension agents, water resource managers, agricultural economists and biophysical scientists. Key to this strategy is to provide the space and means to enable discussion that combines the experiential knowledge of farming families with other types of knowledge. While the project's interventions offer steps forward through use of integrating tools such as *Apna Pani* and *Apna Farm*, a key aspect that has been missing from these discussions is a set of perspectives that ecology could bring. This was a product of decisions made at the project's design stage, when we were steered away from adopting a social-ecological systems approach which did not seem to fit well with the funding agency's focus on agricultural research. On reflection, it might have been beneficial if we had been able to explore how a social-ecological systems approach could extend and embellish the established agricultural perspectives and approach that underpinned the research. Extending this approach by more overtly linking with the concepts of social-ecological systems, such as the multiple benefits for local people that can be obtained from agricultural landscapes, could provide new perspectives and further opportunities to combine knowledge to improve how groundwater and other natural resources are used and managed.

13.3.4 Investment Planning

Individual projects can only go so far. To improve management of groundwater in the Indus Basin and to meet the policy requirements set out in the National Water Policy and the Provincial Water Policy in Punjab will require improved information, technical capacity and regulation to assist farmers to adapt to a water scarce environment. Based on what we have learned from the Improving Groundwater Management Project, we identify five areas for future investments, as detailed in Table 13.1.

13.4 Conclusion

In the earlier chapter in this volume by Westcoat et al., a vision is presented of the "Indus Basin as a garden", offering a transformation from its current state. Our chapter has provided a framework and examples of strategies that can assist such a transformation – that is, to enable systemic change.

The Improving Groundwater Management Project aims to encourage and support transdisciplinary research and implementation. Useful and hopefully ongoing partnerships have been formed, with shared operating spaces enabling new situation framing, questions and practices. Collaborating, learning, capacity building and reflecting enable this project to go beyond imposition of technical concerns and solutions onto groundwater users who needed to be 'changed'. The Improving Groundwater Management Project embraced change at institutional and organisational levels, and some innovations have emerged that are likely to have some traction in the communities within which they were developed.

It is important to note that this research, like almost all research in this field, is funded on a short-term project basis, meaning that researchers and funds come into an area and then leave, often, as is the case with this project, just when momentum of collaborating and innovation has built to levels where real change may occur. New funding may be sought, and maybe even gained, but in the interim momentum is lost and trust is reduced. We are trying to transcend this pattern of project by engaging and building the capacity of those who have ongoing responsibility for water resources management in Pakistan. By simultaneously building capacities in groundwater and economic modelling, as well as collaborative inquiry and reflection, project team members will be able to continue to use and benefit from the research investment long after the research project has ended. Mobile applications facilitate continued logging, mapping and analysing of groundwater data. All of these aspects combined with enhanced capacity and engagement of practitioners is the project's legacy for societal change. For this to have deep and lasting impact, agency and other organisational staff must have the support of their organisations, in the form of time to participate, if the new operating spaces are to have longevity.

Table 13.1 Suggested areas and actions for investment planning

Priority areas for investment	Strategic actions
Water resources information management	Conduct needs assessment for monitoring and management at community, canal command, sub-basin and basin scales. Develop robust information management systems, data archiving and access. Map spatial and temporal trends to evaluate the state of groundwater. Make strategic and robust monitoring systems operational for use in groundwater assessment, planning and management (quantity, quality, uses and users). Improve access to data for all researchers and institutions.
Sustainable management of groundwater resources	Delineate groundwater management areas and develop strategies to manage depletion and water quality degradation to improve sustainability of the groundwater resource. Develop groundwater models to improve understanding of sustainable extraction and scenario analysis for adaptation to climate change. Delineate groundwater depletion, waterlogging and salinity and groundwater contamination areas (hotspots).
Basin scale planning	Identify and manage risks to basin water resources (water use for irrigation, environmental flows, water quality and salinity management plans). Introduce sustainable diversion limits at sub-basin and canal command scale. Sustain freshwater lakes and environmental assets. Establish a basin management authority similar to the Murray-Darling Basin Authority and other successful models.
Agricultural water productivity	Establish agro-ecological zones for improved agricultural water productivity. Identify best options for conjunctive water use in agriculture. Reassess canal duties within and between canal command areas. Support adoption of high value – low water use crops and associated value chains to improve agricultural productivity and farming livelihoods. Build capacity of farming communities to improve water management practices.
Water resource institutions	Build water resources management institutions (not just organisations) with capacity to manage surface and groundwater in an integrated manner. Build capacity of staff to use technical tools, undertake monitoring, mapping and modelling, and provide policy support. Seek and support opportunities for collaboration across organisational and physical boundaries, modelled on the project's stakeholder forums as spaces for collaborative learning and design of interventionist investigation.

The same reasoning also reinforces why it is important for research projects to have a legacy for environmental change. Water resource management involves social and ecological dynamics, and people working with both social and ecological factors need enhanced capacity for adaptation and transformation. The social-ecological system may need to be able to bounce back from disruptive changes, or it may need to be able to bounce forward to new ways of operating if the old ways are no longer tenable given the changed conditions.

A broad systems approach to situations such as declining groundwater resources highlights the potential benefit of investing in collaborative research with institutional, social and environmental aspects to improve water resource use and management outcomes. It also helps develop a platform for extending the reach of the research and the development and implementation of additional approaches that can benefit the communities within which they were developed.

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