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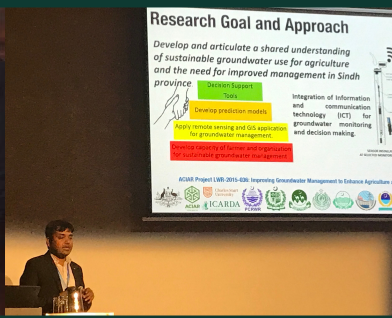


# Improving groundwater management to enhance agriculture and farming livelihoods in Pakistan: Literature review

Report No. 147

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**Institute for Land, Water and Society**

# Improving groundwater management to enhance agriculture and farming livelihoods in Pakistan: Literature review

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# Disclaimer

The views expressed in this report are solely the authors, and do not necessarily reflect the views of Charles Sturt University or any other individual or organisation consulted or involved in the research.

# Contents

# Abbreviations

| | |
|---|---|
| ACIAR | Australian Centre for International Agricultural Research |
| ADB | Asian Development Bank |
| AWB | Area Water Board |
| AWM | Agricultural Water Management |
| BAP | Balochistan Agriculture Project |
| BCM | Billion Cubic Metres |
| BID | Balochistan Irrigation Department |
| BRSP | Balochistan Rural Support Program |
| BUITEMS | Balochistan University of Information Technology, Engineering and Management Sciences |
| CBO | Community Based Organisation |
| CIMMYT | International Maize and Wheat Improvement Centre |
| CSIRO | Commonwealth Scientific and Industrial Research Organisation |
| CSU | Charles Sturt University |
| DAP | Di-Ammonium Phosphate |
| DFAT | Department of Foreign Affairs and Trade (Australia) |
| EC | Electric Conductivity |
| FAO | Food and Agricultural Organisation |
| FO | Farmers Organisation |
| GDP | Gross Domestic Product |
| GoB | Government of Balochistan |
| GoP | Government of Pakistan |
| HOPE | Health Oriented Preventive Education |
| ICARDA | International Center for Agricultural Research in the Dry Areas |
| ILWS | Institute for Land, Water and Society |
| IUCN | International Union for the Conservation of Nature |
| IWASRI | International Waterlogging and Salinity Research Institute |
| IWMI | International Water Management Institute |
| IWRM | Integrated Water Resources Management |
| LBDC | Lower Bari Doab Canal |
| LBOD | Left Bank Outfall Drain |
| MAF | Million Acre Feet |
| MAR | Managed Aquifer Recharge |
| MCM | Million Cubic Metres |
| MNSUAM | Muhammad Nawaz Shareef University of Agriculture, Multan |

| | |
|---|---|
| MUET | Mehran University of Engineering and Technology |
| NED | NED University of Engineering and Technology |
| NGO | Non-Governmental Organisation |
| NPK | Nitrogen (N) Phosphorous (P) Potassium (K) |
| NRSP | National Rural Support Program |
| PCRWR | Pakistan Council of Research in Water Resources |
| PID | Punjab Irrigation Department |
| PIDA | Punjab Irrigation and Drainage Authority |
| PIEDAR | Pakistan Institute for Environment-Development Action Research |
| PLB | Pishin Lora Basin |
| PRA | Participatory Rural Appraisal |
| PRSP | Punjab Rural Support Program |
| RAHA | Refugee Affected and Hosting Areas project |
| SAR | Sodium Adsorption Ratio |
| SAU | Sindh Agricultural University |
| SCARP | Salinity Control and Reclamation Project |
| SID | Sindh Irrigation Department |
| SIDA | Sindh Irrigation Drainage Authority |
| SOFT | Society of Facilitators and Trainers |
| UAAR | PMAS Arid Agriculture University |
| UAF | University of Agriculture, Faisalabad |
| UNDP | United Nations Development Programme |
| UNESCO | United Nations Educational, Scientific and Cultural Organisation |
| UNICEF | United Nations Children's Fund |
| USDA | United States Department of Agriculture |
| WAA | Water Apportionment Accord |
| WAPDA | Water and Power Development Authority |
| WRD | Water Resources Department |
| WUA | Water Users' Association |
| WWF | World Wide Fund for Nature |

# Preface

This literature review provides a foundation for the research developed as part of the ACIAR-funded, CSU-led project “Improving groundwater management to enhance agriculture and farming livelihoods in Pakistan” (LWR-2015-036). In particular, the authors have reviewed literature related to aspects of groundwater management in the case study areas selected for the project; the Pishin Lora Basin in Balochistan; the Lower Bari Doab Canal command area in Punjab; and selected districts covering areas of the Left Bank Command of Sukkur Barrage – initially covering three districts Shaheed Benazirabad (formerly Nawabshah), Naushahro Feroze and Khairpur.

At project inception, the primary purpose behind preparing the literature review was for the project team to use:

1. As the basis for each team member’s own literature reviews when preparing publications.
2. To collect and curate available information in all subject areas of the project
3. To collect case study specific information.
4. To identify and validate emerging research gaps and questions.

The systematic framework used for the review evolved from an initial structure developed during the project’s inception workshop in September 2016, and later revised at an authors’ workshop in February 2017. The eventual structure is divided according to case study areas, and sub-divided into the following themes:

1. Irrigation management
2. Sociopolitical context
3. Gender and youth
4. Role of NGOs
5. Economic context
6. Energy issues
7. Groundwater and hydrology issues

We were not able to include sections of publishable quality on all themes for all case study areas, and literature reviews on some themes were published separately in other project reports. A review covering environmental impacts has been covered in a separate publication (Mitchell et al., in press).

In most cases, authors contributing to the same theme negotiated a structure with similar sub-themes. Having a common structure proved useful for the two provincial irrigation department staff who wrote the sections on irrigation management for Balochistan and Sindh, and they expressed appreciation for the opportunity of contributing to an academic literature review report.

Mitchell, M., Allan, C., Punthakey, J. F., Finlayson, C. M., & Khan, M. R. (in press). Improving water management in Pakistan using social-ecological systems research. In M. A. Watto, M. Mitchell, & S. Bashir (Eds.), *Water resources of Pakistan: issues and impacts*: Springer.

# Summary

Not surprisingly, a common irrigation management issue across all case study areas relates to a need to improve overall governance, including through improved monitoring to ensure safe, sustainable and equitable access to water, better implementation of policies, pricing mechanisms and regulations, and associated capacity building. Overuse of groundwater is another common concern, with irrigation managers keen to find means for uptake of water efficient irrigated agriculture practices. Given the extreme variability in precipitation, measures such as sub-surface dams are a particular need for irrigation management in Balochistan, while in Sindh, a major concern relates to managing conjunctive use of surface and groundwater to reduce waterlogging and associated secondary salinisation.

The reviews undertaken into the socio-political contexts of each case study area complement how one is to understand and respond to irrigation management issues. The characterisation of an 'institutional void' in Balochistan is matched by efforts in Punjab and Sindh to shift from top-down to more participatory management approaches. These characterisations are in part a product of their contexts. In Balochistan, there has been significant interest in the shift away from the ancient and community-managed karez systems, where groundwater is tunnelled from higher underground storages for use by communities below, towards uncontrolled tube-well expansion, where individual farmers drill down and tap into groundwater reserves at ever increasing depths. Aquifer storages in Balochistan have more localised spatial limits, which have allowed local management of karezes to work well over many generations of use, but have enabled localised aquifer depletion from mass installation of tube-wells. The Indus aquifer, on the other hand, is one of the largest contiguous systems globally, as is the Indus Basin Irrigation System of canals covering much of Punjab and Sindh. Authors of these sections describe the challenges involved in navigating a change of management for such a large system from a top-down approach to one where irrigation management decisions increasingly involve water user associations, especially if the culture among government department staff is not conducive to such a change. For all three provinces, there is a resulting need to explore capacity building that encourages social learning and stakeholder engagement.

A key aspect of the socio-political context relates to roles that women and youth play as part of family-managed agriculture. All authors found documented accounts of cultural constraints faced by women in rural Pakistan society, manifest in terms of restrictions on mobility and the prevention of direct involvement in decision-making. In spite of these constraints, women spend much of their time working on family farms, not just fetching water for domestic purposes, but also being active in many aspects of the family farm business. Indeed, in some contexts, they contribute as "unofficial water managers". All reviews led to recommendations for exploring strategies enabling greater participation of women in groundwater management. Strategies include improved understanding of constraints, and identification of training and capacity needs for both women and youth.

Another important aspect of the socio-political context involves appreciating the crucial role that national and international non-government organisations play in the advancement of rural society, including through promotion of social welfare and community mobilisation programs, and through local-level networking and capacity building. Such a role has been key from the outset of Pakistan as a nation, but has also been fuelled in recent decades due to contributions of international donors. This situation provides an opportunity, expressed as a recommendation that government agencies and NGOs enhance their collaborative efforts to improve policies related to groundwater management and their implementation.

Reviews of the literature related to economic and hydrological contexts are best covered in project reports that cover these themes. However, recommendations arising from this review match those proposed from the reviews related to irrigation management. For example, in the Balochistan context, the review recommends depleted groundwater resources need replenishment by improving means for aquifer recharge, and to explore most feasible options to improve water use efficiency. The reviews here also consider the impact that the rise of solar pumping has had on groundwater use, recommending research that explores options to use solar pumps that can enhance farming family livelihoods without increasing over-extraction.

Arguably, the greatest impact arising from this literature review has resulted from the process of its production. While the final version is only being published as the project draws to a close, a complete version has been available for all team members to read and use since 2017. Its iterative development to that point of completion in 2017, and since that time, has involved all authors collaborating in the processes of structuring, writing, improving, and learning how to improve each individual review of the literature. Its publication now is merely the end point of a critical learning journey for the project. That the review includes contributions from staff in government agencies underlines the critical aspects of this process as an example of the project's approach to promote co-learning.

# 1. Introduction

Authors: Naveed Iqbal (PCRWR), Jay Punthakey (CSU), Muhammad Arif Watto (UAF), Faizan ul Hasan & Muhammad Ashraf (PCRWR), Syed Khair (BUITEMS),
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Pakistan is an arid to semi-arid country with an average annual rainfall of about 240 mm per year (Salma et al., 2012). The population and economy are heavily dependent on about 173 billion cubic metres (BCM) of annual surface water flows into the Indus, Jhelum, Chenab, Ravi, Beas and Sutlej rivers, which together comprise the Indus River system (Young et al., 2019). The headwaters of these rivers are in India and China and are mostly derived from snowmelt in the Himalayas. Through the ages, the people of Indus Basin have adapted to low and poorly distributed rainfall by either living along river banks or by careful conservation and management of local water resources.

The advent of large scale irrigation in the 19$^{th}$ century developed into the Indus Basin Irrigation System, now the largest contiguous irrigation system of the world. The desert literally bloomed, with irrigated agriculture providing the platform for development of the modern economy of Pakistan (Briscoe et al., 2005). Large quantities of water were used to irrigate desert lands where the underlying groundwater was of marine origin and highly saline.

Large scale canal irrigation resulted in excessive recharge from irrigation and unlined canals to the Indus Basin aquifer, which is naturally deep across most of the basin area. By the 1960s, the watertable in many areas was reaching the surface, giving rise to the twin menace of waterlogging and salinity.

Over the last few decades, intensification of agriculture, resulting from the ‘green revolution’ use of mechanisation, agrochemicals, higher-yielding crop varieties and changed cropping patterns, has led to increased demand for irrigation supply. Spatial and temporal variability in water supplies through the canal system has prompted irrigators to increase their use of groundwater to supplement irrigation supply during dry years, the dry season, and at the farthest reaches of the canal system. As detailed below, this has led to a rapid increase in development and use of tube-wells across the Indus Basin, a situation mirrored in Balochistan. The result is that, in addition to areas impacted by waterlogging and salinity, there are other areas affected by groundwater over-extraction, where more water is extracted than is recharged. Much of the literature describes this situation in terms of over use or over-exploitation of groundwater, being more pejorative terms pointing to insufficient management of groundwater, or, more often, implicitly criticising irrigators for not sufficiently valuing groundwater, and using it excessively, indiscriminately and inefficiently.

## 1.1 Pakistan - water challenge

It is widely recognised that Pakistan is among the countries most vulnerable to water insecurity. Climate projections indicate a substantial decrease in surface water inflows which will exacerbate and entrench the shift towards increased groundwater use and associated detrimental impacts on farming family livelihoods from increased costs secondary salinisation. The World Resources Institute (Maddocks et al., 2015) has reported that Pakistan will be among the most water stressed countries of the world by 2040; whereas, according to the Falkenmark indicator, Pakistan is already a water scarce country having per capita water availability of less than 1000 m$^3$ (Ashraf, 2016). Based on the current population and total annual runoff, Archer et al. (2010) estimate a per capita water availability of 725 m$^3$ by 2025 if the population continued to increase at constant rate of growth and the available water resources remain stagnant. Due to reduced water availability, it is estimated that there will be an overall gap of 100 km$^3$ by 2025 which is five times more than the current water storage capacity of 19 km$^3$ of the Indus River System (Archer et al., 2010). It has been estimated that the agricultural sector should grow by more than 4% each year and water supplies by almost 10% to meet the food requirements of the world’s sixth largest country by population (Archer et al., 2010; Sharma et al., 2010; Laghari et al., 2012; FAO, 2016).

Even though Pakistan has the fourth largest groundwater aquifer, available groundwater is not sufficient to meet growing demands and is under immense pressure from over-extraction (Khan et al., 2008; Rodell et al., 2009; Wada et al., 2010). In Punjab, for example, it has been estimated that groundwater provided 8% of farm water supply in 1960 (Byerleee & Siddiq, 1994), increasing to over 60% in 2019 (Qureshi & Ashraf, 2019).

The contribution of groundwater to irrigation water supplies in the Indus Basin has increased from just 8% in early 1960 to more than 50% in the 2000s (van Steenbergen & Gohar, 2005). The dependence on groundwater for irrigated agriculture is up to 100% in parts of Balochistan. In order to meet escalating irrigation water requirements, Pakistan extracts 60 $km^3$ (or 0.06 MCM) of groundwater each year, exceeding the annual recharge rate of 55 $km^3$ (Giordano, 2009); i.e. a situation referred to as over-extraction. It is reported that continued over-extraction between 2000 and 2009 resulted in an annual depletion of 3.61 $km^3$ of the groundwater resource in Pakistan (Döll et al., 2014). Iqbal et al. (2016) reported that about 11.82 $km^3$ of Upper Indus Basin groundwater has been used for anthropogenic purposes from 2003-2010. The study mapped out hot spots of groundwater depletion in different parts of the Punjab province of Pakistan and noted that the highest depletion rates are found in the south-east (i.e. in Bari Doab) (Iqbal et al., 2017). An earlier study predicted that if prevailing dry conditions persisted, there would be a 10 to 20 metres decline in groundwater levels in the upper and the lower reaches of the Rechna Doab (Khan S. et al., 2008). Iqbal et al. (2020) mapped the lateral and vertical spatial variability in groundwater quality in Indus Plain covering the areas of Punjab and Sindh provinces and found that quality deterioration is more profound in the centre of doabs (area between two rivers) in Punjab. The results indicate that about 33% area of Thal and Chaj doabs is under groundwater salinity followed by Bari (28%) and Rechna (21%) doabs with quality ranging from saline (2.6-4.0 dS/m) to highly saline (> 4.0 dS/m). However, in Sindh province, the fresh (<1.5 dS/m) to marginal (1.6-2.5 dS/m) quality groundwater is only available in about 20% of the area and mostly found along the Indus River. Furthermore, the groundwater salinity increases with depth. Figure 1 shows the spatial variations in groundwater quality over Punjab and Sindh province.

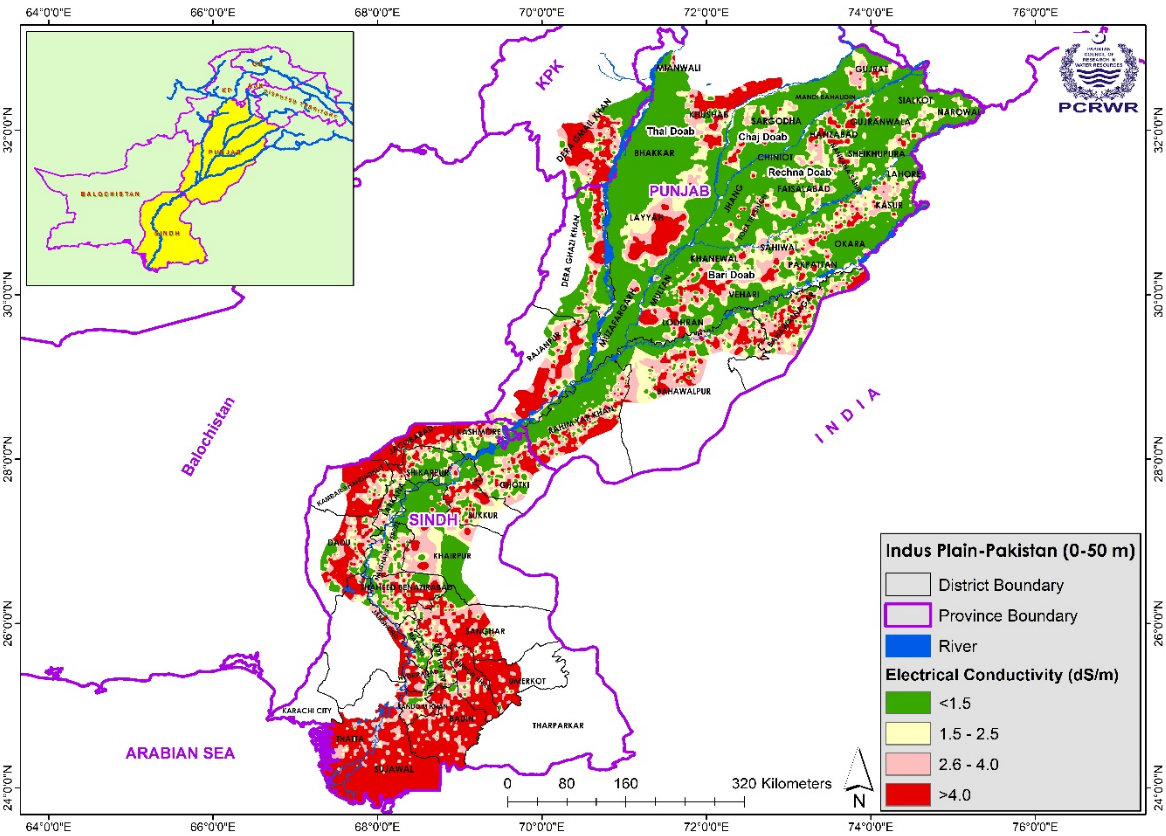


*Figure 1: Spatial variations in groundwater quality in the Indus Basin of Pakistan. Reproduced from Iqbal et al. (2020).*

## 1.2 Causes and consequences of groundwater over-extraction

Overexploitation of groundwater is one of the most immediate challenges facing Pakistan, with a concomitant urgent need to strengthen institutional capacity to manage groundwater and to develop socially acceptable approaches and policies for addressing the imbalance between water withdrawals and recharge (Qureshi, 2011). As most groundwater recharge comes from canal seepage and irrigation application, integrated and effective conjunctive use strategies are required to be put in place (Basharat & Tariq, 2015). However, neither governments nor major donors are strategically funding to cater for these needs.

In the past, the uptake of groundwater pumps by farmers resulted in economic and environmental benefits by reduced waterlogging and salinity. However, the overuse of groundwater is now threatening fresh water aquifers through intrusion of saline water upconing (Basharat & Tariq, 2013). Waterlogging and salinity remain major issues in Sindh and in parts of Punjab. Researchers estimated that 15 million tons of salt accumulate in the Indus Basin annually (NESPAK & MMI, 1993). In addition, climate change is beginning to affect glacier melt in the Western Himalayas. An investigation in 2005 estimated that glacial retreat would continue for the next 50 years, initially increasing river flows and flooding, after which river flows would decrease between 30 and 40% in a hundred years (Briscoe et al., 2005).

In the lower reaches of the Indus, the delta is being degraded due to low flows and low silt loads, impacting coastal communities, vegetation (mangroves) and other biodiversity, and undermining economic progress (IUCN, 2003; Memon & Thapa, 2011; Kamal et al., 2012; Renaud et al., 2013). Intensive agriculture is also resulting in widespread use of large quantities of fertilisers and pesticides (Zulfiqar & Thapa, 2017), adding to Pakistan's overall unsafe water pollution levels caused by untreated domestic and industrial wastewater discharging into freshwater systems (Ashraf, 2016).

Groundwater resources have been playing a key role in agricultural development in Pakistan for a long time. However, the dramatic increase in groundwater use began during the 1960s and has manifested into "silent revolution" by thousands of farmers installing tube-wells on a large scale (Watto & Mugera, 2016a). During the early 1960s, tube-well adoption was largely aided by various government support policies such as rural electrification, subsidisation of electricity, diesel and drilling services, free pump sets and low interest long-term loans (Papanek, 1967; Falcon and Gotsch, 1968; Johnson, 1989; van Steenbergen and Oliemans, 2002). The use of groundwater helped farmers achieve higher yields and greater economic returns (Meinzen-Dick, 1996), motivating them to adopt tube-well technology even without government support policies and leading to an expansion in water intensive crops such as sugarcane and rice (Mohammad, 1964; Mohammad, 1965; Falcon and Gotsch, 1968; Nulty, 1972; Ahmad et al., 2004; Kazmi et al., 2012). Khair and Culas (2013) reported that in Balochistan the groundwater driven agricultural production is increasingly under threat due to rapidly depleting groundwater at the rate of 2 to 5 metres annually. Both government and water users have responsibility for insufficient action to avert the foreseen disaster. The government's groundwater development policies following over estimation of groundwater reserves and water use inefficiency are the main reasons for declining watertable levels.

It is also recognised that intensive groundwater use has temporarily relieved the symptoms of waterlogging and salinity in Punjab, however new issues have emerged from uncontrolled use of groundwater for irrigation purposes. The rapid decline in groundwater levels is beginning to make groundwater extractions economically unviable for some farmers (Watto & Mugera, 2016b) and is causing environmental problems with serious impacts on the sustainability of irrigated agriculture in the region (Kelleners & Chaudhry, 1998; Kahlown & Azam, 2002; Qureshi et al., 2010b). As a result, the areas of the Lower Bari Doab, and especially the districts of Lodhran, Multan, Lahore, parts of Sheikhupura, Khanewal, Narowal, Jhang, Toba Tek Singh and Sargodha, are experiencing conditions which Khan et al. (2016) describe as groundwater mining. The thin layer of fresh groundwater overlying deeper saline groundwater across the Indus aquifer can be rapidly used, resulting in more saline groundwater being pumped instead, with some tube-wells having to be abandoned (Qureshi et al., 2010).

In Balochistan, most of the karez system has run out of water. The centuries old karez system has become a story of the past and the inhabitants are now compelled to rely on dug wells/ deep tube-wells. The quest for water has pushed farmers to install submersible electrical pumps at greater depths to reach falling groundwater levels, especially in Pishin Lora Basin (van Steenbergen et al., 2015). An extended drought during the early 2000s, mismanagement, wastage and lack of proper implementation of groundwater regulations are the main causes of this aggravated situation in Balochistan. Due to the large numbers of tube-wells installed, groundwater extraction has increased rapidly in the region over recent decades and groundwater resources are declining, potentially placing production systems and rural livelihoods at risk (Khair et al. 2015; van Steenbergen et al., 2015). The groundwater situation in Quetta is particularly alarming where the deep tube-wells have been installed by puncturing the hard rock of more than 340 m depth (Durrani et al., 2018).

The consequences of such over-extraction across Pakistan have been synthesised from various aspects. Firstly, some areas are facing excessive depletion of groundwater resources, especially in Balochistan. Secondly, and at the same time, some areas are experiencing challenges of waterlogging and salinity due to poor drainage and over-irrigation. Third, farmers at the tail end of Indus Basin canals and distributaries are not being supplied with an equitable share of surface water, so farmers in these areas often have to use poor quality groundwater for irrigation which exacerbates presence of salinity and sodicity in their agricultural lands. Fourth, the surface water system was designed to enable around 67% of irrigable land to be in production each year; that is, for a cropping intensity of 67%. With multiple crops per year, cropping intensities are now over 150%. Fifth, this increase in cropping intensity, driven by the need to improve food security for Pakistan's growing population, means that the use of both surface water and groundwater for irrigation needs to be efficient and sustainable, and its distribution fair and equitable. These consequences have political dimensions which cannot be ignored. Reluctance to take on these political dimensions means that judicious use of water for irrigation has largely been bypassed in favour of expanding the canal network or seeking out new sources of water. The focus in the future needs to be on improving surface and groundwater use and management at all scales, from basin, canal command, distributary, and down to the farm scale.

## 1.3 The need to improve understanding of groundwater

The arid to semi-arid climate in Pakistan makes agriculture highly dependent on irrigation water both from canal and groundwater. Irrigation water demands are increasing, surface water resources are becoming spatio-temporally unavailable and groundwater resources are inaccessible in some parts of Pakistan. Besides increasing demand for irrigation water, growing awareness of environmental and in-stream water values have added a new impetus to improve the understanding of groundwater resource availability and to balance what is available and what is being extracted. Furthermore, canal water shortages and increased reliance on groundwater requires a rethink of current groundwater extraction decisions and a close investigation into the efficiency of water use in the agriculture sector. The sector is widely seen as an inefficient user of water for irrigation – see assessments by Bakhsh et al. (2015) and Watto and Mugera (2014; 2015a; 2015b; 2016a). Given lower levels of water productivity, as well as annual growth in water productivity, compared with other equivalent nations on the world stage (Young et al., 2019; Davies & Young, in press), Pakistan has substantial potential to increase its water use efficiency, especially given the likely scenario of high water insecurity.

The Indus Basin water resources are amongst the most stretched in the world (Briscoe et al., 2005) and several studies have highlighted the growing water crises in Pakistan (Mustafa et al., 2013; Condon et al., 2014, Kirby et al., 2017). The following factors underscores the need for improved understanding of groundwater in Pakistan:

(i) Growing need of surface and groundwater availability with increasing population.
(ii) Over-exploitation of groundwater with falling watertable levels in many areas particularly evident in Balochistan and the eastern doabs of Punjab.
(iii) Widespread resource degradation due to salinity build up in surface and groundwater, lack of sediment supply to the delta, and water pollution.
(iv) Impact of climate change which is likely to exacerbate the severity of floods and prolonged droughts.

(v) Lack of holistic understanding of the basin-wide water resources (surface and groundwater) with linkages and dependencies between different uses.

(vi) Comparatively lower land and water productivity in agriculture in comparison with neighbouring countries.

Significant gaps in groundwater modelling at the Indus Basin scale were identified by Kirby and Ahmad (2014), and these gaps are being addressed (Schmid et al., 2017). The knowledge gap has undermined a broader, system-wide approach to groundwater management as previous studies were confined to small case studies areas. Several efforts are being made to bridge these knowledge gap with national and international linkages. For example, the Pakistan Council of Research in Water Resources (PCRWR) has recently undertaken evaluations of the Indus Basin Aquifer by mapping its groundwater resources (Khan et al, 2016; Iqbal et al., 2020). This mapping is based on an integrated approach of applying geophysical, isotopic and groundwater modelling techniques. These studies have provided insights in quantifying useable groundwater, identifying sources of groundwater recharge and devising appropriate management strategies. The Sustainable Development Investment Program (SDIP) for the Indus Basin undertaken by CSIRO for the Australian Government has also been developing a regional groundwater model of the alluvial areas of the Indus Basin (Schmid et al., 2017). Like this ACIAR Groundwater project, the SDIP project has a significant capacity development program for the benefit of Pakistan-based researchers and resource managers. In addition to this capacity building, we recognise that integration of perspectives from the social sciences is critically important, which can become a thriving area of research for changing overall social and institutional behaviours in the context of water conservation.

## 1.4 The need for groundwater governance

While groundwater in Pakistan is seen as a common-pool resource, access rights are tied to private property land rights (Mustafa et al., 2013; Gilmartin, 2015). There is no restriction on the use of groundwater and groundwater user rights are not defined and confined. In this sense the groundwater is free, with farmers only needing to pay for tube-well development, and the electricity or diesel costs to run them. Once extracted, groundwater is no longer a common pool resource, as tube well owners have exclusive rights for that water (Meinzen-Dick, 1996). They can extract groundwater and even sell to neighbouring farmers without any restriction and interference either from the government or customary laws (Hussain, 2002). Farmers with large landholdings usually own tube-wells, while small landholder farmers or tenants tend to buy water (Meinzen-Dick, 1996). Such groundwater transactions occur through informal market arrangements (Thobanl, 1998) that in its initial stages improved equity of access to groundwater, exacerbating its over exploitation (Meinzen-Dick, 1996).

Informal groundwater markets are in operation across all provinces of Pakistan, but are most active in Punjab (Meinzen-Dick, 1996). Since the 1970s, when reliance on groundwater started increasing, private tube-well development was highly promoted and currently more than 80% of groundwater is extracted through private sector tube-wells (Qureshi et al., 2010a). The idea of groundwater markets as a groundwater management policy tool has, anecdotally, attracted increased interest over their role in water markets, and their potential and efficiency worldwide. However, the literature available on this subject is limited and there is a need to examine these water markets to have a better insight into their functions and impact on agricultural productivity and resource sustainability in Pakistan (Qureshi et al., 2010b).

Over the past few decades, governments across Pakistan have tried several groundwater management strategies with limited success. For example, in the 1970s, with electrification of rural areas in Punjab, the provincial government promoted tube-well adoption through heavy subsidies, paying for installation costs and waiving or subsidising electricity tariffs. In the next decade, due to low electricity tariffs and heavy subsidies, the number of tube-wells increased by more than 200% (Qureshi et al., 2003). The soaring number of tube-wells and rapid extraction of groundwater forced the government to re-consider its groundwater use policy. The changed policy landscape was now focused on two themes: i) to avoid declining watertable levels and quality in fresh groundwater areas; and ii) to ensure equal access to groundwater (van Steenbergen and Oliemans, 2002). As a result, the government decided to issue permits for further installation of tube-wells especially in areas having low watertable levels. However, pressure on the government to mitigate conditions underpinning rural poverty led to an abandonment of this approach. It was seen as easier to allow open access to groundwater (Qureshi et al., 2010b). So, groundwater was being regarded as a resource for rural development, which further catalysed construction of new wells. The mounting number of tube-wells, ultimately put a heavy burden on electricity sector. In early 1990s, the flat rates for electricity on tube-well irrigation increased by 126% which, coupled with unannounced extended power cuts and fixed cost, made flat rate connections unattractive and farmers started changing to use diesel pumps. The availability of locally made diesel engines and relatively low installation costs (US$1,200) made groundwater irrigation accessible for small farmers (van Steenbergen and Oliemans, 2002). Of over 1 million tube-wells in the Punjab province, 13% are electric and 87% are diesel engine operated pumps (Bureau of Statistics Punjab, 2017).

The average extraction per groundwater structure across India (7,900 $m^3$) was found to be much lower than for the Punjab province of Pakistan (90,000 $m^3$) (Shah et al., 2003). This higher extraction of groundwater in Pakistani Punjab is generally attributed to insufficient canal water supplies as cropping intensities increase. However, under the traditional land tied groundwater rights and informal groundwater markets, farmers also use groundwater wastefully. A typical example of this inefficient water use is evident in Punjab Province where farmers are applying 3,000 mm of water through traditional flood irrigation method to meet the standing water requirements in the rice paddy which is almost six times higher than actual crop water requirement as determined by Soomro et al. (2018). Insufficient information about crop water requirements, and an absence of appropriate pricing system, encourages farmers to extract more water than they actually require (Qureshi et al., 2010b), and achieving change on the ground may be hampered by a risk-averse impulse among many impoverished farmers to trial new cropping patterns and on-farm water management practices. Khair et al. (2015) suggest that to meet the challenge of sustainable groundwater management, Pakistan needs to develop sustainable groundwater policies with the main focus on groundwater management rather than groundwater development and with appropriate governance arrangement to ensure benefits continue into the future.

The synthesis of literature underlines that the non-existence of groundwater regulatory framework in Punjab and Sindh provinces, poor implementation of groundwater act in Balochistan, non-availability of accurate assessment of basin scale groundwater potential, weak and insufficient coordination among relevant stakeholders, lack of confidence across provinces and organisational capacity limitations are the major challenges of immediate consideration. The focused efforts with integrated and multidisciplinary approach by involving all stakeholders are required for the solution of complex issues associated with sustainable groundwater resource management in Pakistan.

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# 2 Balochistan

## 2.1 Irrigation management

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Balochistan experiences more extreme water scarcity than the other three provinces of Pakistan. Balochistan comprises about 44% of the total area of Pakistan and has a population of 12.34 million (Pakistan Bureau of Statistics, 2017). Due to shortages in water supplies and the non-perennial nature of surface water supply, only about 10.7% of the 19.4 Mha area is cultivated (Ashraf & Sheikh, 2017). As a result, dependence on groundwater resources has increased dramatically, with tube well numbers increasing from 5,000 in 1980 to 40,000 in 2015. Groundwater depletion is reported in 10 out of the 18 major river basins in Balochistan, with Pishin Lora Basin (PLB) at the top of the list (Ashraf & Sheikh, 2017). PLB is the largest basin having an area of 1.7756 Mha, out of which, 0.42 Mha is under cultivation (Halcrow, 2008b). Due to low precipitation (average per annum of 217.63 mm) and drought spells, the PLB is classified as semi-arid (within the 200-250 mm annual rainfall bracket) (Halcrow, 2007, 2008a). The Quetta Valley is the most depleted region of the PLB where groundwater pumping has become almost un-economical as tube well drilling has crossed 365 metres. Being the provincial headquarters, the water demand in Quetta has increased manifold to meet drinking water supplies.

The groundwater in Balochistan's aquifers provides a buffer against drought for crop production, and for livestock and human consumption (Siebert et al., 2010; Ashraf & Routray, 2013). Low precipitation, drought, climate change, and poor irrigation methods mean groundwater is being over exploited, and causing karezes, dug wells and shallow tube-wells to dry up. Fast depleting groundwater is a matter of grave concern for agrarian and non-agrarian stakeholders of the PLB (van Steenbergen et al., 2015).

### 2.1.1 Objectives of this literature review

- To obtain a better understanding of available water and its use in the Pishin Lora Basin and the potential for developing an integrated approach.
- To determine a realistic picture of demand and supply for both surface and ground water.
- To identify gaps and loopholes in existing legislation.
- Role and extent of groundwater compare with surface water for irrigation

Water is vital to sustain everyday life. Balochistan experiences acute water shortages and the Pishin Lora basin is one of the most stressed basins given the added challenges of huge influxes of people migrating there from Afghanistan (Sagintayev et al., 2012). Pishin Lora Basin is home to some 35% of Balochistan's population (Halcrow, 2008b). After domestic, livestock and agriculture use, the available surface water (of all types) in PLB is 0.2835 billion cubic metres (BCM) whereas, the available groundwater after use is in deficit at -0.5040 BCM (Halcrow, 2008b).

Other studies have described the devastating condition of PLB. For example, van Steenbergen et al. (2015) has observed that over the last thirty years there has been a steady decline in groundwater levels in the Kuchlagh sub-basin of PLB. In the beginning of 1970s, the karezes and open dug wells were the common source of ground water. A karez is one of the oldest masterpieces of engineering used for irrigation in many countries including Pakistan. This ancient system of water supply, of which 3,000 remained in existence by 1970, had been a buffer against droughts and had helped transform the agrarian landscape of the uplands by improving socioeconomic conditions in Balochistan (Ashraf & ul Hasan, 2020). From the 1980s onwards, there was an increase in the use of groundwater, as the development of transport to large markets like Lahore and Karachi occurred. There was also an economic expansion and the influx of Afghan refugees. In the late 1990s and early 2000s a position was attained where the main alluvial aquifer in Kuchlagh was depleted (van Steenbergen et al., 2015).

The six-year drought between 1998 and 2004 affected the province very severely. Ahmad (2007b) offered evidence to show that the drought had an adverse impact on surface water flows in Balochistan. There was a 48% fall in the surface water flow during the period of the drought compared with the pre-drought year 1997. These figures reflect the critical condition facing water management in Balochistan. One opportunity to explore is to harvest flood water for use in drought years. The government and groundwater users should explore the significance of groundwater in PLB, and take measures to use this treasure judiciously.

### 2.1.2 Demand and supply analysis

Groundwater budget analysis is one of the main tools used in irrigation management to assess availability of water for different uses. Agriculture, human, livestock and the environment all have demands on water but different studies show different results. Agriculture, being the dominant sector, consumes 70 to 80% of groundwater and almost all of the surface water. The water required for agriculture in PLB is 486 million cubic metres (MCM) (SMDams Project Consultants, 2016). An imbalance of about 0.396 BCM between demand and supply has been reported in the PLB (van Steenbergen et al., 2015). However, it is also estimated that a groundwater potential of about 1,071 MCM is available across the 18 river basins, out of which some 604 MCM is already used to meet various sectoral needs. The basins of Hingol followed by Hub and Hamune-Mashkel have a cumulative potential of about 248 MCM which could be sustainably used to enhance agricultural productivity through efficient irrigation practices (van Steenbergen et al., 2015).

At the 1998 census, Balochistan had a population of 6.56 million, with the National Institute for Population Studies estimating that had increased to 9.9 million by 2016, (SMDams Project Consultants, 2016). The population of PLB was similarly estimated to be about 3.33 million in 2016, requiring 82.8 MCM water per year for human use (SMDams Project Consultants, 2016). Livestock production is a major source of livelihood for people of the province, with range lands cover about 79% of the total area. There are about 20 million head of livestock in the province. In PLB alone, there are 7.27 million head of livestock, requiring 94.56 MCM water per year.

A study on available water resources and their exploitation done by Halcrow (2008b) shows a very alarming situation (data extracted for a year of average precipitation):

| | Available for all purposes (MCM) | Used for all purposes (MCM) | Difference (MCM) |
|---|---|---|---|
| Surface water | 302 | 13.7 | + 288.3 |
| Groundwater | 170 | 670.3 | - 500.3 |

Considering the above figures, projected water use (measured in MCM) for an average year by 2040 will be:

| Basin | Human | Livestock | Agriculture | Nature | Total |
|---|---|---|---|---|---|
| PLB | 116.23 | 127.456 | 5473.6 | 30.00 | 5747.3 |

### 2.1.3 Legislation and policies

According to UNESCO (2003) and Mukherjee et al. (2015) groundwater is one of the world's most mined resources. During recent decades, the exponential growth of groundwater both in scale and intensity has been observed in many areas, and has led to groundwater pollution and aquifer depletion (Giordano, 2009; Wada et al., 2010; Kulkarni et al., 2015).

Legislation related to water management in Balochistan is dislocated and lacks proper structure. Current policies are run on ad-hoc basis and cover only a few aspects of water resource management (Kamal et al., 2012). Other researchers agree that the governments of Balochistan and Pakistan generally do not have appropriate legislation regarding control and sustainable management of groundwater (van Steenbergen & Oliemans, 2002; van Steenbergen, 2006; van

Steenbergen et al., 2015; Theesfeld, 2010; Khair et al., 2015).Existing legislation related to water in Balochistan is listed below:

- Water Rights of Locals Clans
- Balochistan Groundwater Rights Administration Ordinance, 1978
- Balochistan Canal and Drainage Ordinance 1980
- Water Users Association Act, 1981
- Quetta Water and Sanitation Authority Act, 1989
- Indus Water Apportionment Accord, 1991
- National Environmental Quality Standards, 1993
- Balochistan Irrigation and Drainage Authority Act, 1997
- Pakistan Environmental Protection Act, 1997
- Community Irrigation Farmers' Organisation Regulation, 2000

There is limited means for the government in Balochistan to provide guidelines to those involved in water regulation. With no framework, and because inter-agency linkages between implementing agencies is poor, the impact of any legislation on the ground is scant.

Another major threat contributing to groundwater over-exploitation is the emergence of solar powered tube-wells. If installation of these tube-wells proceeds without due permission or policy, the groundwater situation could become even more dire in the near future.

### 2.1.4 Irrigation structures, conjunctive use and managed aquifer recharge

Quetta Valley is a covered valley with karstic bedrock in a tectonic depression. Aquifers are located near the foothills of the Murdar and Mian Ghundi regions. There is a Samungli-Baleli water gap about 10 km wide in the northwest region of Quetta, which joins the Quetta Basin with the Bostan-Pishin Plain. The drainage of Quetta Basin makes its way through this gap to join the Pishin Lora River (Murray et al., 2007).

Despite substantial investment by the World Bank and others in gravity flow perennial systems and 'delay-action dams', these efforts were partial and scattered reactions to the issue, and over exploitation of groundwater continued unabated (Mustafa & Qazi, 2008). The launching of different projects for sustainable groundwater use has been a one sided effort, and many have asserted that governments will need to work collaboratively with water users to achieve the goal of reducing groundwater use, and a longer term strategy will be required (e.g. van Steenbergen, 2006).

### 2.1.5 Distribution management, practices and decision making

As in other parts of Pakistan, water access is determined according to a farmer's landholding. The traditional karez water distribution system was very accurate and is still honoured, despite a transition away from this system (Mustafa & Qazi, 2007). All shareholders of a spring, karez or any other common source would choose a person unanimously to take care of each farmer's share. There is evidence that farmers designed water distribution structures using a log with slots in it according to the share of farmers. The modern design of water distribution structure from a source for different farmers is almost the same. When a project is launched, modern techniques of water distribution, water conveyance and check structures are introduced, along with social structures. These new inventories have replaced the old system in many areas. However, it is still the case in Balochistan that decision making is the right of senior male family members; females are not allowed to take part nor move outside the home for work or trade (Qasim et al., 2011).

### 2.1.6 Existing irrigation practices/ methods/ modes/ tools/ techniques

Irrigation through a karez or a spring can be considered as the oldest irrigation practice/technique. Karezes and springs were the chief source of irrigation during early to mid twentieth century (Mushtaq et al., 2013; Khan & Nawaz, 1995). Karez irrigation system in Balochistan is under tremendous threat from the rapid expansion of tube-wells, which could lead to their complete disappearance (van Steenbergen & Oliemans, 2002). The area under karez-based irrigation has decreased from 43% (1971) to 3.7% in 2015 (Ashraf & ul Hasan, 2020). Farming families are seeking to make the most of the area under crop and to increase productivity thus rejecting the earlier and traditional form of irrigation (Mustafa & Qazi, 2008). *Khushkaba* (when only localised (within field) runoff is used from incident rainfall and crops suffer moderate to severe moisture stress during crop cycles) and *Sailaba* (when water is harvested through ephemeral streams, and crops complete their life cycles using stored moisture) irrigation practices are used where no other means of irrigation are available or accessible (Ahmad, 2007a). Barrages, canals and tube-wells are used as follows:

- Canal command areas of Pat Feeder and Kirthar canals.
- Command area of minor perennial irrigation schemes.
- Tube-well irrigated agriculture.
- Minor groundwater schemes – springs, karezes.

### 2.1.7 Conclusion and Recommendations

Through the literature review and PRA conducted in PLB (Khair et al., forthcoming), it is concluded that a groundwater crisis has been reached due to frequent drought spells, over exploitation of groundwater, urban expansion, poor understanding of hydrogeological conditions, poor assessment of availability of water, poor groundwater governance and lack of coordination among different agencies working on water. To address this crisis, the following recommendations are suggested:

Measures should be taken to harvest the flood water in terms of recharge and storage.

- A safe yield line established for each aquifer to establish an equilibrium.
- Rules and regulations be followed with letter and spirit without any political compromises.
- Drilling of new tube-well be stopped immediately and subsidies on existing tube be withdrawn.
- Due to load shedding from national grid, tube-well owners switching over to solar pumping must be stopped.
- Water pricing should be enforced.
- Sub-surface dams should be constructed.
    - These dams are very cost effective.
    - They do not extract the natural flow of a nullah as the crest of dam is 1m below the surface.
    - As the dam is constructed on a hard rock, it traps all seepage water, increasing the watertable upstream.
    - The minimum life is 50 years, but it is considered a life time structure.

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## 2.2 Sociopolitical context

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Balochistan has been the focus of significant academic contributions to a global understanding of the social, cultural and institutional aspects of groundwater use for irrigated agriculture (van Steenbergen, 1995; Mustafa & Qazi, 2007, 2008; van Steenbergen et al., 2015). In particular, the longitudinal study led by van Steenbergen (1995) poses the critical dilemma being faced in the Balochistan context of a 'socio-institutional void' – or lack of effective management. His study includes a focus on Kuchlak – one of potential case study locations within the Pishin Lora Basin – and is further described immediately below.

### 2.2.1 Description of management regime

Van Steenbergen's (1995) paper provides a fascinating historical account of what was then an emerging disaster for groundwater management. Written at a time when the 'groundwater rush' was in full swing, it documents how formal government-led and informal community-led institutional responses failed to form an effective regime to manage groundwater over-exploitation. This was a boom time; the 'apple economy' was providing four to five times the returns that farming families had previously achieved (Khair et al., 2015). Depicting the rush as a classic 'frontier' problem, van Steenbergen describes the failure as a series of ineffective reactions to problems as they arose. In one case, the response was to try to give greater legitimacy to existing norms prohibiting wells being constructed within a certain distance of other wells. In another case, tribal elders were asked to band together to identify solutions. Such a reactive management regime failed to control who could or could not access the common pool resource, nor the extent and timing of their access. An ominous figure is provided (van Steenbergen, 1995, p. 70) that shows what was then the future for Balochistan. The trajectory shown in the figure suggested that if management regime failures continue, the common pool groundwater resource would pass a sustainability point (where extraction exceeds regeneration of the resource), and then a point of return (where any further extraction simply becomes too expensive).

Unfortunately, development continued unabated, and was exacerbated by an extended drought (van Steenbergen et al., 2015; Khair et al., 2015). Focusing on the Kuchlak case study, van Steenbergen et al. (2015) note that aquifers were becoming depleted, with some farmers constructing tube-wells that went deeper into the underlying limestone aquifer. Such wells were built at much greater cost, and had a shorter lifespan. From this, the authors concluded that an effective management regime failed to emerge as one might have expected from either increased conflict over the scarce resource or through an increased desire to build cooperation. Instead, farming families were forced to adapt to the new circumstances in their own different ways. Some sold their land, mostly to Afghan refugees for residential and/or business purposes. Others continued farming, mostly ripping out their failing apple trees and trying alternative crops. Yet others embarked on an enterprising business of selling most of their water to tankers supplying water for urban domestic use, which helped to double their income.

### 2.2.2 Implications of governance decisions

The implication of the longitudinal case study described above is that such a 'socio-institutional void', where an effective governance regime has failed to emerge, is a crucial context requiring further understanding and investigation. This is a similar conclusion to a recent comparable study involving a 'weak' groundwater governance regime in Morocco (Faysse et al., 2014). Studying management regimes that emerge from cases of conflict or cooperation will not provide solutions to contexts like that being faced in Pishin Lora Basin. That noted, it is also important to appreciate that decisions were made, and that it would be incorrect to understand the context as completely devoid of a governance regime. For example, government policies aimed at reducing poverty and catalysing rural development included substantial subsidies to rural farming families for electricity supply. As has been observed elsewhere (Shah et al., 2006), these policies unwittingly encouraged massive over-extraction of groundwater in Balochistan (Khair et al., 2015). This impact has been most stridently put by Mustafa and Qazi (2008), whose surveys showed that large farming operations were deemed the major beneficiaries of the transition to tube-wells, whereas small farms were the main losers (see Figure 10 on p. 184). Groundwater depletion reinforced this effect, ensuring that only the wealthiest farmers being able to afford the high costs of accessing groundwater via tube-wells, and other farmers relying on other means, including karezes, spate irrigation (*sailaba*) and rainwater harvesting (*khushkaba*) that in general offer more marginal returns (Ashraf et al., 2016; van Steenbergen, nd; 1997).

### 2.2.3 Cultural aspects

The strong influence of diverse cultural aspects on groundwater management is broadly appreciated in all the journal articles reviewed. Differences in culture is a key component to the analysis of emergent institutional responses to the groundwater crisis in Balochistan offered by van Steenbergen (1995). More importantly, the changes in how groundwater has been extracted and used has resulted in profound impacts on the culture of Balochistan rural society. Social capital – the glue that binds – was undermined as a result of the shift away from more traditional community-oriented extraction methods that resulted from the rapid uptake of tube-wells (Mustafa & Qazi, 2007). While the traditional karez system of extraction is still present in the Pishin Lora Basin (Ashraf et al., 2016), the spread of tube-wells has reinforced an individualistic and competitive trend among farming families, and exacerbated inequities (Mustafa & Qazi, 2007).

### 2.2.4 Institutional analysis

In addition to the papers reviewed above, other papers have undertaken institutional analysis to explore farmers' perceptions of drought vulnerability, climate variability, the causes of water scarcity, and their adaptation strategies (Ashraf & Routray, 2013; Ashraf et al., 2014; Jilani & Khair, 2014; Khair et al., 2015), and to identify criteria for a more effective institutional regime building on the concept of integrated water resources management (IWRM) (Ahmad, 2007; Baloch & Tanik, 2008). While Ashraf & Routray (2013) found that most farmers appreciated that human actions accelerated drought effects, and those with a longer history of farming appreciated the cyclical nature of climate variability, drought was predominantly seen as being the will of God. Adaptations included adjustments in farming practices and inputs, the pursuit of off-farm employment, selling assets, borrowing, and out-migration (Ashraf & Routray, 2013). On the other hand, a critical finding from Khair et al. (2015)'s survey is that most respondents recognised that mass installation of tube-wells and associated over-extraction of groundwater was the primary cause of water scarcity, rather than belief that water is an infinite resource. Such a finding negates the view that farming families are to blame because they lack awareness and understanding. The groundwater crisis that has occurred in Balochistan requires a response that overcomes 'ill-directed groundwater policies and lack of political will' and an 'inadequate understanding of farmers' perceptions and drivers' (Khair et al., 2015, p. 627). So, in addition to the need for a more effective integrated regime able to develop and analyse data to understand the groundwater crisis, a clear implication of this finding is that farming families need to become a partner in acquiring data, understanding the problem, and discussing solutions.

### 2.2.5 Local political context and influences

No literature was found that described the political context and influences related to groundwater management, apart from those mentioned above exploring cultural aspects.

### 2.2.6 Critical evaluation of literature identified

We are fortunate in this case study to build upon a solid base of good quality literature.

#### *2.2.6.1 Research Gaps*

The need to improve farming family engagement in discussing the groundwater crisis in Balochistan, and the well-documented longstanding inefficacy of the management regime there requires the development of new approaches. These new approaches fit well with our project's objectives.

In particular, the literature reviewed above reinforces the need for the ACIAR Groundwater project to enable a shared understanding of the problem (Objective 1), especially between farming families and relevant government and non-government agencies. Given the weakness of the current governance regime, it may be useful to consider adopting a 'social learning' approach, as was pursued in the account by Faysse et al. (2014) in Morocco.

#### *2.2.6.2 Questions Arising*

- To what extent would social learning become an effective approach for building a shared understanding of the groundwater problem in Balochistan, and for identifying solutions?
- What strategies can be developed to create an effective groundwater management regime in Balochistan, and that could be applicable to other contexts where an effective governance regime has failed to eventuate?

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## 2.3 Gender and youth

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Gender is a primary cultural factor determining how social relations are coordinated, and gender inequality persists because of embedded cultural beliefs that “men are high status and effectively more competent at most things than women” (Ridgeway, 2011, p. 27). This inequality has a particularly pertinent effect in agriculture and natural resources management as it limits the impact of innovations, and risks further deteriorating the poverty and wellbeing of poor rural women and their families (Badstue et al., 2015). Prevailing gender inequalities in the benefits and costs of innovations may also result in harmful outcomes. This confines the capacity to design and scale out agricultural innovations that deliver benefits fairly to poor women and men (Badstue et al., 2015).

The United Nations Sustainable Development Goals intend to end poverty in all forms. Most of the population in less developed countries lives in rural areas (c. 75%) and thus depend on agriculture and associated jobs (Anríquez & Stloukal, 2008). This means that innovation and development in agriculture and natural resource management is crucial for rural development. However, due to several factors such as low market values, cropping choice and patterns, poor irrigation techniques, traditional agronomic practices and scarcity of land and water, success on this front has been limited. In addition, gender inequality in agriculture further hampers the potential of the rural economy (Petrics et al., 2015; van der Ploeg, 2013). Even so, women retain a salient role in the total agriculture labour force (i.e. 43% share). Hence, women are in many cases absent from statistics (FAO, 2011) and invisible in agricultural censuses (Mishra et al., 2017; FAO et al., 2010; World Bank, 2012).

Property rights and land tenure are those factors that account for under-performance of family farming systems in developing economies (Ghori, 2016; Ragasa et al., 2013) regardless of efforts to mainstream gender into agricultural extension delivery over the last few decades (Ragasa, 2014). According to FAO (2011), if women had the same access to productive resources as men then developing countries could achieve an average increase of 20-30% agricultural yield and 2.5-4% agricultural output.

### 2.3.1 What can women contribute?

Gender is indeed a primary cultural device for coordinating social relations. In Pakistan, women remain demoted from mainstream economic activities due to several factors including the dominant religious and patriarchal ideology hindering and violating women’s roles in rural development, despite having equal rights under the 1973 constitution of Pakistan (Shah, 2015). There is an exceptionally low level of reported female labour participation (with a rate of 25%) compared with men (82%) in Pakistan (World Bank, 2017). Pakistan ranked 141 out of 142 countries in the Global Gender Gap Index Report of the World Economic Forum (2014). Similarly, Shah (2015) indicated that the situation in the country is steadily deteriorating for women who continue to be sidelined in mainstream economic activities. She further reported that Pakistan is also one of the 10 lowest-performing countries on the global gender gap sub-index of ‘economic participation’ and one of the three countries with the lowest percentage of firms with female participation in ownership.

Female participation in agriculture varies among countries and among regions within each country. It also varies in relation to crop grown, the production cycle, and the age and ethnicity of the women in question. In rural areas, women have extra labour burdens over men including unpaid household duties such as food preparation, livestock stall feeding, fuel and water collection. Women contribute to agriculture and related work through feeding livestock, caring for poultry, harvesting and weeding of crops, etc. (Samee et al., 2015). However, they are not socially recognised as farmers or paid labourers despite working alongside men, and their ownership of houses or agricultural land is also disallowed. Many women are involved in home-based income-generating activities such as embroidery and tailoring (Pishin District Government, 2011). Apart from that both males and females are involved in processing and securing food from agriculture for consumption (Amin et al., 2009); women have a significant role in livestock management (Arshad et al., 2010) and women's participation has an overall positive impact on the income of farm households (Ashfaq et al., 2008).

There is much potential for improving farming family livelihoods across Pakistan, including in Balochistan, by enhancing women's role in agriculture. It is important to improve understanding of gender norms, prevailing rules, allocation procedures and practices to make the most of approaches that seek greater participation of women (van der Molen, 2001). For example, while research into drip irrigation technologies has tended to focus on hardware aspects, recent research suggests that the predominant adoption of these technologies for use on crops grown by women has helped to reduce women's workload and improve domestic nutrition, thus contributing to reduced poverty (Upadhyay et al., 2005). Some Asian studies on poverty and irrigation suggest that poverty will be reduced through productivity gains resulting from improved irrigation practices (van Koppen & Safilios-Rothschild, 2005). In this regard the organisational design of new water users' associations with men and women both having formal rights of membership and leadership is important (van Koppen et al., 2001).

In a study from the Philippines, Mishra et al. (2017) found that female headed farm households have lower irrigation costs than their male counterparts. The study also found that while women are less efficient in their farming, they are more likely to adopt improved rice seed varieties. Another study from Kenya suggests benefits from institutionalising gender-sensitive policies along agricultural value chains (Oduol et al., 2017). A study of the farming family system in eastern Gujrat, India found that the introduction of lift irrigation schemes improved women's economic and social empowerment, leading to improvements in agricultural production, food consumption and incomes, and reducing out migration (Saini and van Koppen, 2001).

In rural Balochistan, local norms do not generally support female access to credit, labour, markets, agriculture extension opportunities, and networks beyond their households. Men are however, allowed to participate. Women and children are prone to food deficiencies due to the persistent drought prevailing in the province. They also experience the highest estimated infant and maternal death rates in South Asia i.e. around 130 out of every 1000 children who are born die in the province (PDMA Balochistan, 2015). In most rural areas, women are generally responsible for collecting water for daily household needs, often carrying it over long distances. When there is scant rainfall, this burden increases because they have to bring water from even more distant places. Hence they experience more physical exertion, mental stress and become more susceptible to diseases. The low quality of water in many areas also causes water-borne diseases such as cholera, diarrhoea and hepatitis, especially affecting women and children (BUITEMS and UNDP, 2015).

Balochistan, with 44% of the geographic area of the country, has diverse agro-ecological zones and a myriad of cultures. Each ethnic group has its unique traditional and cultural characteristics. In rural Balochistan, women are generally responsible for domestic activities and men carry out outdoor farm and/or work on other enterprises to fulfil family needs. However, educated rural women also teach in community schools. Women have lower access to productive resources and are faced with discrimination from formal and informal institutions, particularly with regards to inheritance, property rights and land tenure (CIMMYT & BUITEMS, 2016).

The survey undertaken by CIMMYT and BUITEMS (2016) also found that women are not involved directly with farming in Loralai district of Balochistan (Pashtoon ethnic majority group), but they are considered good if they support their male family members indirectly by preparing food and its delivery to the farm. However, women perform several agriculture-related jobs within the home, such as seed and grain storage, fruit cleaning and storage, livestock keeping and associated activities like milking, milk processing, shelter making, wool handling and preparing dung for fuel. In poor families, teenage boys work alongside men by harvesting vegetables, providing grass for domestic animals, collecting wood and fetching water, and in some case this work is done by women as well. In general, women usually have full control over domestic matters, but do not have any role in agricultural activities outside the home.

By contrast, the survey found that women in Naseerabad district of Balochistan (Baloch ethnic majority group); are faced with various challenges associated with intra-household arrangements and field activities. The norms vary between well-off and poor families in the sense that the women of well-off families are less exposed to physical exertion than women from poor families. Women of landlord families are prosperous and look after household matters such as cleaning, cooking and washing whereas in women tenant/poor families work on the farm as well as looking after home and family. These local norms are more rigid in the case of younger women and men than older men and women. Younger women are not considered good to move freely within the village and outside the village. In the case of older women, such norms are treated with greater flexibility and they are allowed to move within the village for genuine reasons. Younger men are controlled by their elders and work under their command. Their future related decisions (to study or work, to get married, selection of profession/work.) are usually made by the family elders (customarily father).

The Gender Reform Action Plan approved by the Provincial Cabinet in July 2004, is seen by many as a milestone step towards achieving gender equality. The objective of the plan is greater involvement of women in social, political and economic activities. Foreign-funded NGOs and the Federal government's Benazir Income Support Program are also trying to reduce gender inequalities. District Social Welfare departments have established women's groups for training in income-generating activities (BUITEMS & UNDP, 2015). Hamid and Afzal (2013) suggest that international agencies should place greater emphasis on the participation of rural women and youth in community planning for the management of large-scale water projects including of groundwater resources. Women's restricted access to water resource management should be examined.

### 2.3.2 Research gaps

A good understanding of local gender norms is crucial for improved groundwater management for improved livelihoods and rural development. Women's roles in groundwater management should be viewed as equally important as men's roles, yet these roles are challenged by the wider gender gap that exists across a myriad of different cultures and poverty contexts across Balochistan. These differential contexts need to be understood as part of the delivery of the project's objectives.

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## 2.4 Role of NGOs, CBOs, FOs in water management in Balochistan

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### 2.4.1 History of the Development of Non-Government Organisation Sector in Pakistan

The desire to help the poorest and most disadvantaged citizens of the nation has been evident long before the birth of Pakistan. There have been many examples of rulers dating from the Muslim era (8th to 18th century) who during their reign ensured the wellbeing and safety of their subjects, rulers such as Nasiruddin Mehmood, Feroze Shah Tughlaq, Sher Shah, Akbar and Aurangzeb (Iqbal, Khan & Javed, 2004). During the years of the British Empire the British believed the local population was too corrupt or incapable of self-rule. This led to the Utilitarian movement to pursue a policy of remodelling the socio-economic society of India. The result was the registration and institutionalisation of voluntary organisations. These served two purposes for the British: (1) to keep a check on organisations to prevent any action against the crown, and (2) to encourage philanthropist to share the burden with the government in providing social services (Iqbal, Khan & Javed, 2004). Acts of law were passed in 1860 and 1863 and 1882 to regulate voluntary organisations. Besides the British, Christian missionaries were also a source of social services. After the British cemented their dominancy in the subcontinent they were allowed to work freely, their area of concern was the provision of education and health care. Their impact was strongly felt that many at that time changed their religion and outlook; today in Pakistan many of their schools and hospitals are operational under their original names.

After independence the Non-Government Organisation (NGO) sector began to take on full steam, stepping up where the local and federal government had failed. NGOs in Pakistan have been focusing on two main areas: (1) to create awareness on issues such as human rights, women’s development, health care, agriculture development; corruption. through advocacy and lobbying; and (2) the provision of basic services such as health care, primary education, rehabilitation during natural disasters, water sanitation and water management. The NGO sector has grown tremendously from volunteer organisations to large institutions, with heavy reliance on project funding provided by philanthropists, local government and foreign donors. The various governments of Pakistan have supported the development of this sector in all of their five action plans.

NGOs usually stay away from areas that lie in the domain of the government, due to the need for such large infrastructure development areas such as water and sanitation, irrigation, urban development and environmental issues (Asian Development Bank, 1999). What we are seeing now is a changing trend. NGOs through Community Based Organisations (CBOs) and Farmer Organisations (FOs) are creating awareness programs regarding these issues and if partnered with linkages from local government or private sector are able to carry out such related projects like the Aga Khan Rural Support Program (Asian Development Bank, 1999).

### 2.4.2 NGOs Establishing Community Based Organisations

There are several NGOs operating in Pakistan aiming to work at the grassroots level in cooperation with community volunteers and community leaders. For example, HOPE is based in Karachi and pursues objectives of self-sufficiency and sustainability. They organise community volunteers into CBOs and all activities are carried out by the CBOs. This ensures that the community becomes self-sufficient and the results are reaped well into the long term. They encourage women’s participation and support from all, and focus on basic health, sanitation and hygienic related issues through literacy programs, awareness sessions and income generating activities (HOPE, 2008).

Projects such as the above support the need for the inclusion of local community at the strategic and operational level to achieve success in a project. The need of the local community was documented in a paper by Nawaz (2000), referring to water management of karezes being handled by local communities. The water was used for drinking, sanitation, industries, irrigation and the environment and so the government invested in infrastructure to relieve increasing demands on available water. It was found in the highlands of Balochistan that the local communities would manage water rights, access and its collection in a way that benefitted all. Nawaz concluded that increased communication and information knowledge among various government departments as well as resource mobilisation could help in the management of water in Balochistan.

The United Nations Development Program works with the government of Pakistan and 176 other countries to achieve its development objectives on a large range of issues relating to democratic governance, crisis prevention and recovery, environment and climate change and development policy. In regards to water management, UNDP has initiated a project in Pishin for the construction of a flood wall. Since 2011, Balochistan has been facing flash floods that has affected around 700,000 people and has damaged hundreds of thousands of acres of crops and agriculture land. Dilsora, a village in Pishin, suffered from flash floods in 2013, and two leaders established a community organisation Bala SoorKash to save the livelihoods of villagers, seeking financial help from the Refugee Affected and Hosting Areas project (RAHA) (another UNDP initiative) to construct a flood wall. With assistance from this project and UNDP the adverse situation these villages have faced has improved (United Nations Development Program, 2017).

The Balochistan Agriculture Project (BAP) began in 2005, and was designed and implemented by the Food and Agriculture Organisation of the United Nations with the assistance of USAID. The aim of the project was to increase the income of 17,000 households by 20% in around 800 districts of Killa Saifullah, Loralai, Mustang, Quetta, Zhob, Musakhel, Pishin, and Sherani. There main activities were to deliver training on improving crop and livestock production techniques, to provide newer seed varieties and technologies, management techniques in the area of value addition and marketing, provision of district markets to sell their produce and regarding water management improved irrigation systems through rehabilitation of karez systems, land levelling, and pipe irrigation. The project ended in 2015 with impressive results due to the introduction and training of community based organisations such as farmers' marketing collectives, and mutual marketing organisations set up farmers' marketing collectives, and mutual marketing organisations (USAID, 2016).

The Quetta water project aims to enhance the health of the target population of Quetta, Pishin and Qilla Saifullah by working with local communities to improve water service delivery and sanitation. The project is carried out by the Balochistan Rural Support Program (BRSP) and funded by the Federal Republic of Germany through the KFW Development Bank. At the end of the project 54 rehabilitated water schemes in 12 floods affected districts of Balochistan had been completed. More importantly, the project resulted in the formation of 11 water management committees to deal with the management and sustainable use of the scare water resources, including one in Pishin (Balochistan Rural Support Program, 2017b).

BRSP also completed the “Social cohesion and stabilisation through sustainable water management in the refugee hosting area of district Killa Abdullah” project in October 2015 funded by the Federal Republic of Germany. The objective was “to improve livelihoods, rehabilitate environment and enhance social cohesion within communities of refugee hosting areas” (Balochistan Rural Support Program, 2017a). The project was achieved with the formation of 217 community organisations, who were provided with capacity building training and technical support to identify potential water points. Key deliverables of the project were: 5 rehabilitated karezes where the local population gained access to clean drinking water, 31 check dams constructed with local stones, ensuring the recharging of karez water and stability of the watertable, 60% increase in land cultivation and 4% increase in households engaging in agriculture and the provision of additional olive, grape and forest trees by the forest and agriculture departments respectively (Balochistan Rural Support Program, 2017a).

NGOs throughout Balochistan are able to provide services that the local government is unable to provide by working at the grassroots level and engaging local communities. This has resulted in an enhancement in the quality life of the community for generations to come. NGOs on their own are able to deliver technical, educational and consulting support. For the objectives to be truly successful and have a long term impact in a community, the formation of community organisations is essential to deliver the awareness and support the community needs to thrive and sustain it.

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## 2.5 Economic context

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Balochistan is the least developed province of Pakistan with an annual growth rate of 2.5% during the period 1999-2000 to 2014-2015 as compared with 4.4% for the same period at the national level. Similarly, Balochistan's share of the national economy fell from 3.8% in 1999-2000 to 2.9% in 2014-2015, and the per capita income of the province was estimated as almost half the national average (Pasha, 2015). Reasons include hostile terrain, erratic climatic conditions, scarcity of water resources (Bhatti et al., 2008), persistent drought, scanty rainfall, and absence of effective governance and coherent management (Ahmad, 2007a; BUITEMS & UNDP, 2015; BID, 2016). Likewise, the 2015 multidimensional poverty index (MPI) was 0.394, poverty incidence 71.2% and intensity of poverty 55.3% as compared to 0.197, 38.8% and 50.9%, respectively at the national level. The province experienced the slowest reduction in poverty (12.2%) while the national figures showed a relatively greater reduction in poverty (16.4%) for the period 2005 to 2015 (Planning Commission of Pakistan, 2015).

### 2.5.1 Sources of livelihood

Economically, Balochistan has comparative advantage due to its vast rangelands, large numbers of livestock, rich mineral and gas deposits, and good quality deciduous fruits (Baloch and Tanik, 2008). In the mining sector, coal, chromite and marble contribute an important role, even though the sector is not being developed to its full potential. Agriculture is the mainstay of the livelihood of about 60% of the population of Balochistan, accounting for an almost 29% share of the provincial GDP. The sector employed some 52% of the provincial labour force during 2015 (Pasha, 2015). Horticultural crops, fisheries and small ruminants are the main source of livelihoods in rural agricultural areas of the province, with horticultural crops also providing an important contribution to the agriculture sector. Key horticultural crops such as apple, apricot, grapes, tomato and vegetables accounted for around 45% of agriculture value added in the province and around 12% at the country level (Balochistan Bureau of Statistics, 2015).

### 2.5.2 Access to social amenities

Balochistan's rural population faces many problems due to remoteness, inadequate infrastructure, and overuse of natural resources (Khan et al., 1996). Pumped groundwater is the main source of drinking water and households are being served by tube-wells/piped schemes. According to information provided by the local government, only 57% of the population in Pishin district had access to improved sources of drinking water, of which some 52% had access to water within one km distance, while only 2% disposed wastewater safely and adequate sanitation is available to only 23% of the population (IUCN, 2011). Another problem is lack of access to health facilities by a significant proportion of the population. In many areas, there are almost no health facilities provided by the government and treatment is provided by local private traditional practitioners who are generally not well trained. Educational facilities are almost negligible and the literacy rate is very low – almost zero among women in some areas. Over half of farmers are illiterate, with 20% having primary education only and a mere 1.3% are above intermediate level of education (Mengal et al., 2012).

### 2.5.3 Problems

Groundwater is considered a common pool resource because of its public good nature (Khair et al., 2015a). Lack of planning and management of resource use is a major cause of environmental degradation, and water resources are heavily overdrawn. The destruction of natural vegetation cover (Baloch and Tanik, 2008) and groundwater over exploitation and mismanagement (Khair and Culas, 2013) has depleted the water resources of the province, and led to the near eradication of the historical karez irrigation system (Memon et al., 2017; Khair et al., 2015a). Erosion of the traditional karez system has also led to erosion of social capital (Mustafa & Qazi, 2007).

Groundwater levels are declining sharply at the rate of 2 to 3 metres per annum in the important basins of Balochistan due to mass installations of tube-wells, subsidised electricity, groundwater development policy and scanty rainfall (Khair et al., 2010). To combat the situation, farmers have adopted certain coping strategies. For example, one study found farmers in one area had converted from flood irrigation to controlled basin irrigation method (100%), dug more tube-wells (89%), increased irrigation intervals (Jillani & Khair, 2014), while other studies have shown a reduction in crop areas by more than 50% (BUITEMS & UNDP, 2015; Kakar et al., 2014). In worse conditions, water shortage causes drying of the orchards, decline of farmers' incomes (both agriculture and livestock), and increased unemployment (Kakar et al., 2014).

The agriculture sector is underlying the slow economic performance due to several factors including scarcity of irrigation water, inadequate production technologies, poor agronomic practices, problems with quality, quantity and timeliness of input supply, and low producer's share for output in the market (Khair et al., 2006; Rasheed et al., 2005). Khair et al. (2012) reported that the shortage of irrigation water was the most serious and common problem, while other problems included low market prices for output, insect and disease pests, capital shortages, fluctuation and low voltage of electricity, expensive transport and lack of technical knowledge about crop production. Applications of crop inputs are either below the recommended rate or in excess by most farmers. For example, the application of DAP, urea, and NPK fertilisers are used at rates contrary to recommendations of the agriculture department (Achakzai, 2013). Flood irrigation methods are being adopted by farmers for fruit orchards such as apples, apricots and plums, and there is lack of use of high efficiency irrigation techniques in the over-extracted and relatively over-populated Pishin Lora Basin.

### 2.5.4 Losses due to droughts

The reduction in irrigated crop production during the drought period (1998-2002) was estimated at around 33% (Ahmad, 2007a) and ranged between 20-40% during the 2013-2015 drought (BUITEMS & UNDP, 2015). In particular, subsistent growers in Khushkaba/Sailaba districts lost 69% of their income, while livestock losses were estimated at 37%. Drought also caused production losses in agriculture, leading to income losses for farmers, especially landless labourers and small marginal farmers (BUITEMS & UNDP, 2015). Kakar et al. (2014) indicated that there was excess demand for both surface and ground water for irrigating crops. Thus, water shortages led to declining cultivated land and drying of orchards, thus lowering farmers' incomes and increasing unemployment. The study recommended introducing high efficiency irrigation system and construction of dams. Another study recommended that sustainable development of water resources required strategic planning (Ahmad, 2007b). Policy needs to shift from groundwater development to long-term groundwater management (Mushtaq et al., 2013).

### 2.5.5 Existing agriculture practices, cropping systems/patterns; crop yields, crop margins

In the Pishin Lora Basin area wheat, *jawar* (sorghum), and barley are the major cereal crops, with fruits and vegetables the major cash crops. Most of the population raise sheep, which occupies most of the land (Khan et al., 1996). Yield of major cereal crops are far below the national average due to limited adoption of progressive farming techniques. Wheat productivity analysis indicates that essential inputs like a reliable irrigation through tube-well, fertiliser and farm yard manure application have a significant economic impact on productivity of wheat crop in the Pishin Lora Basin (Khair et al., 2015b). The study further revealed that a reliable access to irrigation water through tube-wells increases crop productivity as those farmers having their own tube-wells had greater yields than those who bought water and those who did dry land farming. Al-Said (2011) analysed water productivity and vegetable crop and identify suitable combinations of vegetable crops grown under drip irrigation that can maximise the profitability by using optimum water. Results showed that tomato had the highest crop water productivity (11.9 kg $m^{-3}$), followed by cabbage (7.8 kg $m^{-3}$), sweet melon (5.7 kg $m^{-3}$) and sweet pepper (2.2 kg $m^{-3}$). Cabbage and tomatoes also had the highest income/gross value of production per ha and thus the highest return on investment in irrigation water. The results also showed that most vegetable crops grown using drip irrigation had high yields.

Khair et al. (2006) revealed that the highest yield among all apple varieties was golden delicious (*Shin Kulo)* (9422 kg per acre), followed by *Kaja* (8602 kg) and *Amri* (8538 kg). Moreover, the benefit-cost ratio and internal rate of return of apple was estimated at 1.32 and 28% (Rasheed at al., 2005). While, benefit-cost ratio and internal rate of return were 4.82 and 38% for grapes (Khair et al., 2008). However, annual income of bearing apple trees in Killa Saifullah district was estimated by Jogezai (1997), who reported that an apple grower after meeting all expenses on production and marketing, earned net cash return of PKR 213,029.54 per hectare on an average and PKR 149,565 per hectare in Pishin district (Panezai et al., 2006).

The share of the price received by apple producers compared with the price paid by consumers for major apple varieties *Tor Kulu* (Red Delicious), *Shin Kulu* (Golden Delicious), *Amri, Mashadi, Kashmiri* and *Kaja* were 24, 24, 19, 20, 19 and 31%, respectively (Shah et al., 2011; Khair et al., 2008).

### 2.5.6 Role of agriculture service providers

Agriculture service providers play an important role in providing farmers with crop inputs such as seed, fertilisers, pesticides, extending credit facilities, and are therefore well placed to enable change in attitudes of farmers towards adoption of new technologies and improved agriculture practices. In the past, procurement and supply of fertiliser was the responsibility of public sector agents who fulfilled their role well and were active in motivation and providing guidance to farmers. However, the rapid growth of the agriculture sector has not been matched with increased government support for agriculture extension services, such that the primary role of the public sector has been superseded by an increased shift of service provision by private sector agents. No visible organised formal extension setup exists in the private sector, so informal change agents such as shopkeepers (non-technical seed, pesticide and fertiliser dealers), fellow farmers, elders, and progressive farmers play a more important role in terms of giving necessary farm related advice. The majority of farmers and their representative organisations have very limited knowledge about the use of improved varieties and application of recommended doses of ecofriendly fertiliser and pesticide application (Achakzai, 2012).

Mengal et al. (2012) reported that private extension agents are disseminating more and better information regarding important crop agronomic practices as compared with public extension field staff. According to the results, more than 24% of the farmers reported that public sector extension staff did not visit their farm; while some 20% reported that they were visited by extension staff once or twice in a year. The farmers also indicated that the extension workers were impotent to explain the nature and benefits of new technology. But in many cases, their limited knowledge and non-convincing and ineffective methods meant they were unable to remove doubts of farmers associated with the risk attached with adopting new technology. All this points to the benefit of training to increase the expertise of extension staff.

### 2.5.7 Research gaps

Ahmad (2007a) recommended that the depleted groundwater resources need to be replenished through groundwater recharge activities in the already over-drawn basins. There are also serious concerns about data acquisition and its reliability on groundwater use, irrigated crop area and average discharge of tube-wells as well as the spatial coverage of hydro-metrological data network (Ahmad, 2007a; Baloch and Tanik, 2008). Traditional and inefficient irrigation methods are being used, and other crop inputs are not being used as per recommendations. These recommendations are in line with our first two research objectives.

### 2.5.8 Research questions

What feasible options are there for farmers to adopt modern crop inputs and high efficiency irrigation systems to increase their incomes for improved livelihoods?

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## 2.6 Energy issues, subsidies, solar power generation

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### 2.6.1 Nexus between energy and irrigation

There is a close nexus between energy and irrigation as energy is needed to use water for irrigation to produce food. The competition over soil and water for the production of food versus energy will increase in the future as about 60 percent more food will be needed to be produced by 2050 and the demand for energy is projected to grow by approximately one third between 2013 and 2040 (OECD/IEA, 2015, cited by Ardakanian et al., 2016). To meet the great challenge of food production for the coming decades with fewer resources such as water, soil, energy, and other ecological services, the effective and sustainable use of these resources is extremely important (Ardakanian et al., 2016). To achieve sustainability, there is need to think of a complete water chain approach i.e., a water food-energy and ecology nexus, a broader framework to ensure all the stakeholders involvement from start to end with the aim to produce more crop per drop per kilowatt of energy. Moreover, to meet future challenges, unconventional thinking and solutions are required that include more efficient water use, use of non-conventional water resources, and water harvesting to increase water supply (Ardakanian et al., 2016).

### 2.6.2 Subsidy to Agricultural tube-wells

The subsidy to agricultural tube-wells has been provided for the last few decades in some areas of India and Pakistan aimed to boost agricultural production. But these are causing over exploitation of groundwater. Shah (2014) reported that energy subsidies have caused substantial decline in groundwater levels, worsening groundwater quality, rising pumping costs, increasing the carbon footprint of agriculture, and mounting financial burden of energy subsidies. Groundwater over-exploitation can occur when farmers independently act in their own self-interest with little inducement to practise conservation that would primarily benefit other farmers. This leads to excessive extraction for irrigation purposes (Strand, 2010; Badiani et al., 2012). However, if all users follow this self-interest logic, the result will be steeply rising marginal costs for the group as a whole as supplies become more difficult to obtain, which in turn causes exacerbated water shortages. The situation is further aggravated when farmers pay less than the full cost of electricity used for groundwater pumping due to subsidies for agricultural tube-wells in South Asian countries. Various studies have been conducted to suggest measures to minimise groundwater over exploitation by tube-wells operated with subsidised electricity.

### 2.6.3 Measures to minimise groundwater exploitation

Shah et al. (2008) suggested metering electricity use and charging farmers at near commercial rates based on power consumption is an ideal solution to South Asia's tenacious electricity–groundwater nexus. However, it may have political repercussions. The efforts to rationalise the electricity subsidy to regulate groundwater over-extraction have been unsuccessful and subsidy on electricity to agricultural tube-wells 1970-2008 not only caused the overexploitation of groundwater aquifers but also made the electricity supply companies bankrupt and affected the non-farm economy badly in Gujrat India (Shah et al., 2008).

In response, electrical feeders in Gujrat supplying electricity to agricultural users was separated from those supplying electricity to non-agricultural users by providing non-agricultural users with 24-hour power supply but restricting agricultural users (tube-wells owners) to eight hours per day at full voltage on a pre-announced schedule. That scheme worked very well and improved the electricity supply to both agricultural and non-agricultural users as well as reduced the over-extraction of groundwater by some 30-50%. Many changes occurred: tube-well owners had to manage with the daily power ration they are provided and the flat-rate power pricing regime was changed into a rational one.

An effective power tariff policy along with volumetric water allocation for efficiency, sustainability and equity in groundwater use in India was emphasised by Kumar (2005). He presented a theoretical model for analysing farmers' responses to changes in electricity tariff and water allocation regimes vis-a-vis energy and groundwater use. Water productivity in groundwater irrigation was analysed under different electricity pricing structures and water allocation regimes. The results showed that the unit pricing of electricity improves the productivity and efficiency of groundwater use. It also shows that the demand for groundwater and electricity becomes elastic to electricity tariff at socioeconomically viable price levels. The highest water productivity impacts of pricing are achieved when water is volumetrically allocated with rationing.

Strand (2010) suggested that the current trend of ever-increasing water demands can be changed through policies to increase water use efficiency without affecting equity concerns. One important way to induce water use efficiency is through appropriate water pricing measures. Prices can be used to measure economic scarcity, environmental externalities and reflect physical limits. Strand (2010) showed that an optimal pricing of electricity used for pumping groundwater includes: 1) the full (marginal) economic cost of electricity; and 2) there must be an extra charge for the externality cost of groundwater pumping.

Zekri (2009) proposed a framework for confining the use of groundwater by farmers through electricity quotas by the installation of prepaid electricity meters set with a credit limit. He argued that since controlling groundwater pumping through water flow meters has not been feasible, the alternate is to control electricity usage. A framework is presented which shows that groundwater pumping can be restricted by implementing an annual individual electricity quota monitored online through prepaid electricity meters. The advantages of this system are that the transaction costs of individual monitoring of users are lower as compared to the costs of water flow metering and monitoring. A cost benefit analysis over a 25-year period show that the damage cost to the community, if no active policy is implemented, amounts to USD 288 million. Moreover, farmers will be better-off in the medium and long term due to rising incomes from use of improved water quality. The implementation cost of a prepaid electricity quota with an online management system would result in a net present benefit of USD 199 million. It will also result in indirect benefits by reducing psychological costs to farmers and political costs from farmers' complaints and dissatisfaction.

### 2.6.4 Situation in Balochistan

In Balochistan the subsidised flat rate from 1990s to date on electric tariff was meant to increase prosperity through the groundwater use for agriculture purpose. The farmers pay just 9% of the actual bill, and the rest is paid by the government in the form of a subsidy. This policy achieved its aim but increased use of scarce water resources. There are other negative effects. Farmers are charged uniformly irrespective of the size of the prime mover (i.e. the horse power of the electric motor used) and the duration of pumping and electricity consumed. So there is no incentive for farmers to use energy and water efficiently (Ahmad, 2005). The strategy of groundwater development and energy subsidy for agricultural tube-wells has resulted in a massive drawdown of the watertable, depleting the groundwater at a rate faster than its replenishment, contributing to increasing over-extraction and growing water scarcity conditions (Khair et al., 2015). There are also equity concerns in the distribution of the subsidy. The electricity subsidy is attained by some 16,000 farmers who are running electric tube-wells. The diesel tube-well farmers who run their tube-wells without any subsidy are running their tube-wells without any subsidy. The cost of diesel operated tube-wells is 54% higher from that of the subsidised electric-operated tube-wells (Ahmad, 2005). The poor quality and reliability issues associated with electricity distribution are raised by farmers as they complain about prolonged periods of load shedding, voltage fluctuations and power breaks, which resulted in loss of their prime movers and excessive overhead and maintenance costs (Ahmad, 2005).

Given the importance of agriculture as a major source of livelihood, the removal of electricity subsidies is a politically difficult decision. However, through a wise policy, an improvement in efficiency of water and energy use can be obtained through introducing metering of both the water and energy users in the long run due to difficulties in its enforcement amid large number of scattered tube-wells. However, in the short run, as a policy, the Balochistan government may introduce a "Rational Flat-tariff" system. For the purpose, the energy may be supplied according to the farmers' demand based on crop water requirements in the different months of the year. The reliability and quality gaps may be filled by the adjustment of the power supply duration per year (Ahmad, 2005). The introduction of high efficiency irrigation techniques/methods such as drip irrigation that will reduce the overall water need at farm and the energy requirement which could eventually reduce the energy bill to one third of the current level (Ahmad, 2005). Moreover, all the public-sector institutions should install high efficiency irrigation systems using drip and sprinklers, which may serve as demonstrations for the civil society. Similar initiative can be taken up by the cantonment authority (Ahmad, 2005)

### 2.6.5 Renewable (solar) energy and groundwater nexus

The renewable energy was found to have significant negative effect on $CO_2$ emission implying that government should focus on the renewable source of energy production in future. Malaysia is naturally gifted with renewable sources of energy like solar and hydro; therefore, a shift towards these less polluted renewable technologies is very much viable and would contribute towards the goals of sustainable development (Gill et al., 2018).

The use of solar energy operated tube-wells is on rise in many areas of Balochistan both privately and at the government level. The government is also subsidising the installation of new, and replacement of old, tube-wells into solar to meet the rising electricity shortage problems without taking into consideration the possible pressure on already stressed aquifers. Moreover, the introduction of solar tube-wells is rolling back the efforts for water management through energy rationing that is being practised by the energy company consciously or unconsciously on electric tube-wells. It is also considered that water pumping will further accelerate with the introduction of a more reliable solar energy run tube-wells. Many researchers believe that this intervention could further accelerate groundwater extraction and that it should have been made carefully after examining the carrying capacity of groundwater aquifers. This policy seems prone to political incentives similar to the case of electricity subsidy (Khair, 2016).

Despite the current severe depletion of groundwater, governments have been maintaining restraint with regard to its groundwater related policies of tube-wells subsidy and groundwater development. The Balochistan government is constrained from reducing or removing the subsidy due to a lack of political will, poor institutional and administrative capacity and political incentives faced by decision makers. Instead, more tube-wells have been included in the subsidy net during 2015. Similarly, the subsidy on solar power tube-wells and their installation is widely appreciated both at the government and private levels. In many areas with comparatively shallow watertable, the replacement of electric tube-wells by solar tube-wells is also going on, which has further accelerated the groundwater pumping (Khair, 2016).

### 2.6.6 Research gaps

The literature review suggests that many studies have been conducted to address the issue of electric subsidy and groundwater exploitation. But no work has been done so far to examine the socioeconomic and groundwater extraction impact of solarisation of existing electric tube-wells.

### 2.6.7 Research questions

What feasible options are there for farmers to adopt solar groundwater pumping to enhance their livelihoods and avoid increasing over-extraction?

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# 3 Punjab

## 3.1 Irrigation management

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Punjab province, being the largest agricultural producer in Pakistan, is also the largest user of freshwater resources among the country's other provinces. The province is entitled to a total of 56 MAF, or 69 billion cubic metres (BCM), of surface water flows as per the Water Apportionment Accord of 1991 (IRSA 1991). It is reported that 26 BCM (37.5%) is lost during conveyance before reaching farmers' fields. Similarly, irrigation efficiency at the field level is also reported to be very poor across the province (Watto and Mugera, 2015). About 17 BCM (25%) of surface water is lost due to poor management practices for irrigation. Putting together the conveyance and distribution losses of 43 BCM (62.5%), only 26 BCM (37.5%) of surface water is available to meet crop water requirements compared whereas the amount of surface water required to meet overall irrigation water requirements is estimated to be 52 BCM. Surface water supplies are regulated and managed by the Punjab Irrigation Department (PID). However, groundwater remains unregulated and has become a major source of irrigation given increased water demands from increasing cropping intensity and inadequate and variable surface water supplies (Watto and Mugera 2016).

The Lower Bari Doab Canal (LBDC) Command System is situated in the Bari Doab between the rivers Ravi and Sutlej in the Punjab's south-east. The Lower Bari Doab Canal originates from left river Ravi at Balloki Headworks. The design discharge capacity of LBDC is 278.70 $m^3$/sec and it stretches across some 200 km along the length of command area of about 0.676 million hectares. The LBDC has 65 distributaries and 14 direct outlets. Although most of the canal command area receives perennial irrigation water supplies, groundwater is also being used. The average annual rainfall varies between 366 mm to 249 mm which contributes about 1.3 BCM water each year. Besides low rainfall, canal water supplies in the LBDC are not adequate enough to meet irrigation water requirements sufficiently. The current canal water allocation meets about 44% of total crop water requirements, meaning that 34% of requirements is provided through groundwater pumping, and the 22% deficit remaining results in the practice of "stressed irrigation" being imposed. Due to spatio-temporal unavailability and shortage of surface water, irrigated agriculture is highly under stress particularly during critical periods of cropping seasons (Hussain, 2011).

### 3.1.1 Irrigation system: demand and supply analysis

The above-referred gap between allocated canal water supplies (supply) and crop water requirements (demand) has been estimated for the Lower Bari Doab Canal command area by Shakir et al. (2011). They estimated that average annual canal water supplies were 36% less than crop water requirements. However, this gap even widens and reaches above 50% if actual canal water supplies for the last ten years are compared with crop water requirements. They made comparisons of the gap between actual canal water supplies and the allocated canal water supplies based on the water allocations under the Water Apportionment Accord (WAA) of 1991. The Accord approved an annual water allocation of 5.9 billion cubic metres (BCM) with 3.2 BCM for the *kharif* season and 2.7 BCM for the *rabi* season. However, this allocation to the LBDC system varies from year to year depending upon the total water availability in the Indus River System. The data from last 10 years indicate that there has been an average shortage of 20% in the canal water supplies to LBDC as allocated by WAA in 1991.

Basharat (2012) estimated that on average 4,849 MCM water deliveries were released to LBDC command while the average annual crop water requirement was calculated at 6,953 MCM between the year 2001-09. Of the total these canal releases about 48% was available for crop consumptive use whereas about 44% recharged groundwater resources through and watercourse seepage and the remaining was lost during filed applications. Thus, the net canal water availability is about 2,364 MCM which is about 33.8% of the consumptive crop water requirements. They reported that in order to meet consumptive crop use requirement of 6,953 about 3,954 MCM is pumped through groundwater. Approximately 2689 MCM (68%) of the total pumped groundwater is used as consumptive crop water requirement. About 1,406 MCM comes from effective rainfall (the average annual rainfall is about 472 mm at head end and 212 mm at tail end of the command). Putting together the total water supplies from all the three sources, there is a net shortage of 495 MCM of irrigation water under the business-as-usual scenario – i.e., if farmers follow their traditional irrigation practices, such as flood irrigation, and existing cropping patterns.

The groundwater resources are being reported to be rapidly depleted in the Bari Doab. Basharat et al. (2014a) found that the groundwater resources are being depleted at annual rate of rate of up to 0.55 metres in the lower part of Bari Doab while in contrast the groundwater level is stable in the upper parts. They suggested that the crop water requirements and water availability situation should be revisited. Shakir et al. (2011) reported that the groundwater levels in most parts of the LBDC are depleting at an annual rate of 30 to 40 cm and this trend may increase future due to increasing crop water requirements. The most intriguing aspect of excessive groundwater use in the lower parts of Bari Doab is its spatio-temporal variability, especially as determined by the inability of available canal supplies across parts of the landscape to meet local crop water requirements.

Basharat et al. (2014b) noted that most of the groundwater depleted areas in the Punjab province are within the lower and central parts of the Bari Doab with approximately 65.4% area of the Bari Doab highly depleted. In particular, the groundwater level is even much lower in central part of the Doab, i.e. along the course of old Sukh-Beas River as compared to other parts of the Doab. The groundwater level estimates of between 2002 and 2012 indicate that approximately 23.3 BCM groundwater has been depleted from Bari Doab aquifer, which is equivalent to an annual groundwater depletion of 2.33 BCM. It is projected that by 2031 there would be an additional depletion of 8–11 m in the lower half of the LBCD command (Basharat and Tariq, 2015).

One of the most negative externalities associated with groundwater depletion is, perhaps, the groundwater quality deterioration in the Bari Doab (Basharat et al., 2014b). In terms of quality, groundwater is saline in many parts of the Bari Doab. In the upper part of Bari Doab between Raiwind and Okara/Sahiwal there are vast pockets where groundwater quality in terms of total dissolved solids (TDS) ranges between 1,000 to 10,000 ppm. The groundwater quality is also found to vary with depth. In central lower Doab, groundwater is also very saline ranges from 5,000 to 10,000 ppm. In many parts of the Bari Doab, salinity level increases as the depth between the upper (fresh water layer) and lower layer decreases because fresh water in the area is attributed to recharge from rivers, canals and water watercourses seepage (Basharat et al., 2014b).

In most of the Bari Doab, groundwater extractions have exceeded the groundwater development potential. Particularly, groundwater resources in the lower and central parts of the Bari Doab are being mined rapidly. In fact, in the lower and central parts groundwater depth has gone beyond 20 metres. It is being projected that if the current rate of groundwater depletion continues, it could have serious threat to the ecology and sustainability of irrigated agriculture which is vital for the country's food security (Basharat et al., 2014b).

The rapid depletion of groundwater resources in the lower part of the Bari Doab is creating many negative environmental externalities and many socio-economic problems for the farming community, especially the high installation and pumping costs. According to an estimate a decade ago, the cost of installing a tube-well had gone up to one million rupees (Latif, 2007). Basharat (2012) calculated that the unit cost of groundwater increases by 3.5 times as groundwater depth drops from 6 metres to 21 metres in the LBDC command area. Similarly, the cost of installing a tube-well increases seven times when groundwater depth decreases from 6 metres to 24 metres (Qureshi and Akhtar, 2003). Due to higher rate of groundwater depletion farmers at the tail-end of canals incur 2.19 times higher irrigation costs as compared to the farms near canal head-ends. It is expected that if the current rate of groundwater depletion continues, the irrigation cost anomaly would be further aggravate by increasing 2.36 times by 2031(Basharat and Tariq, 2015).

### 3.1.2 Irrigated agriculture practices

Based on a field survey Ashraf et al. (2010) reported that lack of knowledge about the actual crop water requirements and time of irrigation is one of the major reasons of low water productivity in the region and overall in the country. Studies from other parts of the Indus River Basin indicate that farmers generally over-irrigate their crop fields, which results in low crop water productivity (Kahlown and Kemper, 2004; Kahlown et al., 2007; Watto and Mugera, 2016).

Ashraf et al. (2010) reported the cost of groundwater pumping and canal water supplies in the Lower Bari Doab Canal Command area. The canal water was being supplied at a flat rate of US$5.56 or Rs. 333/ha/year. However, the cost incurred on pumping groundwater was about US$2.27/hr or Rs. 136/hr for a diesel operated engine and about US$5.83/hr or Rs. 349/hr for a tractor operated tube-well, respectively. The cost of irrigating one hectare with a diesel engine tube-well becomes US$16/ha or Rs. 960/ha, and that for a tractor operated tube-well the cost goes up to US$40/ha or Rs. 2400/ha. It indicates a huge difference in irrigation cost by canal and tube-well water.

There is lot of variation in irrigation water application practices at different farms between different water courses and different distributaries. Farmers usually follow traditional irrigation practices and there is no systematic record and information available in irrigation water applications at head, middle and tail-ends. It simply depends on the individual farmer and the water available to them at the farm. Ashraf et al. (2010) computed excessive irrigation water application to different crops across different watercourses and distributaries in the LBDC area. They reported that the average irrigation water application along Jandarak and 15-L distributaries to maize crop was 70 and 52% higher than the actual water requirements. The average irrigation water application to cotton crop was 4%, and to rice crop 76%, higher than the potential crop water requirement.

Basharat (2012) estimated that annual groundwater pumping for agriculture in the Lower Bari Doab has gone up to 3.954 BCM with an annual growth rate of 4.6% in groundwater pumping which is even higher than the average population growth in the country.

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## 3.2 Sociopolitical context

Authors: Muhammad Zeeshan & Saira Akhtar (UAF)

### 3.2.1 Abstract:

Insufficient canal water and agriculture intensification are forcing Pakistani farmers to increasingly access groundwater reserves. Unchecked tube-well growth is resulting in waterlogging, salinity and groundwater depletion, and a decline in quality and quantity of groundwater. Studies indicate that Pakistan will be a water-scarce country by 2025 (Briscoe et al., 2005; Watto & Mugera, 2016). A major drawback has been the lack of adequate policies related to groundwater extraction, resulting in uncontrolled extractions and improper water market. Punjab Irrigation Department's emphasis on engineering led the Asian Bank to suggest a new approach was needed. A farmer-oriented institute, Punjab Irrigation and Drainage Authority (PIDA) was set up in 1997 at the provincial level, working under PID and with Area Water Boards and Farmer Organisations. These developments have not resolved surface water paucity, overuse of groundwater, and worsening groundwater conditions. This chapter reviews the efforts and is organised as follows: institutional policies for groundwater management and the role of communities in groundwater management. A separate chapter reviews the role of NGOs.

### 3.2.2 Institutional policies for groundwater management

Use of groundwater for agriculture has its roots in the 1950s and 60s with the green revolution, of which Pakistan was an early adopter. To cultivate waterlogged lands, it was suggested that tube-wells be installed. The government established some high capacity tube-wells, that helped lower the watertable in the waterlogged land, and provided water for crops supplementary to canal water. These tube-wells were public, and farmers had desirable control over the water resource, which was not possible in the canal system where the rigid '*warabandi*' system was prevailing (Anwar & ul Haq, 2013). For tail farmers (that is, farmers at the tail end of distributaries), the supply was often not enough especially for small farmers. The public tube-wells showed the way for the private sector to follow and private tube-wells started growing in number, though of lower capacity than the public ones (up to 2 cusecs [56 litres] as compared to 3 cusecs [84 litres] for public tube-wells) (Chaudhry, 1990; Johnson, 1989). In addition, the public sector encouraged tube-well instalments, with the result that the number rapidly increased and intensive discharge started in late 1980s. The whole activity impacted on groundwater quality, increasing salinity. While watertable levels in waterlogged areas reduced in some areas, misuse/irresponsible use of ground water created new waterlogged areas.

In the irrigated areas of Pakistan, ground water is mostly recharged by canal water, and a little by the precipitation. In many areas where groundwater quality is good, the canal water supplies are not adequate to meet total irrigation requirements. Because of this, the government allowed tube-well adoption to increase and did not impose any policies to check and control how much groundwater could be pumped to ensure groundwater use would be sustainable. Much of Pakistan's groundwater is being pumped in Punjab, as it has most of the tube-wells (Meinzen-Dick, 1996) where the cropping is more intense than other parts of the country.

The federal government has also provided subsidies for electric tube-wells, with Time of Day meters being installed free of cost, and with electricity charged very low during off peak hours. Currently, solar tube-wells by Punjab Government are being promoted, with the government paying 80% of the total cost for farmers who have less than 12.5 acres of land. Bio-gas supplemented tube-wells have also been promoted since 2012 in Punjab (Doggar & Alvi, 2015).

Some government and government funded institutes are conducting research, evaluating the situation and forging awareness among communities, including:

- Pakistan Agricultural Research Council
- Pakistan Council for Research in Water Resources
- Water and Power Development Authority (WAPDA) and its International Waterlogging and Salinity Research Institute

Agricultural universities and other institutes are also conducting groundwater-related research, including the Agency for Barani Area Development Punjab, Agricultural Research Institutes in Arid and Semi-Arid Territories, Cholistan Development Authority at Bahawalpur, Cholistan Institute of Desert Studies. Yet little adoption of their suggestions in policies and law have eventuated.

It is clear that there is no check and control policy for groundwater use in Pakistan to stipulate who will own a well, how and where water will be used, how long it will be used for, how much will be extracted, how deep a tube-well can be sunk, and which crops should not receive water from tube-wells. Though there is a campaign for drip irrigation adoption to reduce water consumption, it is currently too expensive to be adopted by the majority of farmers despite some relief or subsidies from government. This has resulted in the current scenario, with Pakistan now the fourth largest groundwater extracting country. The threat of future water scarcity will be realised if proper policies are not put in place and effectively implemented.

A brief overview of government initiatives is provided below.

### *Punjab Irrigation Department*

The Punjab Irrigation Department (PID) was established in 1849 to enable diversion of river water to farms for irrigation. After 1947, the department remained working in Pakistani Punjab for canal water management. The agency mostly employs engineers. With increasing water demands the focus has been on the design of water channels. However, the lack of social science expertise has made it difficult to address the needs of the farming communities as they had limited linkages into the community and have insufficient understanding of the social set up and specific issues of respective communities (Ganewatte & Pradhan, 1995).

An Asian Development Bank report (ADB, 2016) states that the century-old PID has not been capable of operationalising complex water issues despite reforms introduced between 1998 and 2013. The report concluded that “a comprehensive policy and institutional review and a complete transformation of PID into a responsive water resources department (WRD) are required.” (ADB, 2016, p. 1).

### *PIDA*

In response to the kinds of concerns raised above, the Punjab Irrigation and Drainage Authority (PIDA) was set up through an enactment in 1997 at provincial level with representation of farmers. Likewise, Area Water Boards (AWB) at each canal command and Farmer Organisations (FOs) at distributary level were constituted. At time of writing[1], five Area Water Boards have been operationalised on Lower Chenab Canal (East) Circle Faisalabad, Lower Chenab Canal (West) Circle Faisalabad, Lower Bari Doab Canal Circle Sahiwal, Bahawalnagar Canal Circle Bahawalnagar and Dera Jaat Canal Circle D.G. Khan by establishing Farmer Organisations. These organisations are participating in the management affairs of their distributaries under a comprehensive legal framework.

PIDA is basically a social institute, having deep contacts with the community and works as a bridge/link between the farming community and PID, the requirements, information, and recommendations are effectively communicated between the department and the community through PIDA, for which they are organising the community through different organisation, mainly the Farmer Organisations. PIDA also sends the recommendations to PID on its own observations. The organisation’s vision is to provide equitable and sustained irrigation to the cultivable land of Punjab, that would in turn result in increased productivity, social security,

[1] *This section was written prior to the 2019 repeal of the Act that established PIDA. As a result, PIDA as an organisation has been abolished along with its AWBs. The Punjab Khal Panchayat Ordinance has been enacted in its place.*

poverty alleviation and rural development, and thus help ensure food security of Punjab and Pakistan as a whole.

#### *Area Water Boards*

Under PIDA, Area Water Boards (AWBs) are being formed to assume responsibility for managing and financing the operation and maintenance cost of the irrigation and drainage network progressively within its jurisdiction. The AWBs will manage the system at main or branch canals.

Punjab Irrigation and Drainage Authority (PIDA) is pursuing the implementation of Institutional Reforms in irrigation sector of Punjab. The establishment and formation of farmer organisations have been carried out in five Area Water Boards out of 17 during different years i.e. Lower Chenab Canal (East) Circle Faisalabad (2005), Lower Chenab Canal (West) Circle Faisalabad (2007), Bahawalnagar Canal Circle (2011), Lower Bari Doab Canal Circle Sahiwal (2012) and Derajaat Canal Circle, D.G Khan (2013). Firstly, three Pilot Farmers Organisations were formed on 4-R Hakra, Sirajwah and Bhukan Distributaries of Bahawalnagar Canal Circle in 2000. Further, 85 FOs were formed in AWB LCC(East) Circle,67 FOs in AWB LCC(West) Circle, 70 FOs in AWB Bahawalnagar Canal Circle, 120 FOs in Derajat Canal Circle and 54 FOs in LBDC Circle.

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## 3.3 Gender and youth

Authors: Saira Akhtar & Muhammad Zeeshan (UAF)

### 3.3.1 Abstract

Excessive extraction is increasing groundwater scarcity, and climate change is increasing extremity of floods and droughts. Restricted access to decision-making and resources makes women more vulnerable to such disasters. Modernity, education and lessening profit margins in agriculture causes male income earners to move away from the rural sector in search of better paying jobs, and women are left behind to take care of agriculture. About 75% of working women render their services for agriculture, but have limited involvement in irrigation as cultural labour divisions mean women are not permitted to undertake heavy duty work. If women are required to irrigate, groundwater is preferred for its on-demand availability, as women can only work during the day time, as a cultural expectation for their protection. Youth of both genders are becoming more fascinated by urban living and are making less contribution to farming. Women farmers need to be involved in planning and applying land and water management to ensure they have access and control. Being unskilled is another drawback for women in adopting technologies, and this issue is too often ignored by policymakers. Gender sensitive training and rights awareness through co-inquiry may be helpful in decreasing the gap between men and women.

### 3.3.2 Gender and youth engagement in groundwater management

Most of Pakistani agriculture is reliant on the Indus Basin Irrigation System, including canal irrigation and groundwater. About 95% of the water resources are spent on agriculture in the country. Global climate change and excessive exploitation of groundwater has become a threat for agriculture, as the water becomes scarce and climate change brings increased extreme weather events, such as unusual floods and droughts. Women are more vulnerable to these disasters as they have restricted access to resources, and limited or no decision-making powers (Hamid & Afzal, 2013).

The agriculture sector in Pakistan is greatly dependent upon women. About 75% of working women are involved in the sector as compared to 35% of working men. However, the social set up, limited decision power, and lack of land ownership in particular contribute to women having less opportunity to benefit from irrigation, even though across Pakistan most domestic water needs are fulfilled by women. Studies show that women spend up to 1,200 hours per year fetching water for household needs (Hamid & Afzal, 2013).

There is a division of labour between men and women in the Punjab province. Men usually do the levelling, use machinery such as tractors, threshers and tube-wells, and water the crops. But in some areas, such as in Pothohar region, men and the youth are leaving their villages in search of jobs in urban areas, as they find agriculture an insufficient source of livelihood. The result is that women are increasingly taking responsibility for agricultural tasks in their absence. However, even in this situation, irrigation, market, land levelling and other jobs are still done by men only (Taj et al., 2007).

With increases in literacy rates, youth in Punjab are also leaving rural areas. As most educational institutes are situated in urban areas, it is becoming increasingly unlikely for youth to return to their villages, especially after enjoying the urban lifestyle. Employment opportunities and imbalanced development also play a role. There is also a gender disparity, as it is mostly boys who can obtain education at better or more distant educational institutes. If permission is granted for girls to study, they are generally required to study at local institutes, and are less likely to be able to stay at hostels away from their families. Thus most male youth are abandoning rural areas and agriculture. The few who remain join their other family members on the farms to help and to learn agriculture techniques. However, boys tend to stick to “men’s work”, while girls mostly stay at home doing housework and other agriculture activities that can be done at home, like livestock care and managing stores. The result is that male youth are more active in groundwater management than female youth.

Traditionally, decision making regarding land and water management is considered a male domain because women are seen as lacking knowledge, requirements, and rights of proprietorship with respect to policies and programs. It is therefore necessary to actively involve women farmers in the planning and application of land and water management plans so that they are able to participate in developing the policies that affect their access to and control of these aspects (Ashfaq et al., 2008). Access to clean water is a particularly important consideration for women given they have prime responsibility for family health (Akhtar et al., 2018).

Groundwater expansion is broadly focused on individual male farmers who are seen to have the skill to use the technology and generally have greater control over resources. Tube-well subsidies are promoted among larger farming businesses (such as plantations) who are mostly managed by men. The requirement for tube-wells to be allocated to landowners discriminates against women, small landholders, and renters (Asghar et al., 2018).

The role of gender in agriculture has attracted considerable attention from policymakers, donors and researchers since 2012. Gender parity tends to increase agricultural efficiency as well as increased women's control over domestic assets that can result in improvement for the next generation (FAO, 2011, p. 4; Revenga & Shetty, 2012). While few in number, women who are economically, socially and politically empowered can have effective decision making, as their day-to-day decisions may have an effect on their family's farms and households.

Incorporating gender considerations in groundwater development and management would help in securing groundwater access for women (de Jong et al., 2012). Gendered water rights regulate women's access and control over the groundwater resources. The division of male-oriented and female-oriented tasks and technological choices regarding groundwater withdrawal are differently affected while introducing groundwater development interventions a gender analysis have to be undertaken throughout the project cycle (World Bank et al., 2009, p. 6).

Major gender issues that arise in agricultural water management (AWM) projects are needed to be addressed and fixed based on existing good practices, experiences and lessons of gender equality from similar situations where AWM projects and policies are being implemented. When men and women are actively involved in planning, designing and implementing the process of any project, it will often assist in producing a women leader's group and decision making positions. Similarly, through the provision of complementary contributions like access to credit, agricultural allowances, and marketing, women growers can help extend the effect of water structured investments and overcome institutional weaknesses preventing access to these facilities. Women should be provided with basic technological training in order to achieve broader developmental goals (Amin et al., 2009).

Providing training to women in the use of different technologies such as foot pedal pumps, shallow tube-wells and deep tube-wells will be more effective if managerial and technical skills are also provided. In Bangladesh women were able to manage and operate the tube-wells effectively and successfully as a shared water-selling enterprise when they were given management control from the beginning (Van Koppen, 1999).

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## 3.4 Groundwater management in Punjab: Role of NGOs

Authors: Rizwana Warraich (independent consultant), Saira Akhtar & Muhammad Zeeshan (UAF)

Improvement in people's living standards in many developing countries like Pakistan is predominantly undertaken by non-governmental organisations (NGOs) and civil society. From the outset, Pakistan NGOs were involved in accommodating migrants especially in helping those who had been wounded in riots. Many women-led volunteer organisations started working for public welfare. During the rapid growth of NGOs in the 1980s, most were run by international donors, including UN agencies, international NGOs, foreign governments, World Bank and Asian Development Bank, along with support from the Government of Pakistan (Aftab, 1994).

National and international NGOs have had a central role in promoting social welfare in Pakistan, relying principally on funds received from foreign governments or international NGO projects. However, many claim hindrances due to a lack of Pakistan Government facilitation and procedural support (e.g. Ali & David, 2016; Ullah, 2015). Given the Government of Pakistan is a signatory to the Millennium Development Goals and Sustainable Development Goals, there is considerable scope to pursue these goals in partnership with NGOs to mutually support and enhance each other's capacities (Khan et al., 2013).

Initially NGOs avoided areas under government jurisdiction, but increasingly government and NGOs are accepting each other's roles. This partnership and collaboration is leading to good results, saving resources, avoiding duplication and ensuring community participation (Bano, 2011, 2019). Government sector projects are mostly long-term, time consuming, less expensive and properly budgeted, whereas projects run by NGOs tend to be expensive, highly subsidised and operate for limited durations. The work of NGOs encounters difficulties due to limited technical expertise and accessing sufficient funds to contribute to long term initiatives. NGOs are usually reluctant to contribute to long-term projects like irrigation groundwater management due to their dependence on donor funds; funds that are subject to each donor's own objectives. This reluctance is in spite of having staff who are well trained and have good engagement with communities. Instead NGOs tend to be involved in short-term projects, seeking to make a difference over one or two-year projects. Their strong points are their flexibility and responsiveness in supporting local farmers' groups and in taking well-timed initiatives. Their challenges include unavoidable dependency created among rural communities on government and big donors, and limitations imposed on their operations and activities as determined by memoranda of understanding (Bano, 2019). NGOs also face limited human, technical, material and financial resources due to their reliance on external grants and funding arrangements.

In terms of groundwater management for irrigation in Punjab, NGOs have no visible role, except for research. They are mostly involved in the provision of safe drinking water, sanitation and hygiene education. For example, UNICEF, is working with the Government of Pakistan's Ministry of Environment, Pakistan Council of Research in Water Resources (PCRWR), local government departments and others to raise provincial and urban access to safe drinking water and sanitation, including raising community awareness about avoiding use of groundwater polluted with bacteria and arsenic (Source: https://www.unicef.org/pakistan/). In addition, a multidisciplinary group led by the Pakistan Agricultural Research Council's Range Research Institute created a national action plan which will be actualised through community-based organisations (CBOs), area level applicable organisations, tehsil level offices, NGOs, and Rural Support Programs (Anwar et al., 2008). Some NGOs, such as the National Rural Support Program and Pakistan Institute for Environment-Development Action Research, have contributed to small-scale, grassroots level irrigation systems. These NGOs are skilled in approaching rural households, presenting community planning and establishing networks for information dissemination about new irrigation technologies.

**National Rural Support Program (NRSP)**

Source: https://www.nrsp.org.pk/

NSRP has been engaged to re-establish water supply to communities drawing on subsidies from UNDP and the Pakistan Government. It has played a pivotal role in developing and extending surface and groundwater irrigation schemes, especially in more remote rural areas, such as

Badin and Turbat in the south, Rawalakot in the north, and in Turbut where 12 karezes have been restored. In Punjab, NRSP is providing small loans to install tube-wells and other accessories, and establishing Water Users' Associations (WUAs) along each watercourse. Training is provided to ensure participation by woman and the poor in these WUA initiatives, and to ensure all benefit from services and training courses provided.

NRSP is also involved in a project to improve a piped irrigation system in Dhoke Jhatti village in Chakwal district. The system will enable good quality groundwater to be used for irrigation of a proposed 12.6 ha. command area that is currently dependent on rainfall. This activity exemplifies NSRP's ongoing involvement in developing groundwater use for irrigation. NRSP was involved in expediting groundwater development, as a supplement to surface irrigation, through Salinity Control and Reclamation Projects (SCARPs). Initially, SCARP was a public sector initiative where large capacity (60-150 lit/sec) tube-wells were installed to control waterlogging in irrigated areas. SCARP tube-wells subsequently spurred private sector development of groundwater via small capacity (30 lit/sec) tube-wells. NRSP also recommended that groundwater be accessed using lift irrigation. These are used to lift water from a depth of 60 to 90 metres, where bacteria levels are low, for irrigation and drinking purposes. If the level of dissolved solids is also within acceptable limits, this groundwater can be a good source for community water supply systems.

NRSP was involved in irrigation management in Punjab, especially in the construction of water channel systems from canals and supplementary groundwater. NRSP offers savings and credit services to community participants investing in small-scale irrigation schemes. It is currently offering an interest free loan under one of its project in the district of Okara in Punjab, together with the Punjab Government (Source: NRSP Islamabad). The NRSP Microfinance Bank Ltd. is a leading microfinance bank which commenced in March 2011 to provide financial services to poor and marginalised segments of society, especially small and landless farmers. The bank provides loans with small interest rates to farmers including for investment in irrigation, and Kissan Zarri Taraqiati Loans for clients purchasing solar power for tube-wells, tractors, laser levellers and other agricultural equipment (Source: NRSP Bank Office Bearer and NRSP Microfinance Bank Ltd. website).

**Pakistan Institute for Environment-Development Action Research (PIEDAR)** is an NGO registered in March 1992 as an independent not-for-profit entity. The idea of PIEDAR emerged from Pakistan's National Conservation Strategy, which identified the need for a policy institution in the field of environment and development. A wide-ranging process of consultation underscored the need for such an institution to have solid roots in research undertaken in partnership with communities (Source: http://www.piedar.org/).

**Climate Change, Alternate Energy and Water Resources Institute**

**Agricultural Water Management Program, Islamabad**

Source: http://www.parc.gov.pk/index.php/ur/caewri-rshprog/caewri-awmp

The Agricultural Water Management Program is a modification of the Irrigation Systems and Water Management Program that had started in 1991 under the Water Resources Research Institute. It began in collaboration with international institutions such as USAID. Access to adequate water is one of the main constraints in increasing yield and bringing more area under cultivation. The objectives of the Agricultural Water Management Program are to:

- Optimise water management practices to improve water productivity in irrigated/rain fed areas of Pakistan.
- Design and adapt existing innovative irrigation techniques to enhance agricultural production
- Develop and evaluate water management interventions for groundwater/low quality water management to sustain crop production
- Disseminate knowledge/technology and build capacity of stakeholders.

The program is involved in executing several national and international projects, on job training, consulting services, evaluation and management of drip and sprinkler irrigation systems, and development of methodologies and technologies to improve crop per drop. Some areas are as follows like: Surface irrigation systems, Furrow- Bed systems, Drip irrigation systems

- Portable and solid set sprinkler systems
- Soil-Water-Plant-Climate Modelling
- Centre pivot sprinkler irrigation systems
- Integrated water resource management
- Ground water management
- Low quality water use for sustainable production
- On job trainings and technical services

**Punjab Rural Support Programme** (PRSP) is a provincial level non-government organisation also having some expertise in irrigation management. It operates in 28 Punjab districts through 6 regional offices (Faisalabad, Multan, Gujranwala, Sahiwal, Lahore and Sialkot), and provides the following services:

- Network of water supply
- Network of sanitation and conservancy
- Removal and disposal of sullage, refuse, garbage, sewer or storm water, solid or liquid waste, drainage
- Express ways bridges, flyovers, public roads, streets, foot paths, traffic signals, pavements and lighting
- Public parks, gardens, arboriculture, landscaping, bill boards, hoardings, firefighting
- Land use control
- Zoning, master planning
- Classification declassification or reclassification of commercial or residential areas, markets
- Housing
- Urban or rural infrastructure
- Environment and construction
- Maintenance or development
- Enforcement of any law or rule

Sources: https://lgcd.punjab.gov.pk/Punjab%20Rural%20Support%20Pogram and https://lgcd.punjab.gov.pk/Services

Its agricultural water management projects include the Punjab Barrage Improvement Project, Crop Maximisation Project, and the National Program for Improvement of Watercourses (Source: http://www.prsp.org.pk/Projects/Projects.aspx). As a result, the NGO has helped create some community-based organisations (CBOs), with the understanding that community needs to be engaged in discussions on supply issues and the strategies to be adopted for various conditions.

**The U.S. Department of Agriculture (USDA)** partnered with the International Centre for Agricultural Research in the Dry Areas (ICARDA) and 11 Pakistani institutions in a US$3.3 million, 4.5-year project that demonstrated and disseminated best practices and technologies in watershed rehabilitation and irrigation improvement to rural farmers. USDA and ICARDA work in partnership across the provinces of Punjab, Sindh, and Khyber Pakhtunkhwa with two provincial agricultural research institutes, three Pakistani universities, three institutes of the Pakistan Agricultural Research Council, a provincial agricultural extension department, the Pakistan Council of Research on Water Resources (PCRWR), and a Pakistani agricultural NGO. Through this project, technical experts from USDA visited Pakistan to provide training and technical consultation to Pakistani partners, who then conduct demonstrations and dissemination activities with local farmers.

Source: https://pk.usembassy.gov/u-s-department-of-agriculture-pakistani-experts-and-icarda-collaborate-to-help-farmers-use-water-more-efficiently/

**Water-Aid Pakistan** started in 2006, aiming to engage and influence the Pakistan government through a Rights Based Approach. With the help of its partners, it has sought to work with CBOs to enhance their managerial, technical and social mobilisation capacities. WAP works with relevant government departments and agencies on water related issues, and with local partners to improve hygiene behaviour and community access to water supply and sanitation services.

Source: https://www.wateraid.org/where-do-we-work/pakistan/

A number of international NGOs have partnered with government entities on groundwater management projects. In particular, the International Union for the Conservation of Nature (IUCN) established an office in Pakistan in 1985 with a mission to influence, encourage and assist societies conserve the integrity and diversity of nature, and to ensure use of natural resources is equitable and ecologically sustainable. Its contribution to groundwater management includes a water program in Balochistan province. IUCN contributed by establishing an artificial groundwater recharge pilot/demo project at Ballo Zai Dam Balochistan. Similarly, IUCN was also involved in installed recharge structures (boreholes and infiltration galleries) in two dams; downstream of the Murghi Kotal Dam and upstream of the Dargai Dam to increase recharge for increased flow in karezes and water levels in open wells under “Groundwater Aquifer Rejuvenation Demonstration Pilot Project” for Balochistan (Source: IUCN Islamabad Office, IUCN Pakistan website).

National and international NGOs can play role in community mobilisation, capacity building, networking, strengthening Public Private Partnerships, conducting training workshops, identifying needs, engaging technical expertise and professional and financial services, and supporting extension services. They can create awareness among communities on productive use of groundwater for irrigation, using water efficient technologies, and sharing of information on water recharge (artificial or permanent). They need to be encouraged to work with government on policies and their implementation. The collective efforts of NGOs, federal and provincial government departments, relevant district and local authorities and communities will help rehabilitate groundwater resources and enhance groundwater through adoption of water efficient technologies, capacity building, rule enforcement, conflict resolution and local level FO leadership capacity enhancement.

Out of al the NGOs in Punjab focused on irrigation management and related issues, NRSP is easily distinguishable from the others as its water related projects cover a wider range both geographically and dimension-wise. This makes it the most suitable organisation with which to collaborate to save time and money. The NSRP will not need much in terms of training and demonstrations or models, and they have ample knowledge about groundwater. PRSP is another NGO that works well at provincial and especially with the farmers in Punjab. Collaborating with these two NGOs can help advance the project. IUCN Pakistan’s experiences with groundwater management in Balochistan could also be applied to the Punjab context.

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## 3.5 Economic context

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The chapter prepared for this section is published separately as part of the project's socio-economic analysis report (Chapter 3).

# 4 Sindh

## 4.1 Irrigation management

Author: Aurangzeb Memon, SID

The province of Sindh is located in South-East of the country. It is the third largest by area and second largest by population province of Pakistan. The landscape mainly consists of alluvial plains. In the East, Thar Desert exists which borders with India. The population of Sindh is estimated at 47.89 million (2017 Census), up from 30.4 million in the 1998 Census). The River Indus is the main source of surface water supply for agriculture, industry and domestic usage. There are three barrages; Guddu, Sukkur and Kotri on the River Indus at considerable intervals from where a number of main canals emanate, forming an irrigation network.

The groundwater plays a large part in fulfilling the water requirement for agriculture and domestic use. Unfortunately, more than 80% of lands in Sindh are underlain by the saline groundwater unfit for irrigation that is a major constraint in irrigated agriculture. The fresh groundwater is found mostly in a strip parallel to the left bank of Indus River and some pockets in other areas. (SIDA 2006).

### 4.1.1 Role and extent of groundwater compared with surface water for irrigation:

The overuse of groundwater is like withdrawing from a bank account and taking more money than you deposit into it for its fair maintenance. Similarly, the Indus Basin Irrigation System is facing more extraction of groundwater than its recharge. At the head reaches of branch canals, major distributaries and minors the groundwater extraction is low due to the availability of surface water; however, as we move down to the tail reaches, we witness substantial amount of groundwater pumping. The use of groundwater for irrigation in Sindh is far less than that of Punjab because of the. unavailability of fresh groundwater; however, in certain regions along Indus River freshwater pockets exist with a meagre amount. These pockets get recharged by seepage in flood seasons or if there is any substantial increase in the flows of Indus River. A large part of the groundwater use in Sindh is from the riverine areas where there are no irrigation canals and soils are relatively sandy. In the canal command areas there is relatively limited use of groundwater (Lashari et al., 2015).

The Indus is almost the sole source of surface water for the Province of Sindh. About 40 percent area of the province is under irrigation through the canals off-taking from three Barrages in Sindh: Guddu, Sukkur and Kotri. Irrigation supplies to Sindh Province are around 56 BCM (Lashari et al., 2015). In other words, groundwater use stands at less than 4-8% of surface water use, whereas in the canal areas of Punjab the use of surface and groundwater at farm level are approximately 50:50 (Lashari et al., 2015).

### 4.1.2 Demand and supply analysis:

The use of groundwater is very diverse, ranging from domestic, municipal, and industrial to agricultural activities. The major consumer is agriculture sector. Insufficient supply of surface water triggers the use of groundwater at large scale. Also, the intensity of agriculture has also increased as compared to past, giving enormous rise to demand of water.

The domestic and municipal demand of water has also increased substantially due to population growth and urbanisation in past decades. Groundwater in Sindh is saline in 80% of irrigated areas and is unfit for both drinking and irrigation (Habib, 2006, cited in Ghazanfar, 2009). Currently, 3.1 BCM of groundwater is pumped for agriculture (including livestock) and domestic usage (Ghazanfar, 2009). This meagre amount has a little significance in meeting the demand of water. Ultimately, surface water is the only viable resource for irrigated agriculture.

*Table 1. Growth in cropping intensity for Pakistan*

Source: Ahmad 1995, cited in Basharat et al., 2014

| Year | Cropping Intensity |
|---|---|
| 1960 | 102.8% |
| 1972 | 110.5% |
| 1980 | 121.7% |
| 2012 | 172% |

In Sindh, it is obvious that the water demand is not fulfilled by groundwater alone. Therefore, surface water supply is mandatory for survival. Mangan et al. (2016) conducted a study in four districts of Sindh to assess the impact of tube-well irrigation on underground water, soil quality and crop yields. It was concluded that 23% of farmers were fully dependent on groundwater for irrigation and the majority (77%) were using groundwater and surface water conjunctively. By using marginal quality water, the soil gets affected and ultimately the cost of land per acre decreases.

### 4.1.3 Legislation and policies:

Groundwater is a very significant and integral part of water reserves. Its value cannot be overlooked for it is a good supplement to cater to the water needs of the province. Unfortunately, legislation that can effectively manage groundwater use is still a distant dream. In fact, the management and legislation of groundwater is a multidimensional issue. It requires a reliable assessment of water in an aquifer, its quality, recharge capacity, probable pollution and distribution. On the other hand, a greater responsibility lies on the society, farming community, and industry for its managed utilisation. According to Agriculture Statistics of Sindh (2009), there has been a drastic increase in public and private tube-wells in the past decade.

The data in Table 2 reveal a very bleak situation of groundwater extraction. There has been tremendous increase in the number of private tube-wells compared with public tube-wells, which implies that groundwater is extracted without any management of aquifer recharge. Without sufficient aquifer recharge, such extraction causes a heavy drop in the watertable.

*Table 2. Growth in public and private tube-wells in Sindh. Source: Agriculture Statistics of Sindh (2009)*

| Year | Public Tube-wells | Private Tube-wells | Total |
|---|---|---|---|
| 1998-99 | 7090 | 21501 | 28591 |
| 2002-03 | 12234 | 53225 | 65459 |
| 2006-07 | 12880 | 74696 | 87576 |

Where there are fresh groundwater strips along Indus River, the extractions are unrestricted. The tube-well installation was promoted to control the waterlogging and salinity problem and to use the marginal water for agriculture. This practice led to an increased number of private tube-wells in Sindh. In order to tackle the situation, there is an urgent need to form regulation mechanism for use of ground water like surface water so that groundwater resources can be used sustainably over the long term.

### 4.1.4 Irrigation structures:

The practice of conjunctive use of water (that is, using both canal and groundwater) is common in areas where surface water is insufficient. In those areas, the water is applied in cyclic way. For instance, if a crop requires water three times per month then water is applied once from surface water, and two times from groundwater. This practice is common in tail end command areas of any branch canal, major or minor distributary. However, at certain places, farmers are solely dependent on groundwater. Resultantly, the watertable levels in these areas is considerably lower and declining.

For managed recharge of the aquifer, small dams are constructed in Sindh. In the areas of Kohistan (Western side) of Sindh; and in areas of Nangarparkar (Eastern side) of Sindh, these small dams are constructed for harvesting rainwater from hill torrents. Construction of small dams in Sindh started in 2007 and is successfully recharging the aquifer of those areas (Bhatti et al., 2019, 2020).

### 4.1.5 Distribution management and practices, including decision making, and how information is accessed:

In most of the areas, traditional practice of free flooding and furrow irrigation is followed. Farmers gets their share of irrigation water on the basis of a document called ‘share list’. This share list is prepared by the Canal Assistant who is an employee of Sindh Irrigation Department. However, another practice called ‘*warabandi’* is also common when there is less availability of water and it has to reach the tail-end of the branch canal.

In some canal command areas which are operating under Sindh Irrigation and Drainage Authority (SIDA), there are Farmers’ Organisations (FOs). The primary role of FOs is to ensure the fair share of irrigation water and collection of water charges (*abiyana*) from farmers. However, there is acute need of training and capacity building of farmers to use efficient irrigation techniques, because there is a prevalent notion that ‘more drops more crops’.

Water losses are also a chronic problem at farm level. In order to address the issue, lining of canals, distributaries and minors is done. Therefore, certain reaches are lined every year.

### 4.1.6 Conclusions and Recommendations

Through the literature review and PRA conducted in Sindh (Khair et al., forthcoming), it is concluded that groundwater extraction in Naushero Feroz and Shaheed Benazirabad district has been increased due to frequent droughts, shortage of surface water availability especially in the tail reaches, poor understanding of hydrogeological conditions, population growth, poor assessment of water demand, poor groundwater governance and lack of coordination among different stakeholders. To solve this complex problem, following recommendations/measures are suggested:

- Assessment of crop water demand be carried out. Reallocation/rationalisation of canal water supplies is needed. In irrigated areas with deep fresh groundwater, the canal supplies be reduced.
- Revenue generation mechanism should be enforced.
- Irrigation water structures at tertiary level should be maintained and thereby improve the equity of water distribution to the farmers.
- Assessment of optimum groundwater potential for different areas is required. Rules and regulations for groundwater usage be followed without any political compromises.
- Solar pumping tube-wells in the waterlogged and marginal saline groundwater areas be encouraged with the conjunctive use of surface and marginal saline groundwater.
- In areas with shallow fresh groundwater, skimming wells need to be promoted.
- A safe yield line of aquifer may be drawn to create equilibrium between discharge and recharge. Sub-surface fresh groundwater reservoirs must be maintained.

The overall improvement in governance of canal and groundwater in the province is a first and foremost requirement. For that, capacity building of the irrigation department, both technical and managerial, along with feeling the responsibility of the job is necessary.

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## 4.2 Sociopolitical context

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At the time this review was written, the case study locations for the project had not been determined. Literature searches were undertaken using Google Scholar and Scopus with reference to three districts likely to be considered for case study locations: Shaheed Benazirabad (formerly Nawabshah), Naushahro Feroze and Khairpur. Rapid thematic analysis was undertaken of the literature uncovered that might be of relevance to understanding the socio-political context for irrigation management in these districts. This analysis revealed three themes:

1. Efforts to build capacity for transfer of irrigation management to water users' associations (see section below on 'description of management regime').
2. Analysis of and explanation for the prevalence of inequality affecting farming communities (see section below on 'institutional analysis').
3. The role of farmer field schools and other extension approaches in changing farmer behaviours (see section below on 'local political context and influences').

### 4.2.1 Description of management regime

The Government of Pakistan initiated a significant institutional reform for a more devolved approach to irrigation management through legislation enacted in 1997 (Memon et al., 2001). In the case of Sindh, this followed pilot investigations into the potential of devolved management (Starkloff, 2001). Transfer of the management of the irrigation network from government control (via the Sindh Irrigation Department – SID) to locally organised water users' associations has been in process since then, with the latter organised through the Sindh Irrigation and Drainage Authority (SIDA). Transfer can only proceed following the establishment of "self-accounting, self managed and self financing Area Water Boards" run by farmers' organisations (FOs) at the local scale (i.e. at the secondary canal level) (Memon et al., 2001, p. 1). As this transition is still in process, parts of the surface water irrigation network in Sindh is now being managed at a provincial level by SIDA, with the remainder of that network still being managed by SID. While this has the effect of having two agencies responsible for operation of irrigation management, SIDA functions under the Sindh Government's Secretariat for Irrigation through SID (SIDA, 2011). There is an associated expectation that a proportion of SID's budget and personnel will be transferred to SIDA (PKR 1.25 billion and 5,000 staff respectively according to SIDA, 2011, p. 202).

The available reports did not clarify what the implications of these surface water arrangements might be for the management of groundwater. The SIDA (2011) review of provincial level institutional arrangements and capacities highlighted the impact of irrigation on increased waterlogging and salinity, and the associated mismanagement of tube-wells, where saline groundwater ends up being discharged into drains. A significant proportion of tube-wells are no longer functioning. While the majority of tube-wells are privately owned, responsibility for their management is under SID, even though the policy is to transfer them to the private sector (SIDA, 2011, p. xviii).

### 4.2.2 Implications of governance decisions

Our initial search failed to uncover any independent contemporary analysis of this transition of surface water irrigation management arrangements specific to the case study context. Much had been written during the early stages of the reform, especially under the auspices of the International Water Management Institute (IWMI) (Memon et al., 2001; Murray-Rust et al., 2001; Starkloff, 2001; Ur Rehman et al., 2001). IWMI's research activities had been initiated at the request of the Government of Sindh, and built on a solid base of participatory action research approaches similar to that our project is aspiring to establish (see, for example, Bandaragoda, 1999). It is likely that research associated with our sister project analysing participatory irrigation management in Sindh and elsewhere might help redress this dearth of contemporary analysis, at least as it relates to surface water management. We could find no research analysing the implications of this reform for groundwater management in particular, suggesting that this is a gap that needs to be addressed.

### 4.2.3 Cultural aspects

Our initial search failed to uncover any contributions to understanding the socio-political context of irrigation management and groundwater related to cultural aspects.

### 4.2.4 Institutional analysis

Institutional arrangements include the rules, norms and strategies that shape the decision-making of individuals and organisations. Thus institutional analysis to support the aims of this project means more than just analysing decision-making processes by government and non-government organisations related to groundwater management. Such analysis needs to consider the impact of these processes on individual decision-making, especially of groundwater users, the factors that enable and constrain how these individuals respond, as well as the dynamics between individuals impacting how they respond. While a detailed institutional analysis is beyond the scope of this review, one identifiable theme arising from the current review is that inequality is a major factor to be considered when analysing institutional arrangements in Sindh.

Regional-level inequalities were explored at the district level by Mahmood and Ahmed (2014). The three districts being considered as suitable for case study locations for the purposes of our project were found to be comparatively well developed in that they were more economically developed than the majority of other districts, but less than those districts with major urban centres. What their analysis reveals is the critical role that irrigation has played. While the three districts all scored poorly on the climatic conditions suitable for cropping, they were among the districts with the highest scores on the component that combined agricultural and rural infrastructure development. Of course such district-level analysis hides the true extent of inequality in rural areas, which is compounded by socio-political dynamics of land ownership, tenancy and dependency (Tagar et al., 2016). While poorly written, Tagar et al.’s (2016) paper provides the kind of critical analysis essential for our understanding of the root causes of poverty affecting rural Sindh. Nawaz-ul-Hada et al.’s (2013) analysis is more considered, with reasons for inequality derived through factor analysis of census data. It is interesting that two of the factors that Mahmood and Ahmed (2014) identified as contributing to regional disparity are also key factors driving inequality: the process of urbanisation exacerbates inequality among urban populations, while they conclude that agriculture should be championed for its significance in alleviating social problems associated with poverty. The positive impact of agricultural development needs a significant degree of qualification given the level of inherent inequality in rural society, as suggested by Tagar et al. (2016).

Such inherent inequalities have a direct bearing on water resources management, and groundwater management in particular. As Murray-Rust et al. (2000) identified, inequities in the distribution of canal water undermines overall performance of the system. Those worst affected are more likely to have to rely on low quality water, or to pay more for their water to those in a better position to profit. These conditions can lead to under-reporting of and/or undocumented water access, which can in turn test the validity of data that forms the basis for hydrological assessments (as was found to be the case in an example involving groundwater over-extraction in Chile – see Budds, 2009).

### 4.2.5 Local political context and influences

A positive aspect of the institutional arrangements for Sindh farming communities is the influence of locally organised activities, such as farmer field schools. This aspect is reflected in the literature uncovered from searches (Khan & Iqbal, 2005; Khan et al., 2007; Yasmin et al., 2013a, b), which has documented the impact these activities have had on changing the behaviour of farming families. While the focus on these papers has been to show the impact of these activities through increased adoption of recommended environmentally-friendly agricultural practices (such as integrated pest management), they also offer description and evidence of the participatory processes used. In particular, the process used by Yasmin et al. (2013a, b) among women farmers champions the collaborative learning approach our project aspires to achieve, and its authors are associated with the ACIAR sister project focused around farmer field schools, including their shared partnership with the NGO involved, SOFT. This provides a valuable legacy we can build on.

In a more recent study, Kumbhar et al. (2016) explored the success of farmer field schools in comparison with other extension methods drawing on an analysis of farmers' perceptions. While their key recommendation is that farm level training be conducted using farmer field schools, other extension methods could also be developed for other purposes, such as dissemination of information by radio and through demand driven technologies. The baseline studies of four villages by WWF Pakistan (2007) includes the kind of information suitable for this section (included under the heading of 'social capital'), but the villages involved (Keti Bunder, Kinjhar, Pai forest and Chotiari) do not correspond with areas where we are likely to be doing our studies.

### 4.2.6 Critical evaluation of literature identified

It is interesting that the better quality literature related to Sindh is mostly in the 'grey literature', and especially in IWMI reports that are well over a decade old. Most of the academic work has been published in low impact journals, and some of these publications are of poor quality. This represents an opportunity. It suggests that there are good and publishable research activities being undertaken in Sindh that we can build upon, and that we can assist in ensuring that these activities are disseminated to a wider audience. Also, given that a sister ACIAR project exploring participatory irrigation management includes a study of developments in Sindh, we are well positioned to build on any publications arising from that project, especially given the complementarity of the two teams area of focus: theirs focused primarily on surface water management, while ours is focused on groundwater management. It is therefore in our interests to work cooperatively with this team.

### 4.2.7 Research Gaps

There is a need for research to study the impact of reforms towards more devolved management of the Sindh irrigation system. However, our project's focus warrants a focus on what these reforms mean for groundwater management.

The baseline report by WWF Pakistan (2007) provides a good example of the kinds of information we can gather through our PRA activities. There seems to be a gap in providing high quality analyses of local-level socio-political contexts and their implications for participatory research activities. This is despite the claimed successes of research activities that have adopted a participatory approach, and the recognition of inequalities as a significant aspect of the socio-political context in Sindh. Also, while cultural dimension seems to have been integral to many of the relevant studies involving Balochistan, this has not been covered among the studies found involving the proposed Sindh case study areas.

### 4.2.8 Questions Arising

- What has been the impact on groundwater use and management from the progressive handover of the Sindh irrigation system to local water users' associations?
- What is the nature of the inequalities among the farming communities our project becomes engaged with, and how do these inequalities affect the way groundwater is used and managed?
- Are there cultural dimensions that affect how groundwater is managed, and, if so, how should our research activities take these into account?
- What recommendations can we make to those adopting participatory research activities to better account for inequalities and cultural diversity?

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## 4.3 The current status of women in rural households of Sindh and their role in water management

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### 4.3.1 Status of rural women in Sindh

Sindh is the second most populous province of Pakistan and women constitute 50 percent of its population. Most live in rural areas (Government of Pakistan, 2015), and are major contributors in running the wheels of the rural economy. They play significant roles in agriculture, livestock and off-farm income generating activities. Rural women are heavily burdened by their dual roles as family care providers and paid or unpaid workers. Rural women normally work 16 hours a day and more than 70 percent women labour force is engaged in carrying out intensive field work of seed sowing, weeding, harvesting, cotton picking, grass cutting and livestock rearing, small scale home based entrepreneurships activities besides maintaining household; arranging water, fuel and food and look after children and other family members (Samee et al., 2015; Javed et al., 2006; Haider, 2013).

Cotton and rice cultivation accounts for more than one third of rural women's annual farming activities, and cotton production is considered as a female led activity. In the cotton and rice growing areas of Sindh, rural women spend 50 percent of their time with cotton crops and 39 percent with rice crops. The result is that they also suffer from different kinds of skin diseases and allergies, making it difficult to perform their daily household activities. In rural areas of Sindh male dominated activities include land preparation, threshing, marketing, transport, fodder production, selling animals, and purchase of feed and medicines (Samee et al., 2015).

While Sindh's rural women are highly productive, they are among the least empowered segment of society. There is little recognition and appreciation at any level (household, local and national level) of the work they perform. They are mostly perceived as helpers and thus their work usually remains unpaid. Although their contributions to crop production, dairy and livestock related activities may be more than that of men, and their involvement in household activities is 100 percent, cultural and social customs result in their work not being appreciated as work, and negatively influencing their potential. Gender norms dictate the roles women take on and the type of work opportunities they are given. The roles given to women restrict their time and mobility for education, training, empowerment and economic activities. Rural women have limited access to productive resources and are socially, physically, economically, politically and educationally deprived. They can be empowered by acquiring the capacity to initiate and run their own entrepreneurships in their own village circumstances without any contradiction or clashes with local customs (Samee et al., 2015).

### 4.3.2 Social issues that perpetuate their lower status

Rural women in Sindh face numerous social, cultural and economic problems. They perform difficult farming tasks and produce output on land owned by men who enjoy stronger economic and social status. Rural women's social and economic status is determined by various factors including access to property, land, education and health within the constraints of the social and cultural environments they live in. Key challenges and issues encountered by rural women are discussed under the following headings.

#### *Gender discrimination*

Pakistan provides another classic example where women are placed in derogatory positions (Bhattacharya, 2014). Indicators of gender inequality in Pakistan have remained unsatisfactory over many years due to discriminatory laws, social norms and attitudes practised against women. Pakistan was ranked at 157 out of 160 countries on the UNDP 2015 Gender Development Index (GDI), and 147 out of 188 countries on the Gender Inequality Index (United Nations Development Program, 2016). In rural Sindh, gender discrimination starts from childhood. Females are taught throughout their life that they shouldn't value themselves above the males in their family. Women are also not allowed to participate in major decision-making at the household level – even for decisions regarding their own education, health and marriage etc. (Samee et al., 2015).

### *Poverty*

Poverty is one of the major reasons for female disempowerment. The proportion of women entrepreneurs is very low in Sindh. Poverty levels are very high in rural areas, yet this is where most of Pakistan's population lives, and where agriculture is practised providing livelihoods for 43.5 percent of the rural population and 20.9 percent of the country's GDP (Government of Pakistan, 2015). The World Bank's 2013 poverty headcount analysis indicates that in Pakistan about 30 percent of the total population is living below the poverty line (World Bank, 2018). The great philosopher Adam Smith suggested that a society cannot flourish if major parts of that society are poor and living their lives in miserable conditions; yet this clearly represents Pakistan's present condition. The above figures demonstrate the mismatch between the high contribution agriculture provides and the low level living standards of rural people providing agricultural produce. This low productivity for the rural labour workforce results from a lack of access to modern technologies, lack of availability of productive resources and unskilled labour. Another important reason is that half the population have been left unskilled and least empowered. The high potential of women can significantly contribute to rural development, yet this is so often ignored (Samee et al., 2015). Rural women face issues of complex loan procedures to gain access to micro credit. They also lack training in marketing their products and access to markets (Chaudhry & Rahman, 2009; Makhijani et al., 2015).

### *Lack of awareness of legal rights and role in decision making*

Women rights are frequently violated in rural communities. Along with cultural constraints, poverty, lack of basic facilities, lack of control over productive resources and decision making, rural women in Sindh lack of awareness of their legal rights, access to legal aid and delays in getting justice, compounding the victimisation of women and gender discrimination in Sindh (Zakar et al., 2016).

### *Limited access to education*

Though the Pakistan constitution recognises education as a basic right for its entire population, it is unfortunately the case that gender disparity in education widely exists. Education indicators for Pakistan remained one of the worst globally. The number of children not at school has been the second highest in the world and two-thirds (3 million) of these are girls. Furthermore, out of 49.5 million illiterate adults in Pakistan two-thirds are women, leaving Pakistan ranked at 89 out of 92 countries on the Education for All Development Index (UNESCO, 2015). Poor girls remain the most disadvantaged as over half of them have never seen school. The Federal Bureau of Statistics 2010-11 Pakistan Social and Living Standard Measurement Survey reveals that the literacy rate remains lower in rural than urban areas, indicative of the increasing gender gap and disparity prevailing in the education sector (Government of Pakistan, 2011) – see Table 1 below.

*Table 1 Literacy rate, population (10+ years) 2010-11*

| Country/Province | Urban | | | Rural | | | Total | | |
|---|---|---|---|---|---|---|---|---|---|
| | Male | Female | Total | Male | Female | Total | Male | Female | Total |
| Pakistan | 81 | 67 | 74 | 63 | 35 | 49 | 69 | 46 | 58 |
| Sindh | 82 | 68 | 75 | 60 | 22 | 42 | 71 | 46 | 59 |

Source: Pakistan Social and Living Standard Measurement Survey, 2010-11 (Government of Pakistan, 2011).

The above statistics present a bleak picture of female education in Pakistan, particularly in rural areas. The overall female literacy rate in Pakistan's rural areas is much lower at 35 percent compared with the urban female literacy ratio (67 percent). The situation is even worse in rural Sindh with just 22 percent compared with 68 percent for urban Sindh. There are only 7,283 primary schools for girls out of total 45,044 primary schools in Sindh (Government of Pakistan, 2011).

### *Health issues*

Though Pakistan recognises public health care as a right, women face discrimination, especially rural women. Wide rural-urban, gender, caste and religion disparities exist in health care (UN, 2013). Deficient maternal health facilities in rural areas of Pakistan leaves poor rural women at risk. Lower social status and mobility, prevailing poverty and malnutrition, mean that most rural women, girls and infants suffer from preventable communicable diseases like diarrhoea, pneumonia, tetanus and tuberculosis. Female health workers play very important roles in enhancing service delivery and reach by health institutions, strengthening links particularly to women of poor households in rural areas. However, the 22,767 female health workers employed in Sindh in 2008 provided only 46 percent of the population covered (Rabbani et al., 2016).

### *Limited access to marketing products*

At household level women are involved in a variety of income generating activities including poultry, value added goods and embroidery but they are constrained from marketing their own products due to restricted mobility, marketing skills and market access (Mirani et al., 2014). The involvement of commission agents and middle men further undermines potential incomes for women.

## 4.3.3 Role of women in water management

Women are regularly involved in water-related tasks as part of their domestic duties. Water is needed for cleaning, sanitation, livestock, as well as for irrigation, and the requirement that women obtain water can over-ride their curtailment of movement (Qureshi, 2005). In Sindh mobility of rural women is restricted, therefore irrigating agricultural lands is purely male's work because most of the time irrigation water is available in nights therefore females are not allowed to take part in irrigation process. Fetching water for household use is culturally defined as 'women's work', and remains the main focus of gender interventions, given that women spend much time, effort and energy in collection of water as her crucial domestic responsibility. Sources of water supply are wells, hand pumps, piped supplies and river or irrigation canal. In some areas of Sindh women walk up to ten miles a day to fetch water for household.

The lack of recognition of women's contributions to how water is viewed, used and managed renders them as "unofficial water managers" (Seaforth, 2004, cited in Qureshi 2005), and they are denied involvement in decision-making institutions, such as water user associations. This denial of participation by women contrasts with the UN Millennium Development Goals of equal participation for women at all levels, undermining the potential for rural communities in Sindh to overcome their social, political and economic challenges (Soomro, 2013), including the potential leadership role women could play (Halvorson, 2009).

## 4.3.4 Research gaps and questions:

The following research gaps have been identified:

1. Need an in-depth understanding of the bottlenecks affecting women's participation in groundwater management
2. How can young rural women become more involved in water management?
3. What are the training and capacity building needs for rural women and youth to perform their water management roles more effectively?

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## 4.4 A brief review of water and energy in Sindh province

Author: Jay Punthakey

The chapter prepared for this section is published separately as part of the project's socio-economic analysis report (Chapter 5).

## 4.5 Groundwater and hydrology issues and context

Author: Hadiqa Maqsood, MUET

### 4.5.1 Review of groundwater literature related to Nawabshah (Shaheed Benazirabad) and Naushero Feroze Districts

With the increase in demand for food in Pakistan, there comes great pressure on cropping intensities. This leads to changes in cropping patterns and water supply demand nexus for irrigation. In Sindh province, an unconfined aquifer underlying the irrigated lands that consists of thin layer of freshwater overlying saline water. Lack of adequate supply of surface water supplies to tail-end farmers together with increased cropping intensity and groundwater extractions at high pumping rates has led to upconing of saline water.

The Government of Pakistan started Salinity Control and Reclamation Projects (SCARPS) to irrigate lands in Indus Basin. Under this project 16,700 tube-wells were installed with an average discharge of 0.09 cumec, cultivating an area of 2.6 Mha. It lowered the watertable and produced favourable conditions for crops by reducing the effect of soil salinisation (Bhutta and Smedema 2007).

According to Habib (2004), the water shortage in agriculture has variation from 10 million acre feet (MAF) (equivalent to 12.3 BCM) during wet years to 25 MAF (30.8 BCM) during dry years. After 1970s, groundwater extraction from fresh groundwater zone has played a pivotal role in agriculture sustainability. For the study areas of Shaheed Benazirabad and Naushero Feroze Districts, studies show evaluation on the equilibrium of fresh water and saline groundwater interface and deterioration of pumped water quality. The degradation of water quality depends on the discharge rate, pumping duration, thickness of the fresh groundwater lens, and local hydro-geologic conditions. It is further directly proportional to the impact on agriculture and livelihood of farmers.

### 4.5.2 Water and soil quality assessment

For the evaluation of water quality, salinity/Electric Conductivity (EC) is given prior importance in this project, followed by other parameters such as Sodium Adsorption Ratio (SAR) and pH. This is to differentiate between the fresh and saline zones. In Pakistan, approximately 5.7 Mha of irrigated land is affected by salinisation. Out of this, 44.1% is saline, 55.4% is saline-sodic and 0.5% sodic. Maximum salt affected areas in Sindh is 23 Mha (Zia et al., 2004).

A study by Majidano et al. (2010) tested 38 water samples in Taluka Daur of Shaheed Benazirabad District for multiple parameters for surface and groundwater. The EC values ranged from 250 μS/cm till 3000 μS/cm. Moreover, 19 samples showed values greater than 3000 μS/cm making the sites unsuitable for irrigation. Also, 23 samples (2 surface and 21 groundwater) had SAR values below 6, making it suitable for irrigation. Another study by Shahab et al. (2016) performed hydro-chemical analysis on 218 samples of groundwater and statistics showed that water quality throughout Sindh is not potable according to WHO standards; also, some areas it is unsuitable for agriculture as well (Thatta and Badin). They concluded that drainage is needed in the agricultural areas to reduce the adverse effects of high watertable levels and poor quality.

Mangan et al. (2016) conducted a questionnaire study from four districts (Matiari, Badin, Tando Allahyar and Mirpurkhas) of Sindh province where perceptions of farmers regarding the effect of tube-wells on water and soil quality, and crop yields was done. The data from the study indicates that 23% of farmers were fully dependent on groundwater while 77 % were using both, canal and tube-well water for irrigation. Results also depicted that farmers allocated 63%

of the total time for irrigation using tube-well. Due to high use of tube-well water, farmers were facing issues of high cost of production, loss of soil and water quality and loss of yields. Moreover, due to no technical guidance, there is inefficient and ineffective use of energy (fuel) for pumping (that includes duration of pumping).

Construction of Left Bank Outfall Drain Stage–I (LBOD-I) was a project under taken in 1985. The ultimate disposal of drainage water to the Arabian Sea was planned through the Kadhan Pateji Outfall Drain, Dhoro Puran Outfall Drain and Tidal Link. The results of the project are that the stakeholders at Benazirabad, Sanghar and Mirpurkhas districts have positive perceptions about the LBOD since the waterlogged lands got reclaimed and fresh water became available through scavenger wells. Also, crop production increased, lands became more fertile and storm water disposal became quicker. However, Thatta and Badin districts showed contrasting perceptions since the lands in these districts showed adverse impacts.

There are various studies and research on LBOD where the conflicts have been portrayed (e.g. Ur Rehman et al., 2001); however, some studies have shown improvement in upper Sindh areas. Much of the conflict over the LBOD is in the southern reaches. Drainage water from LBOD is disposed into Narreri Lake which is linked to the sea. The once thriving communities of fishfolk and herdsmen claim their livelihoods have been destroyed due to saline groundwater, municipal wastewater toxic pollutants entering the lake system (Khaskheli, 2008). Several other wetlands have also been affected including Kandri, Jhubo, Sanhro and Mahro lakes, depriving hundreds of families of their source of livelihoods. An alternative view point from WAPDA suggests that without the LBOD the Badin district would have been inundated by salinity and sea intrusion (see also Iqbal, 2005 for the impact of the failure of LBOD). A recent article on the LBOD (The Express Tribune, 2015) indicated the LBOD had destroyed thousands of acres of crops in the coastal district of Badin. Additionally, villages near Dhoro Puran, Kadhan Pateji Outfall Drain, Ameer Shah saline drain, and Pangrio were affected by breaches of the LBOD. In our view much of the beneficiaries of the LBOD are in the upper Sindh areas where saline groundwater is exported out of the cropping lands. Improved management of the LBOD and the drainage channel is required to minimise the risk of flooding for downstream communities along with safe disposal of the saline effluent.

### 4.5.3 Groundwater modelling

A study area, in Kunner-II distributary area, in the Hyderabad District of Sindh, was modelled for skimming tube-wells by Qureshi et al. (2011) for hydro-salinity behaviour of shallow groundwater aquifer. Calibration and validation of MT3D was done for stress periods of 4 and 8 hours, respectively, along with future stress period simulations. They also performed scenarios for increased duration and discharge of the tube-well pumpage. Results determined that the quality is deteriorating with depth and time, due to excessive pumping. They suggested that tube-wells should not run for more than 12 hours continually.

Scavenger wells have been a recent implementation in Sindh to maintain equilibrium between the fresh shallow groundwater and saline groundwater. These wells involve two pumps: one that pumps fresh water for production, and another that pumps out saline water from deeper levels for disposal. The process is intended to ensure that upconing of saline water due to pumping of fresh water is countered by downconing caused by pumping of saline water. A study by Lashari and Kori (2011) examined the command area of 79 tube-wells of District Nawabshah to elucidate the effect of installed tube-wells on sustainable rural livelihood of irrigated agriculture community. They monitored scavenger wells and observed no change in water quality but maintained the interface of fresh and saline water. They concluded that scavenger tube-well was a good approach to control waterlogging, protect salt water intrusion into the freshwater zone, and increase cropping intensity.

Another study conducted by Kori and Lashari (2008) simulated hydraulic performance of two of the scavenger wells (JRS-57 and JRS-60) installed under LBOD project along the right side of Jamrao canal under the boundary of Nawabshah. They performed calibration and validation of groundwater model MODFLOW (Harbaugh and McDonald, 1996) for the tube-wells including future evaluation for sustainable groundwater use with optimised quantities of fresh water and saline water. The modelling was done for a total simulation of 9 and 15 stress periods. The first stress period of each scavenger well was used for calibration of model and the rest of the stress periods were used for validation of model. The simulated results show that the model has been successfully calibrated and validated with the field-observed data.

Using the above study, Qureshi et al. (2010) linked the results of MODFLOW and modelled MT3D for various scenarios including fresh-saline water pumping ratios and daily operational hours. This study was done to achieve optimum management strategy for better control of fresh and saline water interface. Simulations were done for horizontal and vertical dispersivity and porosity. Salinity profiles were achieved illustrating that increase in salinity with increase in depth. Moreover, modelling included running different recovery rate ratio scenarios. Results revealed that scavenger wells could run at the optimum rate of 13.2 hours/day for JRS-57 and 12 hr/day for JRS-60, with the recovery ratio of 0.5:0.5.

### 4.5.4 Conjunctive use of surface and groundwater in Sindh

The conjunctive use of surface and groundwater in Sindh has been a common practice. It is effective to produce an optimal strategy where the conjunctive use depicts the best of the results in agriculture and improvement of land. In the *rabi* season, when the flow in the river below Sukkur Barrage is almost zero, the river receives groundwater, especially the left bank. A report developed by Lashari et al. (2015), and subsequently published for an international audience by van Steenbergen et al. (2015), proposes six action points for balanced use of surface and groundwater in Sindh. They propose to rationalise irrigation duties, increase and intensify the irrigated areas, improve water use efficiency, have well targeted and selective drainage, make use of storm water and lastly to adapt the saline conditions in certain areas. Among these action points, examples and case studies have also been mentioned where in Gotki, waterlogged area was turned in to fish pond, a local farmer along the Dhoro Naro Minor grows salt tolerant wheat, mulching with tree leaves to reduce evaporation and eventually reduce salinisation, installing skimming wells, solar fuelled wells, and more such practices.

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# 2. Conclusions

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A key outcome of this literature review, as noted in the concluding paragraph of its summary, has been the process of co-learning experienced by its authors. This includes how the team presented its conclusions as part of the project's Mid Term Review in November 2018. This section therefore reproduces the brief three-minute presentation delivered by Dr Awan at the Mid Term Review, which he used to spark discussion among the project team concerning what had been learned.

The strategy adopted for the literature review matches that used for the project: the intention was to include reviews covering the multiple disciplines (social, economic and biophysical) that inform how groundwater management can be improved. The structure and content also revealed other specific themes that crossed disciplinary divides: including roles for GIS and remote sensing, NGOs, gender and youth.

In summary, the key research questions identified from the review are as follows.

From a sociopolitical perspective:

1. How will groundwater governance improve groundwater management?
2. How can transdisciplinary approaches help to improve groundwater governance and eventually groundwater management?
3. What institutional settings are required to improve coherence between different stakeholders; e.g. Public-Private-Partnerships (PPT)?

From a biophysical perspective:

1. What are safe/ sustainable/ acceptable yields for groundwater extraction?
2. Can we build groundwater reservoirs? What is the potential for artificial recharge?
3. What are the impacts of solar pumps on sustainable groundwater extractions?

From an economics perspective:

1. How can energy use subsidies assist in attaining safe/ sustainable yields.
2. Can water pricing help attain safe/ sustainable yields?
3. Can low delta crops be an alternative to high delta crops for saving water and improving groundwater management? What markets are there for low delta crops?

From themes that are cross-cutting:

1. How can we enhance women and youth capacities for improving groundwater management, and enhance their full potential?
2. To what extent can our project's decision support tools help regain interest among youth for agriculture and reduce their outmigration?
3. How can we enhance the potential for NGOs to serve as groundwater service providers?
4. What are the constraints and opportunities for integrating GIS and remote sensing into agriculture and irrigation government departments?

The project has been making progress on some of these questions, while other questions could not be addressed within the scope of this project, and can be carried forward for others to continue to address as part of their work to improve the management of resources in Pakistan for the enhancement of farming family livelihoods.

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