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Improving Salinity and Agricultural Water Management in the Indus Basin, Pakistan: Issues, Management and Opportunities: A Synthesis from a Desk-top Literature Review

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Akhtar Ali

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Disclaimer

Publication Note – August 2023

I wrote this report in 2018.

At the time, it was included as an Appendix to the Mitchell et al. (2018) Final Report of the ACIAR funded Small Research and Development Activity (SRA) project 'Improving salinity and agricultural water management in the Indus Basin of Pakistan', which at the time of writing can be accessed at https://www.aciar.gov.au/project/lwr-2017-028.

Since then, a 'Living with Salinity' research program for Pakistan has been launched, spearheaded by:

1. A second ACIAR funded SRA project (Mitchell et al., 2020) https://www.aciar.gov.au/project/wac-2019-102.
2. A 2.5 year project funded by ACIAR 'Adapting to Salinity in the Southern Indus Basin' (ASSIB) https://www.aciar.gov.au/project/lwr-2017-027.

When explaining the rationale behind the 'Living with Salinity' research program for Pakistan, those involved frequently refer to the original 2018 version of the report by Akhtar Ali. Interest in the report has thus increased, and the ASSIB project team decided it was a report that needed to be made publicly available.

This published version of the original report has not been updated since 2018. It has, however, been subject to a second round of editing and proofreading. Figures used in the original publication have been updated to ensure no breach of copyright. This publication note has been added, and a conclusion section has also been added that explains my overall assessment of the significance of this report for the approach to research being pursued as part of the 'Living with Salinity' research program.

Akhtar Ali – August 2023

Abbreviations Used in This Report

ACIAR	–	Australian Centre for International Agricultural Research
ASSIB	–	Adapting to Salinity in the Southern Indus Basin
BVDP	–	Barani Village Development Project
CCI	–	Council of Common Interest
CSU	–	Charles Sturt University
DRIP	–	Drainage and Reclamation Institute of Pakistan
FO	–	Farmers' Organization
GNP	–	Gross National Product
GRF	–	Groundwater Regulatory Framework
IBDP	–	Indus Basin Drainage Plan
IBIS	–	Indus Basin Irrigation System
IRS	–	Integrated research sites
IRSA	–	Indus River System Authority
ISMF	–	Integrated salinity management framework
IWASRI	–	International Waterlogging and Salinity Research Institute
IWRM	–	Integrated Water Resource Management
LBOD	–	Left Bank Outfall Drain
Mha	–	Million hectares
MOM	–	Maintenance and Operational Management
NFDC	–	National Fertilizer Development Center
NDP	–	National Drainage Program
NWP	–	National Water Policy
PCRWR	–	Pakistan Council of Research in Water Resources
PIDA	–	Punjab Irrigation and Drainage Authority
RBS	–	River Basin Scale
SAWM	–	Salinity and Agricultural Water Management
SCARP	–	Salinity Control and Reclamation Project
SIDA	–	Sindh Irrigation and Drainage Authority
SRA	–	Small Research and Development Activity
SRDP	–	Strategic research and development plan
SSRI	–	Soil Salinity Research Institute
STPP	–	SCARP Transition Pilot Project
TIPOs	–	Technical, institutional and policy options
WAPDA	–	Water and Power Development Authority
WRRI	–	Water Resource Research Institute

Note: '$' sign in this report refers to the US Dollar.

Contents

1. Introduction

A map of the Indus Basin, Pakistan is in Figure 1. Since the original soil survey of the Indus Basin under The Colombo Plan in 1953, Pakistan has made major efforts to manage the problem of waterlogging and salt-affected soils, and address their biophysical and socio-economic consequences. This has included assessing the prevailing conditions, launching mega projects such as for salinity reclamation and drainage (see Section 3.6), initiating research and creating institutions. One main focus has been on lowering the groundwater levels through deep pumping, leaching the salts by excess irrigation, application of chemical amendments (e.g. gypsum, acids, organic matter), with international cooperation and an investment of billions of US Dollars in the control of waterlogging and salinity. These efforts have had modest benefits: the impacts have been low, salinity continues to persist over a large area of about 6.2 Mha (38% of total irrigated land), and agricultural water productivity has remained lower than expected. On-farm approaches showed limited success and the early success of basin-wide interventions could not sustained. The low success rate can be attributed to unsustainable interventions, weak research lacking in participatory management approaches, and the very low uptake of the methodologies and technologies by farmers. The problem has consistently persisted and continued to affect livelihoods and the environment, slowing down economic development.

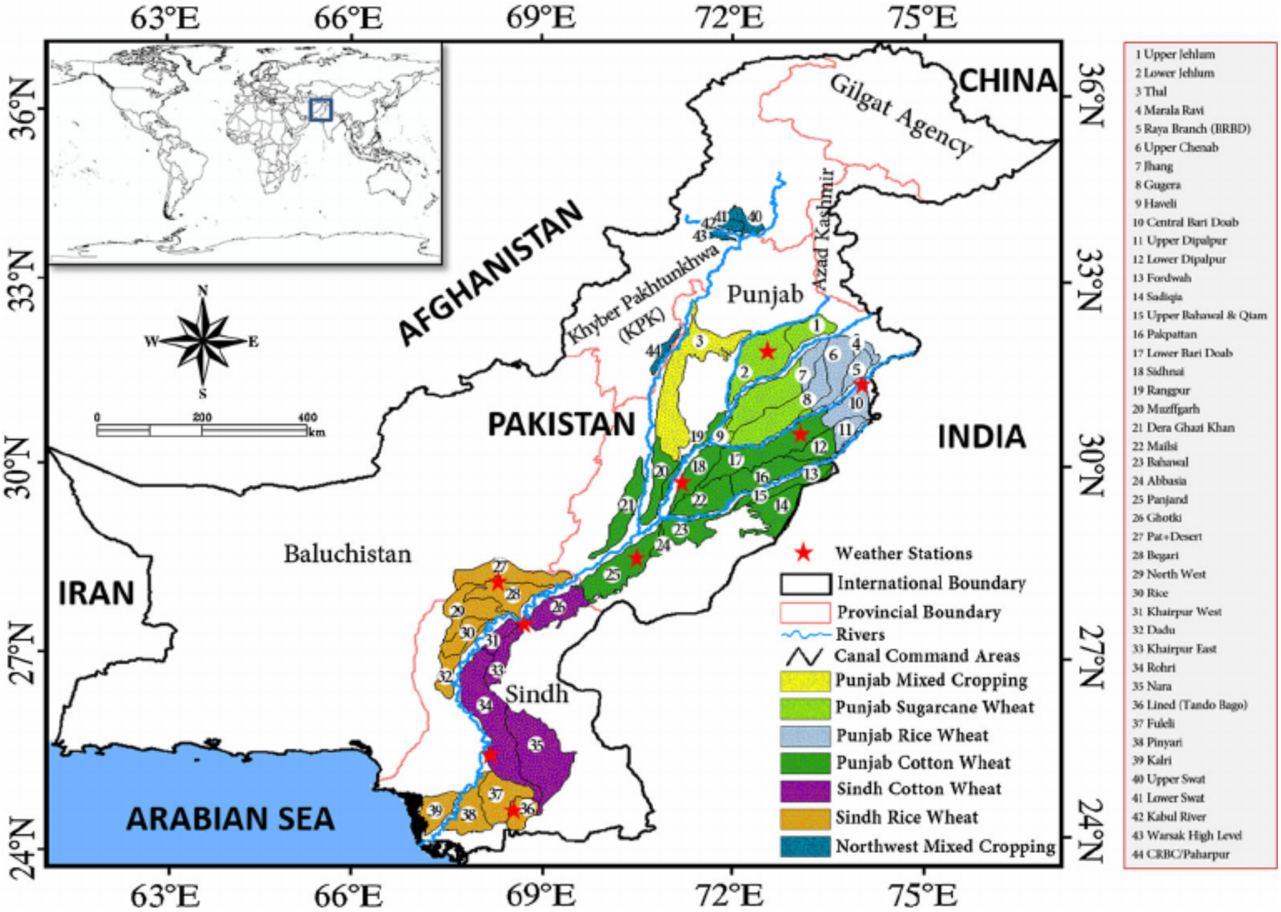

Figure 1: Map of Indus Basin Pakistan

The Australian Centre for International Agricultural Research (ACIAR), Charles Sturt University (CSU) Australia and The Pakistan Council of Research in Water Resources (PCRWR) and partners initiated a short research and development activity (SRA) in March 2017 focused on improving salinity and agricultural water management (SAWM) in the Indus Basin. The Final Report for this SRA has since been published as Mitchell et al. (2018). The SRA required establishing the case for a more holistic approach to salinity and water management, and a network of researchers and intended research beneficiaries able to co-design an integrated salinity research project using ACIAR funding. The SRA objectives were to: (i) develop a holistic understanding of the underlying causes of salinity, and the difficulties that result for farming and coastal communities affected, through review of existing technical, economic and social assessments of salinity; (ii) develop a case for incorporating the broad concept of ecosystem services into an integrated salinity management framework (ISMF) for Pakistan, by exploring its potential to: (a) enhance appreciation of salinity as a systemic issue, (b) help identify opportunities for amelioration of those impacts and/or improve livelihoods of those living with salinity; and (iii) establish a network of researchers and intended research beneficiaries with whom the case for a more holistic approach to salinity management could be discussed, and who could then take a leading role in designing an ACIAR funded research project through which an ISMF for Pakistan could be developed and applied.

This report has been prepared as an output of the SRA and is based on a desk-top literature review of technical, economic and social aspects of the SAWM in the Indus Basin. The review covered the Government's policy documents, published articles and unpublished reports as available to help better understand the water and salinity management issue in the Indus Basin. The rest of the report is divided into three main sections. Section 2 presents the historical perspective of the issue and causes of waterlogging and salinity in the Indus Basin. Section 3 discusses the salinity and water management approach and practices, reviewing technical, institutional and policy options, and analysing outcomes and impacts of the mega projects. It converges on scale, participation and sustainability issues. Section 4 sets out future directions for developing the Indus Basin's SAWM plan, based on sound research and sustainable development principles.

2. The Salinity Issue, Causes and Historical Perspective

2.1. The Salinity Issue

Globally, it is estimated that salinity affects about 20% of irrigated land, reducing the cultivable area and undermining agricultural production and world food supply (Shahzad et al., 2017). In Pakistan, salinity affects 6.2 Mha which is ~40% of the 16 Mha irrigated land and ~29% of the 22 Mha of the total cultivable area of the country. Of the 6.2 Mha, 4.3 Mha are severely affected (70%) and 3.4 Mha are not cultivated (Government of Pakistan, 1997). In 2010, the water-table was reported to be within 1.5 m of the ground surface over 5.25 Mha, and within 3 m of the ground surface over 9.37 Mha. Depth to water-table is strongly affected by seasonal conditions; it has been estimated that there is about 2.0 Mha of land with a water-table within 1.5 metres (5 feet) of the soil surface in June, but 5.2 Mha in October. Shallow and saline groundwater induces secondary salinisation, causing the abandonment of ~40,000 ha of land annually in the Indus Basin (WAPDA, 1989). In 2010, the annual loss of cultivated land was reported to be between 20,000 and 40,000 ha (Anjum et al., 2010).

Salinity is an agricultural, environmental, social and economic development problem as 75% of the population and about half of the gross national product (GNP) is directly or indirectly linked with agriculture (NESPAK and MMI, 1993). Salinity affects agricultural production by reducing crop yields and the area available for cultivation. Shallow groundwater also causes land degradation by restricting plant growth and adding salts to surface soils through capillarity. Waterlogging and salinity have adverse social and economic impacts on communities, causing poor living standards and health problems for people and animals. Decreased livelihood opportunities and degrading infrastructure have forced people to migrate from affected areas, and cause administrative and political problems. Pakistan has suffered high costs from land degradation, estimated at $5.4 billion for water erosion, $1.8 billion for wind erosion; $0.6-1.2 billion for soil fertility decline; $0.5 billion for waterlogging and $1.5 billion for salinity (Anjum et al., 2010).[1] Land degradation has reduced the production potential of major crops by 25% with an estimated loss of $250 million per year (Qureshi, 2011).

[1] '$' sign in this report signifies US Dollar unless otherwise specified.

2.2. Main Causes of Salinity

The Mechanisms that Cause Salinity

There are two main causes of soil salinity: naturally saline or sodic soils and water induced salinity. Most soil salinity is natural. The Indus River and its tributaries transported salts from the upper catchment to the plains during the process of soil formation. The reserves of salt in the soil are generally deep and mostly come to the surface through the pumping of saline groundwater. The water induced salts take two forms. First, there is an average annual salt inflow of 33 million tonnes to the Indus Basin. Of this, around 16.4 million tonnes is washed to the sea, but the remainder (16.6 million tonnes) remains within the canal command area. Only 2.2 million tonnes is deposited in a series of evaporation ponds. The balance (about 14.4 million tonnes) therefore accumulates in the profiles of irrigated soils, in underlying strata and in the aquifer (NESPAK and MMI, 1993). This implies that on an average about one tonne of salt is added to one hectare of irrigated land annually. An indicative salt balance of the Indus Basin is given in Figure 2.

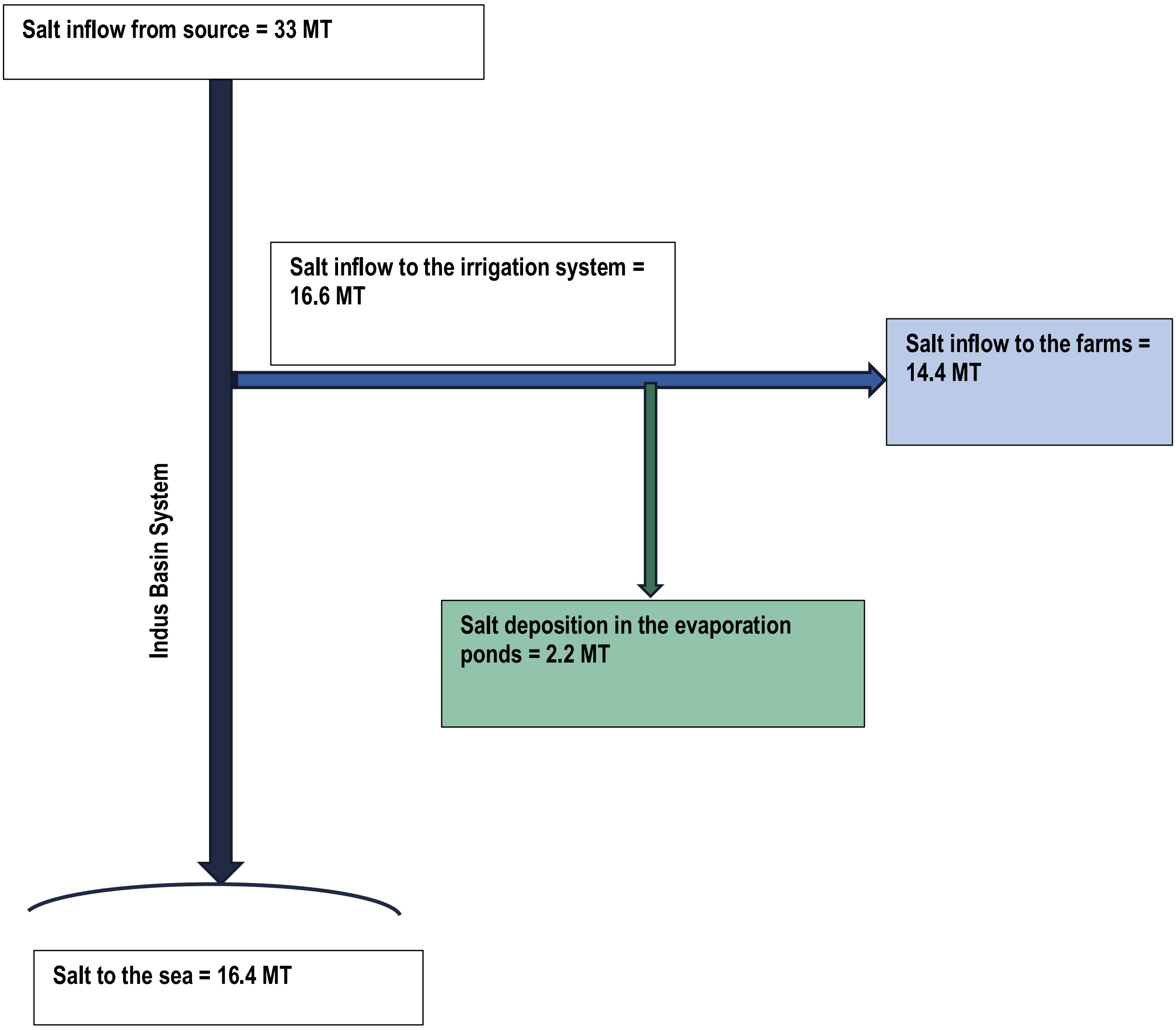

Figure 2: Indicative Salt Balance in the Indus Basin

A second water-induced cause of salinisation is the pumping and use of marginal quality groundwater for irrigation which adds salt to the surface and shallow soil layers. In the Indus Plain, the upper 100 metres of the groundwater reservoir contains an estimated 7,500 million tonnes of salts (ICID, 1991). Use of marginal quality groundwater adds 100 million tonnes of salts to the soil surface every year (ICID, 1991).

In the Indus Basin, salts are transported by water over a large catchment area. More erosion and salts are expected if the catchment area is degraded. In irrigated areas, farmers use more irrigation water to leach the soil, which actually brings more salts into the landscape. A vicious degradation cycle for livelihood opportunities accelerates salt transport in the Indus Basin. The available empirical evidence shows that the decline in productivity because of salinisation ranges from 25 to 70% on moderately salt affected soils (ECe values of 4–8 dS/m) and it approaches 100% in areas where the problem of salinisation is severe (8–16 dS/m) (using definitions developed by FAO based on EC of saturated soils – see Ashraf et al., 2022). Complex links between natural and social processes, weak institutions and farmers lacking practical options constrained salinity and water management.

Water Mismanagement is Linked with the Salinity

While Pakistan's agricultural economy has benefited from the Indus Basin Irrigation System (IBIS) (see Figure 3), the country's large network of irrigation canals (about 57,000 km of primary, secondary and tertiary canals, 88,600 outlets and 1.6 million km of water courses) has also become one of the causes of water-induced salinity (Bhatti and Kijne, 1992). Irrigation without drainage has caused groundwater rise, resulting in waterlogging. Once water-tables reach depths of 2–3 m from the soil surface, capillary rise can bring salts to the plant root-zone and soil surface, constraining plant growth.

Groundwater pumping for irrigation has two effects. In zones with shallow fresh groundwater, it can help to lower the water-table, reducing waterlogging and salinity, and the supplements to irrigation can increase and intensify crop production. However, the pumping of deep groundwater has an economic cost; as well there is the danger of extracting underlying poorer quality groundwater into the mix due to the effect of groundwater 'up-coning'. Pumping marginal quality groundwater for lowering the water-table and reducing waterlogging and salinity may be desirable. But irrigation with the marginal quality groundwater can lead to accumulation of salts in the soil profile and plant root zone, causing secondary salinisation and land degradation and reducing agricultural production.[2] Khan et al. (2004) comparing three irrigated environments in Australia, China and Pakistan concluded that in the Rachna Doab in Pakistan, where groundwater meets about 50% of the irrigation requirement, continued and unchecked pumping may result in soil salinity, if adequate leaching of the root zone is not exercised.

In the Province of Punjab, where groundwater use in agriculture is highest, ~25% of the tubewell water has marginal quality and ~50% is not safe for irrigation. In Sindh, the groundwater quality is rather worse but groundwater uses in irrigation are lower than in Punjab (Ahmad et al., 1998). Qureshi et. Al. (2011) estimated the spatial and temporal variations of hydro-salinity behaviour in a shallow groundwater aquifer underlain by saline groundwater using a skimming well in the command area of Kunnar-II distributary in Sindh. They modelled a pumping test using MT3D model (MODFLOW for Windows) and showed that groundwater quality deteriorates at a faster rate with pumping times of more than 12 hours per day and with increasing depth.

During the extreme drought conditions that occurred from 1996 to 2001, the availability of surface water in Punjab was reduced by 46%. This led to a 59% increase in the number of private tubewells over the same period (Qureshi et al., 2003). An estimated 800,000 small capacity private tubewells were functional in Pakistan at that time. The total groundwater abstraction from these tubewells was estimated at 45 km3 compared with a recharge of 40–60 km3 (Shah et al., 2003).[3] Of this, about 33 km3 was extracted through private small capacity tubewells, which were mostly located in fresh groundwater areas. The remaining 12 km3 was extracted by large capacity public tubewells mainly to provide domestic water supplies to urban areas. In this study, inadequate leaching and consequent accumulation of salts in the plant root zone was attributed to the high evapotranspiration and low rainfall. Lacking an effective drainage system caused waterlogging and salinity. Irrigation without drainage, over irrigation, and use of poor quality groundwater are the main causes of this problem.

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[2] A cautious conjunctive use of groundwater and canal water may help meet irrigation water shortages and maintain agricultural production.

[3] The broad recharge range shows effect of drought and flood years

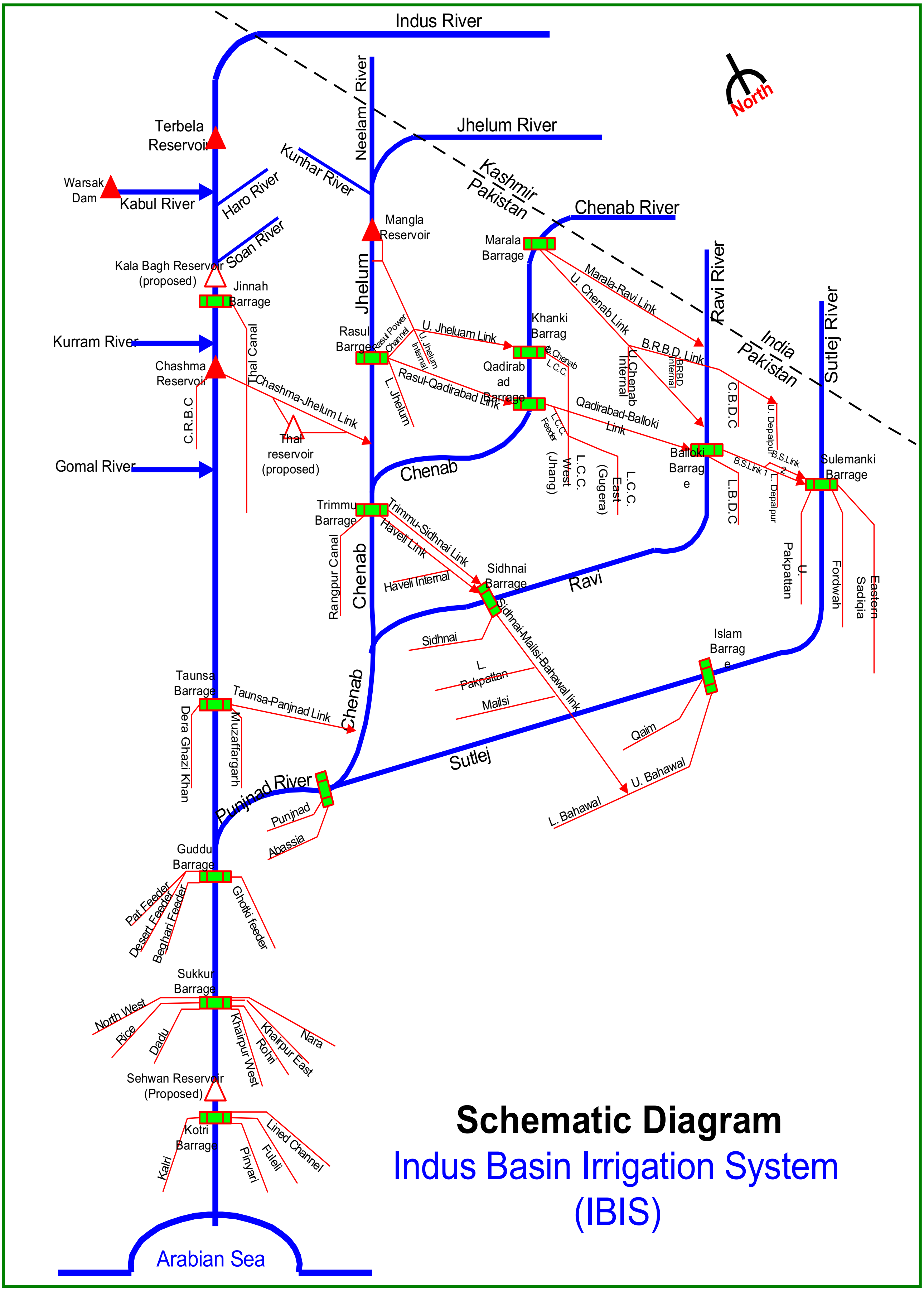

Figure 3: Schematic Diagram of the Indus Basin Irrigation System

Due to an overall shortage of good-quality water, the use of poor-quality groundwater as a supplemental source of irrigation has become routine practice. The large-scale exploitation of poor quality groundwater is a substantial source of salt inflow adding to salinity. Figure 4 shows an indicative representation of groundwater quality in the Indus Basin, which ranges between fresh and hazardous in the major irrigated areas of the Sind Province (Qureshi et al., 2004). Groundwater pumping brings 28.2 million tonnes of salt to the soil surface, annually. This includes 24.7 million tonnes in Punjab and 3.5 million tonnes in Sindh. Low groundwater pumping in Sindh is responsible for low salt accumulation.

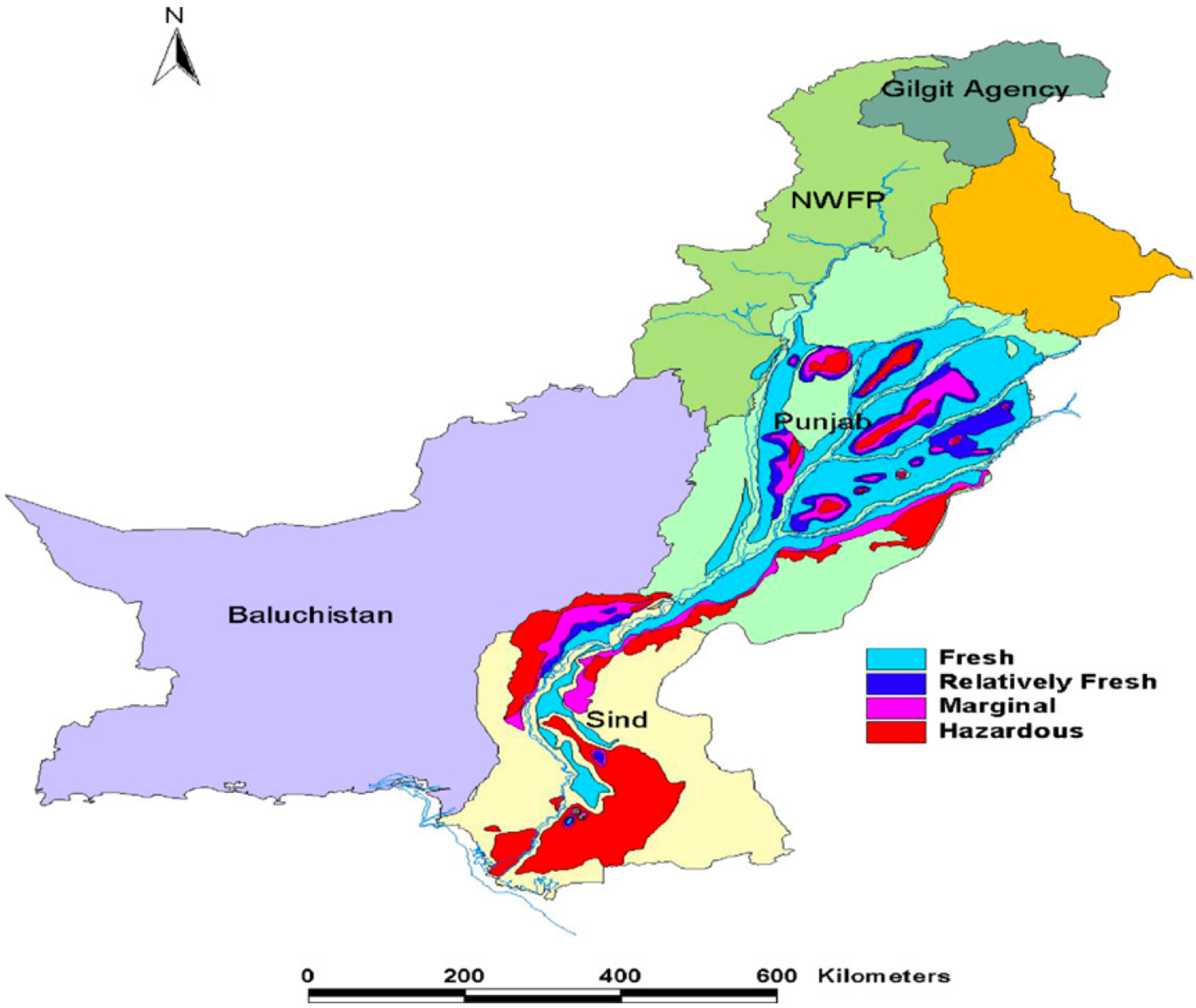

Figure 4: Spatial Variation of Groundwater Quality in the Indus Basin of Pakistan

Reproduced from Qureshi, et al. (2004) with permission from CSIRO Publishing.

Definitions: relatively fresh = EC_w < 1.5 dS/m, marginal = EC_w 1.5-4.0 dS/m, hazardous = EC_w >4.0 dS/m

Climate Change Impact will Further Aggravate the Situation

The impact of climate change in coastal areas will cause a rise in sea level, increasing the risk of coastal flooding, and the inundation of wetlands and other ecosystems. The consequent salinisation of land will negatively impact on the livelihoods of people depending on the location of that land. Sea level rise will also cause saltwater to ingress farther inland during storm peaks. In the plains of Punjab and Sindh, elevated evapotranspiration demand due to temperature rise, will cause crops to need additional irrigation, increasing water requirements, and as a result, accumulating more salts in the soil.

2.3. Selected Highlights from a Walk through History

In the text below, selected key reports show that, despite major investments into salinity abatement, the areal extent of salinity has not substantially changed for over 60 years.

In 1953 and 1954, the land survey of the Indus Basin under the Colombo Plan showed that almost 30% of the 8.0 Mha in the northern zone was either waterlogged or severely saline and of limited use for agriculture production (Government of Canada and Government of Pakistan, 1958). In the southern zone, 53% of the 5.0 Mha were waterlogged or poorly drained and 25% was predominantly severely saline.

In 1962, the Roger's report to the President of Pakistan indicated an average rise of the water-table of about two feet (~0.6 m) a year. This rise in water-table was linked to the 45 to 54% loss of irrigation water during its conveyance to the field. It was reported that of an average annual water diversion of 92.5 cubic kilometres (km3) to canals, only 42 to 50 km3 was available for crops (Mohammad and Bering, 1963).

In 2003, according to the Soil Survey of Pakistan, the total waterlogged summer-rain area in the country was 4.11 Mha and the waterlogged area doubled during the post-monsoon season. In Pakistan, approximately 5.7 Mha of irrigated land are affected by salinisation. Out of this, 44.1% is saline, 55.4% is saline-sodic and 0.5% sodic. Maximum salt- affected areas are in the Punjab (2.6 Mha), followed by Sindh (2.3 Mha) (Zia et al., 2004).

In 2006, 43% of the 16.7 Mha were waterlogged including 4.01 Mha of severely waterlogged land with a water-table between 0 and 1.5 m, and 3.1 Mha of moderately waterlogged land with a water-table between 1.5 and 3.0 m (Zaman and Ahmad, 2009, citing data from a report by WAPDA in 2006).

Zaman and Ahmad (2009) presented temporal variation of waterlogged area in Pakistan (Figure 5). The data suggest that the area of waterlogged land peaked at ~14-15 Mha between 1993 and 1998, but with increased groundwater abstraction, the area of waterlogged land had decreased to ~6 Mha by 2010.

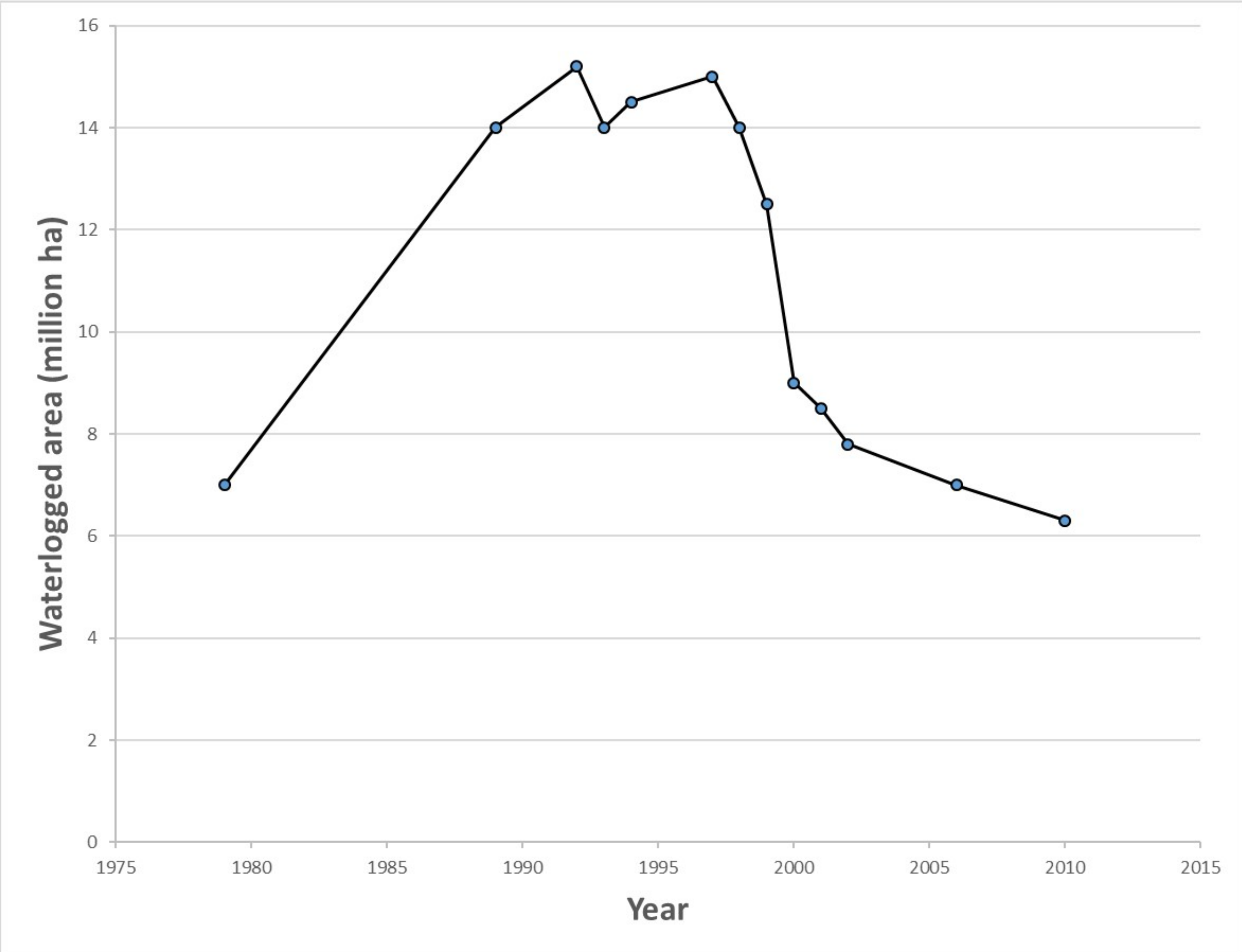

Figure 5: Variation of Waterlogged Area with Time
(Modified from Zaman and Ahmad, 2009)

Anjum et al. (2010) reported around 6.3 Mha of salt affected land in 2010 in Pakistan. Government of Pakistan (1997) statistics showed salt affected area as 6.2 Mha. The areas of different categories of saline land across provinces are given in Table 1.

Table 1: Salinity Affected Soils in Pakistan

(Adapted from Government of Pakistan 1997)
Areas are in thousands of hectares. Definitions: Slightly saline = ECe 2-4 dS/m, Moderately saline = ECe 4-8 dS/m, Severely saline = ECe 8-16 dS/m (www.fao.org/3/x5871e/x5871eo4.htm)

Description	Total Area	Cultivated Area	Uncultivated Area
		Pakistan	
Slightly affected	598.7	598.7	0.0
Moderately affected	1,229.8	1,229.8	0.0
Severely affected	4,345.0	976.0	3,369.7
		Punjab	
Slightly affected	472.4	472.4	0.0
Moderately affected	804.8	804.8	0.0
Severely affected	1,390.3	235.5	1,155.5
Total	2,667.5	1,512.0	1,155.5
Percent of country	43%	54%	34%
		Sindh	
Slightly affected	118.1	118.1	0.0
Moderately affected	324.7	324.7	0.0
Severely affected	1,666.8	708.2	958.6
Total	2 109.6	1,151.0	958.6
Percent of country	**34%**	**41%**	**28%**
		Balochistan	
Slightly affected	3.0	3.0	0.0
Moderately affected	74.6	74.6	0.0
Severely affected	1,270.3	31.4	1,238.9
Total	1,347.9	109.0	1,238.9
Percent of country	22%	4%	37%
		KPK and FATA	
Slightly affected	5.2	5.2	0.0
Moderately affected	25.7	25.7	0.0
Severely affected	17.6	0.9	16.7
Total	48.5	31.8	16.7
Percent of country	1%	1%	0%

In 2017, Pakistan's national policy dialogue on salt-affected soils indicated that over 7 Mha were affected by soil salinity and sodicity in the country. Also, secondary salinisation was accelerating on about 2.0 Mha due to the use of poor quality groundwater, the quantum for which warrants reassessment (Government of Pakistan, 2017). This dialogue was attended by the FAO, USDA, National Fertiliser Development Centre (NFDC), International Peace Institute (IPI), PARC, NARC, ILRI, CIMMYT and ICARDA, with ICBA attending through video links.

Bhutta and Smedema (2007) indicated that reducing waterlogging and salinity in last decade of the 20th century was mainly attributed to the use of fresh groundwater in irrigation. However, decreased availability of fresh groundwater in the future would be expected to bring the problem back, raising questions on the sustainability of waterlogging and salinity management in the Indus Basin.[4]

3. Salinity and Water Management

3.1. The Approach

The literature suggests that in Pakistan, the water and salinity problem was approached through a range of technical, institutional and policy instruments. In the 1950s, the Government showed the highest level of commitment. A country-wide land survey was carried out in 1953-54 under the Colombo Plan. The Water and Power Development Authority (WAPDA) was established through an act of the Parliament in 1958 to develop water and energy resources in the country. Waterlogging and salinity was assessed in 1962 by international experts and an assessment report was presented to the President of Pakistan (Mohammad and Beringer, 1963, citing the Roger report to the President of Pakistan). The Government arranged the required investment and implemented several mega projects including the construction of five barrages and eight inter-river Link Canals (1965-1970), two major reservoirs (Mangla in 1967 and Tarbela in 1976), six salinity control and reclamation projects (SCARPs) and initiated the Left- and Right-Bank Outfall Drain projects.[5] The International Waterlogging and Salinity Research Institute (IWASRI) was created in 1986 under WAPDA mainly to conduct research and gather scientific information on waterlogging and salinity, surface water and groundwater, and the environment. The Government enacted several laws including the WAPDA Act (1958), the Provincial Irrigation and Drainage Authorities Act (1997) and the Pakistan Environment Protection Act (1997). Until the late 1990s, the approach worked well and showed good results including a major relief to waterlogging and salinity through the action of SCARPs. After the failure of the National Drainage Program (NDP) in 2002, the priority of salinity and water management (SAWM) was demoted, and the issue was almost shelved. Except for some fragmented research, no further well-planned work was conducted. An approach blending the lessons learned, innovations and integrating the fragmented work could help better address the problem. A spiral representation of the past development and future direction is in Figure 6.

3.2. National Water Strategy since the 2000s – Drafting a National Water Policy

Pakistan needs a cohesive and approved water policy. The national policy environment in the Salinity and Water Management space has been both dysfunctional and unimplementable. In 2002, the Pakistan Ministry of Water and Power drafted a National Water Policy (NWP). Drainage, waterlogging and salinity were a part of this NWP. As main thrust areas the revised NWP in 2012 recognised the importance of salt build up in irrigated agriculture, the increased intrusion of saline water into the Indus Delta, groundwater management planning and regulatory zones, secondary salinisation, waterlogging, and relevant adaptive research. However, the NWP had remained in draft form since 2002; it was not approved and implemented. Further, to become effective it needs to harmonise with provincial water policies, which are, so far, not available. Therefore, the policy intention could not be effectively translated into action.

The Pakistan Water Sector Strategy (2002) identified as main issues increasing water demand, deteriorating water quality, deteriorating irrigation and drainage infrastructure, waterlogging and salinity on irrigated land and disposal of saline drainage effluent. It emphasised as its main objectives integrated water resource

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[4] Cross-sectoral competition and water reallocation for other uses (households, industry, environment) may reduce freshwater availability for irrigation.

[5] The two reservoirs, barrages and inter-river Link Canals were constructed under Indus Basin replacement work.

management (IWRM), promoting water conservation, regulating groundwater, improving water quality, reducing waterlogging on 2.8 Mha, and providing long-term and safe solution for the drainage of saline effluent (Government of Pakistan, 2002).

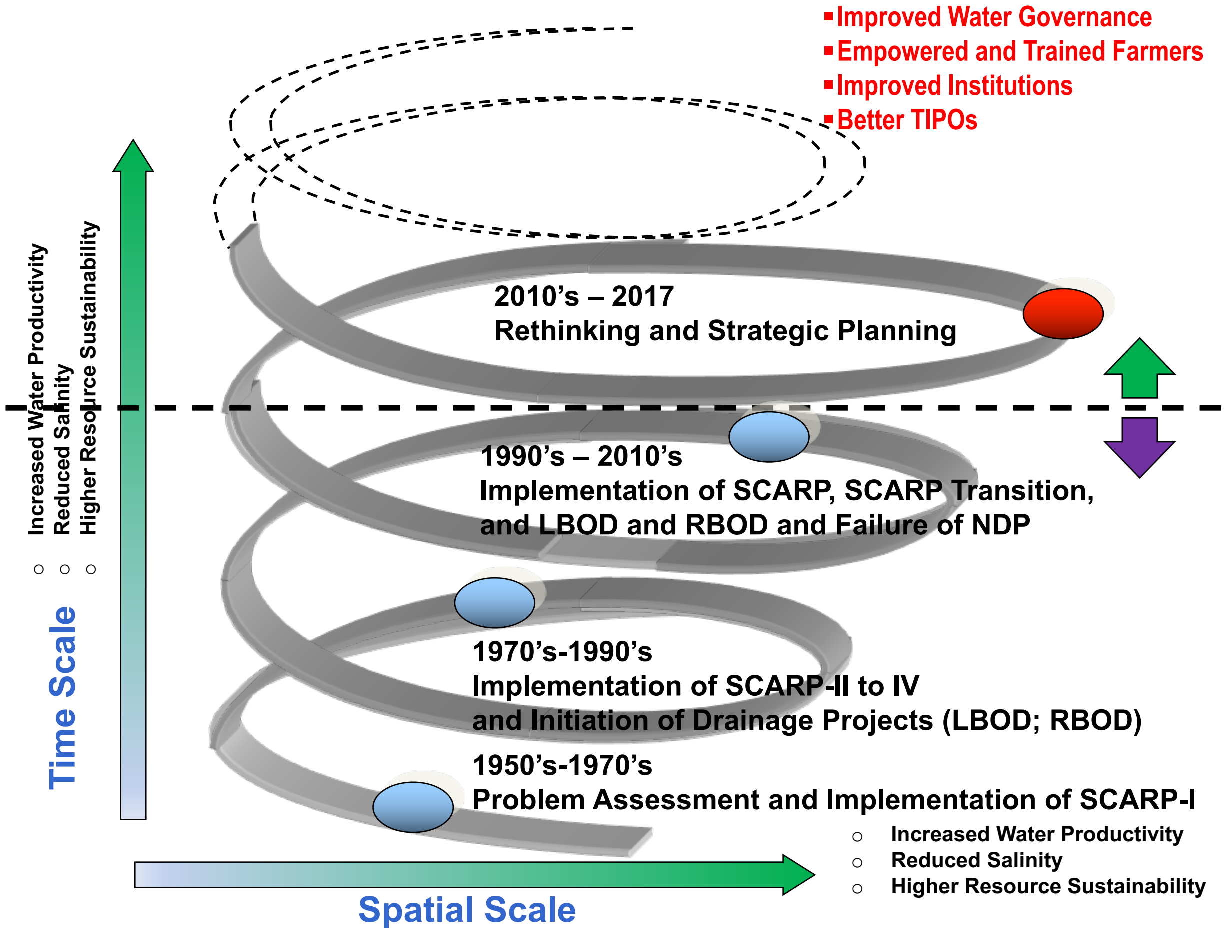

Figure 6: Spiral Representation of Salinity and Agricultural Water Management in the Indus Basin

The dotted timescale dividing line shows that from 1970 to 2010, the main focus has been on structural measures and many mega projects were launched. The era from 2010 onwards involved more strategic thinking when a management-dominated approach was largely followed, or there was a gradual shift from a sole focus on infrastructure development towards more of a management-based approach.

The strategy developed short- (2003-2004), medium- (2005-2011) and long-term (2012-2025) actions for investment of an estimated US$33.6 billion for the water sector including US$11 billion exclusively for irrigation and drainage.[6] The main drainage-related short-term actions were identified as: (i) assessment of the benefits for lining of canals in saline areas, (ii) restructuring the National Drainage Program (NDP), (iii) completion of a feasibility study for a spinal drain, and (iv) groundwater regulation. The medium-term actions included: (a) the lining of water distributaries in the saline groundwater area; (b) completion of a revised NDP I; and (c) preparation of the NDP II, III and completion of the NDP II including the spinal drain. The long-term plan included continuing the lining of distributaries in the saline groundwater area and carrying out the NDP III including the spinal drain. The strategy identified sectoral constraints to irrigation and drainage as: (1) poor project implementation, (2) water scarcity, (3) lack of consensus and cooperation, (4) overuse of water, (5) the inequitable distribution of water, (6) low cost recovery and poor maintenance, (7) institutional weakness, and (8) lack of participation by stakeholders.

Reviewing the implementation of short-, medium- and long-term strategy actions reveals that implementation of the drainage component was weak. The NDP's restructuring and groundwater regulation as part of the

[6] The total for water sector including water resource, urban and rural water supply, industrial and irrigation and drainage was US$33.6 billion.

short-term actions was not completed. So far, progress on these two aspects remains sketchy. The progress on implementation of mid-term actions was even worse. With this progress, implementation of the long-term plan by 2025 appears to be challenging. The identified sectoral constraints are of a serious nature. In particular, poor project implementation, lack of consensus and cooperation, institutional weakness and the non-participation by stakeholders can ruin a good plan anytime. Unfortunately, serious work to remove the sectoral constraints has not been attempted. In the absence of a strategy, groundwater and drainage are neglected areas.

3.3. Legislation

The Government enacted several related laws including the WAPDA Act 1958, the Provincial Irrigation and Drainage Authorities Act 1997 (PIDA/SIDA Act 1997; amendments to Canal and Drainage Act 2006 and 2016; Sindh Water Management Ordinance 2002) and the Pakistan Environment Protection Act 1997. The laws were enacted on an *ad-hoc* needs basis, and their effects were largely fragmented and piecemeal (Box 1). For example, regulatory laws regarding river channels, land use and groundwater are non-existent or weak. The first legislation on groundwater was enacted as the Punjab Soil Reclamation Act of 1952 (Scheumann and Memon, 2003).

Box 1 Major Water-and Salinity Related Legislation in Pakistan

- Water and Power Development Authority Act, 1958
- Water Apportionment Accord 1991
- Indus River System Authority Act, 1992
- Environmental Protection Act, 1997
- Provincial Water Accord, 1991
- Territorial Waters and Maritime Zones Act, 1976
- West Pakistan Land and Water Development Board (Control over Underground Waters) Rules, 1965
- West Pakistan Amendment Ordinance V of 1964
- West Pakistan Amendment Act1956, 1968, and Ordinances of 1970
- Soil Reclamation (Punjab Amendment) Ordinance VI of 1970
- Punjab Minor Canals Act, 1905
- Punjab Canal and Drainage Act, 1873
- Punjab Soil Reclamation (Amendment) Act. IX of 1977
- Punjab Water User Punjab Soil Reclamation Act, 1952
- Punjab Amendment Act 1952. Extension Act 1964
- Punjab Amendment Ordinance 1971 and Amendment Act 1975
- Punjab Water Users Association Ordinance, 1981
- Punjab Irrigation and Drainage Authority Act, 1997
- NWFP Canal and Drainage Act, 1873
- NWFP Amendment Act, 1948
- NWFP Irrigation and Drainage Authority Act, 1997
- NWFP Water User's Association Ordinance, 1981
- Balochistan Ordinance 1980
- Balochistan Groundwater Rights Administration Ordinance, 1978
- Balochistan Water Supply Regulation 1941
- Balochistan Pat Feeder Canal Regulation ,1972
- Balochistan Canal and Drainage Ordinance, 1980
- Balochistan Coastal Development Authority Act, 1998
- Balochistan Irrigation and Drainage Authority Act,
- Balochistan Groundwater Rights Administration Ordinance, 1978
- Balochistan Water User's Association Ordinance, 1981
- Sindh Water Management Ordinance, 2002
- Sindh Irrigation Act, 1879
- Sindh Water Users Association Ordinance, 1981
- Sindh Water Users Association Ordinance, 1982
- Sindh Irrigation and Drainage Authority Act, 1997

The act created the Soil Reclamation Board, later suspended (1964–65); its executive powers for operation and maintenance of the public SCARPs were transferred to the Superintending Engineer (SE) SCARP, established within each provincial irrigation department. However, the SE SCARPs did not become responsible for groundwater development. WAPDA's establishment act stipulated that it would be in charge of the development of groundwater resources and would issue official area-specific rules, which have never been formulated. More confusion was added by the Local Government Ordinance of 1979, which proposed that all groundwater falling within the local area of a union council should come under the control of that local government body. All acts are still in place, which leaves three authorities in charge of groundwater development, WAPDA (a federal agency), the provincial irrigation departments, and local governments. In fact, all stakeholders have free access to extract groundwater without any limitations. Neither rights to groundwater nor obligations regarding its use have ever been specified.

3.4. Relevant Institutions

The Council of Common Interest (CCI) was created in 1973. It comprises the Prime Minister of Pakistan (chairperson), the Chief Ministers of the provinces, and three members from the national government who are nominated by the Prime Minister. The CCI ensures the equitable distribution of water between the provinces, formulates and regulates policies, and reports to the Parliament.

The Water and Power Development Authority (WAPDA) was established through an act of the Parliament in 1958. Before the eighth amendment to the Country's Law and the devolution of powers to the provinces in 2010, WAPDA was responsible for the development of water and energy resources, the management and operation of major water infrastructure, and was required to address the issues of waterlogging and salinity, drainage and groundwater. With the formation of WAPDA, the Groundwater Development Organisation of Punjab was transferred to WAPDA's Water and Soil Investment Division. The first legislation on groundwater was enacted when vertical drainage projects started. The Punjab Soil Reclamation Act of 1952 created the basis for the Soil Reclamation Board, later suspended (1964–65); its executive powers for the operation and maintenance of the public SCARPs were transferred to the SE SCARP, established within each provincial irrigation department. However, the SE SCARPs did not become responsible for groundwater development. The International Waterlogging and Salinity Research Institute (IWASRI), the MONA Experimental Research Station, the SCARP Monitoring Organisation, the Reclamation Research Institute – Lower Indus Management, and so on are WAPDA's subsidiary organisations or units established for specific research, monitoring, and evaluation functions (Scheumann and Memon, 2003).

The eighth amendment delegated the responsibility for the water and agriculture sectors to the provinces. WAPDA was then envisaged as being the national water institution mainly for the planning and implementation of only inter-state and transboundary projects. WAPDA continued to be project-based and, so far, its transformation into a basin-scale national institution has not materialised. Further, WAPDA's engineering-based fabric and culture has not been helpful in enhancing its capacity to deal with diversified cross-sectoral issues. This transformation will require additional resources, time and political will. Nevertheless, WAPDA is capable of implementing mega engineering projects.

The Pakistan Council of Research in Water Resources (PCRWR) functions at the whole of country level to address water related issues. PCRWR has undertaken initiatives to deal with the national water and land related issues. The council is effectively using its position for the coordination and cooperation between national and international institutions. PCRWR's regional office in Sindh, the 'Drainage and Reclamation Institute of Pakistan' (DRIP), conducts research on drainage, salinity control and land reclamation, irrigation and drainage, and seawater intrusion. In addition, there are also knowledge centres which work on water and salinity aspects including centres of excellence in Lahore and Jamshoro, and at engineering universities.

A range of provincial departments are involved in water and land related activities. These include the Departments of Irrigation, Agriculture, Public health, and Environment and Energy. One or the other way, these departments all have some responsibility for water management within their mandate, with the irrigation and agricultural departments being most frequently involved. In general, salinity management and on-farm water management are the responsibility of the provincial Agriculture Departments. However, irrigation water delivery and off-farm drainage are the responsibility of Irrigation Departments. The four Irrigation Departments have acquired about 100,000 staff (Punjab over 50,000 and Sindh around 32,000) but maintenance and operational management (MOM) remains inefficient and ineffective (Scheumann and Memon, 2003). The Directorate of Land Reclamation in provincial irrigation departments is responsible for land reclamation. Unfortunately, the stewardship of groundwater and water quality is missing. Water quality standards differ between institutes. For example, the SCARP monitoring organisation uses different water quality standards to the Directorate of Land Reclamation. Other provincial institutions such as academic institutions and non-governmental organisations have also become involved whenever opportunities exist and the situation requires their involvement.

The Soil Salinity Research Institute (SSRI) under the Punjab's Agricultural Department was established in 1982 to conduct dedicated research on: (i) the economic utilisation of salt affected soils, (ii) the causes of salinity and sodicity, (iii) the development of reclamation technology for salt affected soils, (iv) the development of measures/practices to avoid the salinisation of soils, (v) the standardisation, screening and evolution of salt tolerant crops, vegetables and horticultural plants, (vi) the development of crop production technologies for salt-affected soils, (vii) the identification and collection of natural vegetation capable of withstanding high salt concentrations, (viii) the promotion of aquaculture and farm forestry in areas less favourable for crop cultivation, (ix) the development of cheap drainage system, and mechanical devices for better tillage, and (x) advisory services to the farmers facing soil salinity problems. The SSRI tested rice and wheat varieties in saline soils, conducted research on the safe use of brackish water, the reclamation of salt-affected soils and provided farmers' advisory services (Hussain and Mehdi, 2008). So far success has been moderate and uptake of the research results by farmers has not been significant. This shows that unfortunately, provincial research and knowledge management has not shown impact.

Most of the created institutions were needs-based, created to address specific problems at the time of their creation (Table 2). Some of the long-time task-specific organisations such as WAPDA and provincial irrigation and agricultural departments were constrained by a resistance to evolve. Largely, these institutions worked uni-directionally.

Table 2: Evolution of Water, Drainage and Salinity Related Institutions in Pakistan's Indus Basin

WAPDA = Water and Power Development Authority; O&M = operation and maintenance; FAO = Food and Agriculture Organisation; PCRWR = PID = provincial irrigation department; SCARP = Salinity Control and Reclamation project; SE SCARP = superintending engineer SCARP.
Source: the major part of this table has been adapted from Scheumann and Memon (2003).

Year	Organisation Evolved	Purpose/Result
1917/18	Drainage Board created for Upper Chenab Canal	Investigations for controlling canal seepage.
1920	Drainage Division created in Upper Bari Doab Canal with a drainage engineer	
1925	Waterlogging Inquiry Committee (WIC) created with a superintending engineer	Advisor to government. Waterlogging investigations (1927).
1928	WIC replaced by Waterlogging Board	
1930/31	Irrigation Research Institute established in provincial irrigation department	Research on seepage drains in Upper and Lower Chenab Canal.
1932	Drainage circle created with superintending engineer Reorganisation of drainage circle, i.e. two divisions (jurisdiction over Chaj and Rachna)	Organised around natural drainage basins to better tackle construction of seepage and seepage - cum - storm drains. Investigations in deep water-table areas (1937).
1939	United with Upper Jhelum Canal Circle and Lower Chenab Canal Circle	
1940	Land Reclamation Board created	Recommended non-structural measures Salinity and alkalinity survey in Punjab (1943)
1944	Northern Drainage Circle created with jurisdiction over Chaj and Rachna	Independent circles better suited to construct and maintain drains.
1945	1945 Directorate of Land Reclamation created to reclaim saline and sodic soils.	
1947	Drainage circles closed; Drainage divisions attached to irrigation circles	Drainage divisions better suited because already in charge with maintenance of canals.

Year	Organisation Evolved	Purpose/Result
1947	Pakistan Meteorological Department (PMD), Ministry of Defence	Weather data and forecasts
1951	Two drainage circles created, separate from irrigation circles	
1952	Soil Reclamation Board created for groundwater management	Established after FAO investigations.
1954	Groundwater Development Organisation created drainage circles abolished	Later transformed into WAPDA with a Water and Soil Investigation Division to economise expenditures.
1958	Drainage circles re-established Director of drainage appointed in the office of the chief engineer, irrigation (West Pakistan)	To improve land reclamation and drainage.
1959	WAPDA established	For investigation, planning and implementation of control means. Master Plan, Regional Plan (1967). Action Program for Irrigation and Drainage (1965 – 75). Accelerated Program 'Waterlogging and Salinity Control' (1974/75 to 1984/85), revised in 1985 f or a 21 - year period.
1960	Pakistan Commissioner for Indus Waters (PCIW)	The Indus Waters Treaty (1960), following the provisions of Article VII(1), created the Permanent Indus Commission. Two commissioners, one appointed by Pakistan and the other by India, comprise the full membership of the commission.
1964/ 65	Soil Reclamation Board suspended	Responsibilities/power transferred to PID, SE SCARPs except groundwater management.
1977	Federal Flood Commission	Approval of flood control schemes; forecasting; evaluation/monitoring of National Flood Protection
1977 Plan.	Drainage Circles in Lahore, Faisalabad, Sargodha; Drainage Divisions in other zones	Functional units (O&M of drains).
1982	Soil Salinity Research Institute (SSRI) in Punjab Agriculture Department	To conduct research on causes and remedial measures, testing salt tolerant plants and developing improved technologies and methodologies for salt-affected soils.
1995	WAPDA takes over O&M responsibility for interprovincial drains	Cost - sharing between federal state and provinces.
1986	International Waterlogging and Salinity Research Institute (IWASRI) in WAPDA	Research and planning on waterlogging and salinity
1964/ 2007	Pakistan Council of Research in Water Resources (PCRWR) in Ministry of Science and Technology. Established in 1964 and corporate in 2007	Conduct, organise, coordinate and promote research on all aspects of water, specifically irrigation, drainage and land reclamation, surface & groundwater management, groundwater recharge, watershed management, rainwater harvesting,

Year	Organisation Evolved	Purpose/Result
		desertification control, water quality and saline agriculture.
1991	The Water Resources Research Institute (WRRI) in Pakistan Agriculture Research Council	To develop technologies; new knowledge and management strategies for water resources of the rain-fed and irrigated farming systems to enhance the productivity per unit of water.
1997	Provincial Irrigation and Drainage Authorities in all the four provinces.	To take over responsibilities of farmers managed irrigation and drainage systems.

Although there were successes to share, often their work was fragmented, less effective and of low impact. Their capacity was low and their abilities to transform into responsive institutions was weak; therefore, their sustainability remained questionable. WAPDA and provincial irrigation and agriculture departments are classical examples of organisations with ‘transformation resistive’ cultures. Overall, the role of institutions was partly successful, not as effective as it could be, and was unlikely to be sustainable. Efficiency was low and dominantly non-responsive. To address the complex issues of multi-sectoral water and food security, the combating of land degradation, and the need for improved water and land productivity, an effective transformation of provincial irrigation and agricultural departments and WAPDA may be needed. Farmer-based organisations, water users’ associations, drainage beneficiary groups and community tubewell groups, have struggled for survival. The World Bank’s ambitious reform program (1994-2002) have failed to bring the envisaged changes.

3.5. Research and Data Management

Water and salinity related research has been carried out in the past at two scales: medium- to large-scale research by IWASRI, and field- and farm-scale research by many, including provincial and educational organisations. The IWASRI work was in response to the prevailing environment at that time, but financing constraints significantly downscaled the research work with the passage of time. Further, the information generated was not significantly transformed into policy and institutional tools. Although the small-scale research work undertaken by many organisations was voluminous, this could not be properly screened and bundled together for the uptake of farmers. This research work was mostly disconnected, fragmented and localised. Lacking in appropriate planning, the main focus was in the searching for maximum potential at experimental stations. What was missing was work on farmers’ fields. At least 50% of the research work by these institutions could have been carried out in partnership with farmers on their farms. This could have benefitted by targeting research to real needs, disseminating results through farmer-to-farmers links, and improving the upscaling of research.

Unfortunately, generated data were generally inappropriately managed and were not available in a timely manner for critical review and use. Therefore, a large chunk of the research work remained underutilised. The bigger picture and an integrated research framework were missing. The National Drainage Program (NDP; 1997-2004) developed a strategic research agenda, but due to the failure of the overall program, the research component alone could not yield the envisaged results. An assessment of current research (organisations and their work) might help better plan, organise and manage research work for future.

3.6. The Mega Projects for Salinity Management

In the 1960’s, the Indus Basin experienced a large-scale infrastructural transformation. After the Indus Water Treaty was signed between India and Pakistan in 1960, the Indus Basin Replacement Works (1960-1980) built two large reservoirs (Mangla and Tarbela), 12 inter-river Link Canals and a range of additional pertinent structures. Parallel to this development, between 1964 and 2000 the Government implemented six SCARP projects (SCARP I to SCARP VI) for $2 billion covering 8 Mha. The performance of these mega projects varied, but this infrastructure brought several changes to the Indus landscape. Most of the mega projects were not evaluated for their impacts and sustainability, and so far this information is not available. A summary of the waterlogging and salinity related projects is in Table 3: my comments on the Performance Indicators of the projects are justified in the text below.

Table 3: Investment Mega Projects at a Glance

Project Name	Key Details	Performance Indicators and Results				
		Outcome	**Relevancy**	**Efficiency**	**Effective-ness**	**Sustain-ability**
SCARP I to SCARP VI	1964-2000 for $2 billion	Successful	Relevant	Satisfactory	Effective	Not sustainable
SCARP Transition	1987-1990 for $21.8/14.9 million	Successful	Relevant	Generally satisfactory	Effective	Partially sustainable
Left Bank Outfall Drain	1986-1997 for $150 million	Partially successful	Relevant	Not satisfactory	Modest	Not rated
Private Sector Groundwater Development	Punjab ($33.4 million) (1997-2001)	Partially successful	Relevant but 'quality at entry' was poor	Satisfactory	Modest	Inadequate data
National Drainage Program	Pakistan ($785/$226 million) (1997-2004)	Unsuccessful	Relevant but complex design and 'quality at entry' was poor	Unsatisfactory	Not effective	Not sustainable

Salinity Control and Reclamation Projects (SCARPs)

The SCARPs aimed to reduce waterlogging and salinity by pumping groundwater and lowering groundwater levels. Six SCARP projects for $2 billion benefitted 8 Mha of irrigated land. The first SCARP project in 1961 installed 2,100 public tubewells to serve 600,000 ha land in Punjab. Suitable fresh pumped groundwater was transferred to canals for irrigation purposes, moderately saline water was mixed with canal water for irrigation, and saline water was dumped into ponds to evaporate. The SCARP was moderately successful in lowering groundwater, reducing waterlogging and salinity, and providing additional irrigation supply from areas with fresh groundwater. The additional water supplies and the associated drainage increased cropping intensities from 84% to 115% in most SCARP areas, although the targeted cropping intensities of 150% were not achieved (Qureshi and Sarwar, 2009). This SCARP did decrease salinity but with its high costs of operation and maintenance, the operation of the operation of the tubewells was not sustainable.

Implementation of the first SCARP was done without farmer participation. Farmers lost confidence in the effectiveness of this SCARP for a range of reasons: the system had a high operating cost, there were frequent failures in the delivery of energy for the tubewell pumps and as a result, there was a return of waterlogging. In 1977, the Government launched SCARP VI mainly to encourage farmers to implement their own private tubewells through the development of a credit facility and through subsidies on the price of electricity. This reduced the Government's burden. In addition, horizontal subsurface drainage pipes were installed in many areas between 1980 and 1990. Between 1984 and 2000, the salt free area increased from 56% to 73%. However, by 2000 the SCARP wells were discontinued due to their poor performance, high cost and short life.

SCARP Transition Pilot Project

Project objectives, components and scale. The $14.9 million SCARP Transition Pilot Project (STPP) was implemented from 1987 to 1990 in the SCARP I area of Khanqah Dogran, Punjab.[7] The project objective

[7] SCARP stands for Salinity Control and Reclamation Project. Original project estimate was US$21.8 million. The lower actual cost was due to over estimation of tubewell installation, electrification material and equipment.

was to develop a replicable approach to implementing the Government's policy of transferring the responsibility for fresh groundwater pumping in the SCARP area from the public to private sector, thereby meeting more effectively irrigation and drainage requirements. The project covered an area of 46,000 ha including 11,500 farming families. It mainly tested farmers' willingness and ability to install their own tubewells, when the Government tubewells shut down.

Project performance. The project successfully demonstrated the farmers' installation of private tubewells as substitutes for the closing of public sector tubewells. However, the high cost of electric transmission lines made electric driven tubewells less cost-effective than diesel operated tubewells, and the latter were therefore largely adopted. Necessity and the need to ensure the profitability of farmers made the 'transition' concept successful and replicable.[8] Small-scale interventions, affordability and personal ownership also played an important role in this success.

Project sustainability. Lacking the collection of adequate data, the project's impacts were not assessed. Farmers' full control of the operation of their own tubewells, with them bearing all the operational and maintenance expenses made the project sustainable. In the longer-term, project sustainability will depend on additional income coming from demand driven water availability, with the efficient use of this water to produce high value crops.

Lessons learned. The following lessons can be learned from this project's implementation:

- The low capital cost of diesel-operated pumps is favoured over high capital cost of electrically-driven tubewells.
- A large Government subsidy is not necessarily needed to encourage change in farmers.
- The early implementation of design reviews by the supervisory consultant is important for the smooth implementation of projects.
- A full-scale project of this nature may need international and competitive bidding for the procurement of equipment.
- Monitoring and evaluation should be given more attention.

National Drainage Program

Project objectives, components and scale. The National Drainage Program (NDP), with a design cost of $785 million and an actual cost of $226.5 million, covered the entire country and was implemented from 1997 to 2004. The program objective was to assist the 'Borrower' (Government of Pakistan) and Provinces to implement the first phase of the NDP, which was designed to restore environmentally-sound irrigated agriculture, inter alia, through the minimisation of the saline drainable surplus, and the eventual evacuation of the saline drainable surplus to the sea.[9] The program component included institutional reforms, sector planning and research, investment, coordination and supervision.

Project Performance. Achievement of the project objectives was negligible. On institutional reforms, WAPDA reduced staffing and devolved the implementation of the drainage projects to the provinces, but WAPDA's transformation into a basin-oriented water resources agency was limited. Achievements at provincial levels were disappointing to varying degrees. While there was initial progress on the implementation of Area Water Boards and Farmer organisations in Punjab and Sindh, these later severely declined, and were phased out in less than a decade. Staff from provincial Irrigation and Power Departments were apprehensive about the effect of farmer organisations on their own futures, and their capacity building efforts were weak. Unfortunately, due to these vested interests, even the limited progress that was achieved substantially reverted to the pre-project situation. The project has not achieved its first objective, and the management of the irrigation and drainage system has remained practically the same as before the reform, with minimal changes. A more encouraging postscript could be "since project closure (December 2004), there has been an increased commitment to reform in Sindh and Punjab provinces" and that, "in 2005-06, Punjab has moved forward in the reform process through the Irrigation Sector Development Policy Loan."

Modest achievements were a strengthening of drainage and irrigation research and sector planning capabilities. There were negligible achievements under investing in drainage and irrigation infrastructure.

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[8] About 70% of the irrigation demand was met from groundwater in the project area. Failure of 'transition' means high loss of agricultural production.

[9] The specific objectives were to (i) promote the carrying out of policy and institutional reforms in the water sector; (ii) strengthen drainage and irrigation research and sector planning capabilities; (iii) finance investments in drainage and irrigation infrastructure; (iv) promote the carrying out of policy and institutional reforms in the water sector; (v) strengthen drainage and irrigation research and sector planning capabilities; (vi) financial investments in drainage and irrigation infrastructure.

The main sub-components responsible for the shortfall were the lack of off-farm drainage, and on-farm drainage also had no investments in new drains. The project made only limited progress towards its overall objective, far less than planned, and the project's outcome was rated as unsatisfactory.

Lessons learned. The main lessons learned were:

- The main reason for the failure of the program was its over-complexity.
- A reform agenda needs to give attention to incentives for change for the different stakeholders, and to the processes and sequential actions of the reform program.
- Commitment to reform needs a broad base, preferably a stakeholder-led agenda.
- Reform champions can have major impact, but basing reform on a few champions is a vulnerable strategy.

Punjab Private Sector Groundwater Development

Project Objectives, Components and Scale. This US$33.5 million private sector groundwater development project (PGWD) (1997-2001) aimed at increasing the scope and productivity of Punjab's irrigation and drainage subsector, and increasing farmers' incomes.[10] Specific objectives were to: (i) redefine Government's role in groundwater development and provide assistance to facilitate change, (ii) develop a monitoring program and groundwater regulatory framework (GRF) to ensure the sustainable use of groundwater resources, (iii) develop sustainable farmers' organisations (FOs), which could efficiently operate and maintain groundwater irrigation, improve surface irrigation and establish a base for participation in the management of the canal systems, (iv) increase the incomes of beneficiaries and alleviate poverty, (v) rationalise public expenditure on the operation and maintenance of the irrigation and drainage systems and increase the recovery of public expenditure on irrigation infrastructure, and (vi) avoid the environmental hazard of saline water intrusion into fresh groundwater aquifers.

The project components were: tubewell disinvestment, development of a groundwater regulatory framework (GRF), improvement of irrigation facilities, prevention of saline groundwater intrusion, monitoring and evaluation (M&E), project management, and technical assistance and training. Component 1 involved the transfer of 4,250 government tubewell (TW) sites to cooperative tubewell (CTW) management. The tubewells provided supplementary supplies to surface water canals, as well as salinity control benefits through reducing the water-table. There was not a one-to-one correspondence between existing government tubewell sites with a single community tubewell management group. Sometimes a government tubewell was taken over by several CTW management groups, thus the number of CTWs exceeded the 4,250 disinvested tubewells.

Project Performance. Redefinition of the Punjab government's role in groundwater development was largely achieved by the end of the project, with all 4,250 SCARP tubewells. Development of a monitoring and regulatory framework to ensure the sustainability of groundwater resources fell far short of the overambitious targets because the time needed for consultation and the building of stakeholder ownership and acceptance was underestimated. However, change was facilitated and the number of farmers' groups established and trained exceeded targets. Over 6,700 community tubewells (CTWs) were set up, and 85% of these were judged 'successful' through independent monitoring. About 2,000 water user associations (WUAs) were established. The subsidies on private tubewell construction ended. However, the scheme to implement severance packages for 5,000 redundant operators was not implemented and $8 million remains unutilised. Monitoring data are inadequate to determine if saline intrusion was reduced or if water quality improved in allegedly affected areas.

Significant outcomes. There were substantial improvements in irrigation management within the long-term policy framework adopted by the Punjab government. Promising new agricultural technologies were demonstrated, including resource conservation through the zero tillage of wheat on 60,000 ha (over 2,800 sites), and laser-guided land-leveling on 22,250 ha.

Significant shortfalls. The institutional and technical difficulties of managing surface and groundwater sources conjunctively were underestimated, and the Groundwater Regulatory Framework still needs to be enacted and operationalised. This project was categorised as a poverty targeted intervention (PTI) but alternative PTIs were not considered. The saline intrusion control component was poorly conceived on inadequate data. The lack of a uniform sector policy for farmers' contributions to civil works capital investment created implementation problems and required significant redesign. The M&E system for

[10] Actual cost of US$33.5 million was 32% of the planned cost of US$104.8 million.

agricultural production impact had only 30 control households, which is a small sample. The sustainability of benefits from canal rehabilitation and watercourse improvement were not established.

Project rating. The project outcome was rated as moderately satisfactory. Although community tubewell disinvestment targets were met, poor levels of 'quality-at-entry' (i.e., the project was not thoroughly reviewed for relevant parameters prior to commencing) resulted in a failure to meet the objectives of the groundwater regulatory framework (GRF) and irrigation improvement component. The achievement on institutional development was modest as slow progress in implementing provincial level reforms and the GRF offset the good progress on new management structures at the field level. Project sustainability was not evaluable due to the non-availability of data from the early stage on how likely it was that the ambitious institutional changes would lead to both improved and sustained irrigation management performance.

Lessons learned. The following lessons were learned.

- Establishing a groundwater regulatory framework (GRF) requires the coordination of a wide range of institutional changes, affecting the equity of water distribution, ownership by both communities and local government, and the development of alternative income sources to compensate for decreased reliance on groundwater, and the poverty-targeting of 'critical areas'.
- A public awareness program and stakeholder participation must precede the introduction of groundwater regulation. Users must be involved in groundwater monitoring and voluntary self-regulation.
- Women's Organisations can contribute to conflict resolution among members of farmer organisations/community tubewells and the optimal siting of tubewells.
- To control salinity, non-engineering solutions, for example saline agriculture and biological drainage, may be effective in controlling groundwater induced salinity.

Left Bank Outfall Drain Stage I (Reference ICR)

Project Objectives, Components and Scale. The International Development Association (IDA) credit $150 million project ran from 1986 to 1997 to address problems of waterlogging and salinity along the left bank of the River Indus in Sindh Province.[11] The Project's objectives were to provide surface drainage for about 516,000 ha and subsurface drainage for about 392,000 ha, and to transport excess water and salts out of the area. The project's components were: (i) the remodelling and completion of the main outfall drain to the ocean, (b) construction of surface and subsurface drainage systems over about 970,000 ha, (iii) remodelling and rehabilitation of associated irrigation works, (iv) consulting services and training, and (v) monitoring and impact evaluation. In 1993, after a mid-term review, the project objectives were expanded to include decentralisation, beneficiary participation and private sector dimensions. The project had seven financiers [ADB, CIDA, SFD, ODA/DFID, OPEC, IsDB, SDC, and the M&E Trust Fund (SDC/DFID/CIDA)]. The cost overrun (by 61%), was caused mainly by security-related problems, substantial additional works not identified at appraisal, design changes and weak contractors.

Project performance. At the loan closing date, the physical works were substantially complete. However, some drainage areas were yet to be connected, and irrigation improvements, not fully completed, including the off-stream reservoir, were delayed by resettlement problems. Considerable production, social and institutional benefits were delayed. The project outcome was rated as being marginally satisfactory, since the process had been long and tortuous, costs had risen greatly, and the project was delayed by four years.

The main drain was completed to allow for the discharge of salt and storm water to the sea. Water-course level works exceeded targets (channel rehabilitation and land leveling). Substantial crop production increases attributable to the project were identified by impact studies. Some improvement in land tenure patterns were identified and women's groups had been formed to pursue their concerns.

Shortcomings. These included significant delays, neglected social, institutional, fiscal and sustainability aspects in the initial design, prolonged law and order problems in the interior of Sindh, design changes requested by co-financiers, and poor performance by the contractors. These problems were exacerbated by unusually heavy rainfall in three years (1988, 1992 and 1994). The closing date was extended by four years and even with this extension, works were not completed. The original project design focused exclusively only on engineering construction to solve complex technical, environmental, financial and social problems. The M&E component was flawed in design and execution, despite efforts by both borrower agencies and financing partners to resolve its problems.

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[11] Project implementation completed after 4 years of scheduled completion in 1993. The total cost when the IDA credit closed was US$845.1 million, but this was expected to rise to US$ 1,021 million when the project completed in 2002.

Lessons learned. The following lessons were learned:

- A major multi-disciplinary project of this type and complexity requires a higher order of preparation and detailed planning than either the donor or borrower were accustomed to at the time.
- Early and determined action is needed to maintain efficiency and contain costs to resolve problems on slow-moving projects.
- Complex engineering/social programs need careful analysis of institutional capabilities and risks as critical inputs to realistic scheduling, and some contingency time needs to be built into the program.
- Sustainability, including drainage technology and performance, O&M performance, role of the FOs, and plans for future operation of the system should be fully considered.
- Better contracting arrangements, including with a focus on construction quality and remedial work are needed for serious problems with a 'tidal link'.

3.7. Maintenance and Operational Management of Mega Projects – A Chronic Issue

Maintenance and operational management (MOM) of irrigation and drainage infrastructure has always been problematic. Scheumann and Memon (2003) showed that maintenance of tile drainage and SCARP tubewells fell sharply after they were handed over from WAPDA to provincial irrigation departments. Underfunding and hierarchical influences on budget allocation have been the main constraints for poor maintenance. For example, the Punjab Drainage Circles' establishment, reaches or exceeds international standards in terms of the number of maintenance personnel employed. However, the large working forces of both units, SE SCARPs and SE Drainage Circles, have been unable to cope with drainage requirements because of low labour productivity, lack of qualified staff, and PID staff indifference to the users' drainage demands.

Both inadequate drainage infrastructure and poor irrigation system performance have increased the need for land reclamation. The current rate of land reclamation is lower than the rate of soil deterioration. Reportedly, land reclamation activities were successful in the areas where farmers' committees were established and functional (Scheumann and Memon, 2003). Experience of participatory management in drainage showed modest success. For example, the drainage beneficiary groups (DBGs) in low-lying areas and areas where social mobilisation was more effective were successful. The transfer of public tubewells in freshwater areas to the community was also successful. However, the functioning of DBGs in tile drainage areas has been challenged by high maintenance costs and transfer of public SCARP tubewells in saline groundwater areas.

3.8. Biological Management of Salinity – Non-structural Approach

Qureshi and Sarwar (2009) reported that the planting of salt tolerant crops has been successfully demonstrated in the Indus Basin. Enhanced salt tolerance has been seen in sugar beet at the germination stage, barley at the early seedling stage and rice at the flowering stage. The growth of salt-tolerant plants such as kallar grass and jantar has also been successful in saline soils. They further add that the application of agricultural and industrial waste, e.g. farmyard manure and by-products of the sugar industry, have been used to improve soils affected by high sodicity. A large range of acid materials (as soil ameliorants) has also been tested in Pakistan including sulfur, sulfuric acid and aluminum sulfate.

Biosaline Agriculture. Salt tolerant grasses, trees and saltbushes have been tested, however, the success of biosaline agriculture hinges on the socio-economic conditions and level of community participation. In Pakistan, the generally recommended salt-tolerant plant-species include: 'kallar' grass, and species from the genera Atriplex, Acacia and Eucalyptus (Zia et al., 1986, Zia and Rashid, 1995). The UNDP and AusAid's Biosaline Project (1997) rehabilitated 630 ha of salt-affected soil in partnership with Salt-Land Users and Women's Interest Groups in Punjab. The project also generated livelihood opportunities for poor farmers through fish farming and livestock. The project was rated most successful (UNDP and Government of Pakistan, 2006).

Lashari et al. (2015) have recommended practicing bio-saline agriculture and the use of brackish water ponds for the development of fisheries in the Indus Basin in Sindh, where saline groundwater occurs in 70% of the area and soil salinity affects 20% of the land area. Bio-saline agriculture can make use of 'salt-loving' halophytes and special plants, such as Sesbania sesban, a fodder shrub that can yield as much as 7.5 t/ha of dry matter, or fodder grasses belonging to the family Poaceae. Existing varieties of common crops (wheat, sorghum, sugar-beet, potatoes, etc.) should be tested for their tolerance to the use of brackish irrigation water on free-draining soils. The planting on ridges or field bunds of high value fruit trees such as mango can also be amongst the options to live with salinity.

3.9. Scale is Important in Salinity and Agricultural Water Management

The Indus Basin's resources and services are enormous and resource linkages are complex. An action at one place in a specified time can cause reactions at the same or at different places at different times. Water and salt balances in the basin are dynamic and continue to change with time and in space. Therefore, an appropriate strategy and informed decisions are critical for sustainably improving SAWM in the basin. Secondly, salinity cannot be eliminated in absolute terms; possible solutions and options therefore need to focus around living with at least a certain level of salinity. Thirdly, a SAWM framework with socio-economic and health indicators may help in better management planning. The SAWM framework needs to focus on impact pathways, feedback and monitoring, evaluation mechanisms and management planning, review and implementation. Determining appropriate planning, management and implementation scales can ensure cost-effective solutions and sustainable long-term benefits. Being natural hydrological units, farms, canal command or drainage areas, and basin/sub-basins could be appropriate scales for work.

In the context of the Indus Basin in Sindh, Lashari et al. (2015) recommend six action points to improve SAWM, including the needs to: (i) rationalise irrigation duties, (ii) expand and intensify areas under irrigation, (iii) Improve field water use efficiency, (iv) invest in drainage in a well-targeted and selective manner, (v) make use of storm water, and (vi) adapt to saline conditions in some areas. For six canal command areas, they suggested priorities for water management, investment and agriculture (Table 4). Broadly, water management priorities require policy decisions at canal command or larger scale. However agricultural priorities need to be implemented in cooperation with farmers at 'farm-scale'. However, investment priorities need to be selective, depending on the effectivity and connectivity of on-farm, off-farm and terminal drainage.

Table 4: Broad Agenda for the Six Command Areas in Sindh
(Adapted from Lashari et al., 2015)

Area	Water Management Priorities	Investment Priorities	Agricultural Priorities
Guddu Right Command	Rationalise irrigation duties	Restore surface drainage	Introduce more efficient rice irrigation
Guddu Left Command	Rationalise irrigation duties	Restore surface drainage	Use freshwater zones for high value crops
Sukkar Right Command	Rationalise irrigation duties Improved field irrigation	Restore surface drainage	Introduce more efficient rice irrigation
Sukkur Left Command	Relocate/increasing supplies to fresh groundwater areas	Selective rehabilitation of saline drainage wells Escape structure Lining of drainage section that are in fill	
Kotri Right Command		Restore surface drainage	Reconsider cropping pattern to low delta crops
Kotri Left Command	Rationalise irrigation duties	Flap gates at tail of drains to prevent sea water intrusion Selected drainage investments	Reconsider cropping pattern to low delta crops Introduce biosaline agriculture and aquaculture Introduce more efficient rice irrigation

Farm and Field Scale

Traditionally, three levels of scale have been tested addressing the waterlogging and salinity management in the Indus Basin. Activities at farm- and field-scale are suitable for approaches such as water intensive leaching, chemical amelioration to improve soil structure, the growth of salt loving grasses (the biological approach), and the use of sub-surfacing and deep ploughing (the physical approach). These are all farmer- or community-based interventions. At this scale, saline-sodic soils have been reclaimed or their productivity increased through use of gypsum, farmyard manure, surface scraping and deep ploughing. The Barani Village Development Project (BVDP; 2003-2006) and Integrated Watershed Development Project in Pothowar region in Punjab successfully tested the use of gypsum to improve farmers' income and profitability from saline soils.[12] Regarding of the use of gypsum for reclamation of saline soils, Ali and Kahlown (2001) showed that a subsidy on the price of gypsum increased its use from 600 tonnes in 1972 to 218,000 tonnes in 1980, and the area of land reclaimed increased from 177 ha to 29,000 ha, almost 165 times, in 8 years. Based on experiments in Punjab from 1980 to 1985, it was concluded that best results occurred with the use of gypsum for Khurianwala soil and subsoiling plus gypsum for Ghandara soils (Ahmad et al., 1998).

Water course improvement and laser land levelling (which help conserve water and improve water productivity), and the implementation of biosaline agriculture (i.e. the growth of plants that survive in saline soils and have monitory value), have all been tested, and in some cases been well-demonstrated, by farmers and farming communities. Biosaline agriculture could be a potential intervention at this scale. Potentially, it could create 'bright spots' demonstrating a good example of living with nature. Sheikh and Ashraf (2010) evaluated the use of low quality groundwater for crop production in farmers' fields in Punjab, Pakistan. They found that 15–40% more land could be irrigated compared to normal farmer-practices by adopting the following strategies[13]:

i. Using saline groundwater for irrigation provided there can be leaching of salts at the end of cropping season.
ii. Mixing canal with groundwater in the ratio of 25:75; this is more appropriate than using sodic groundwater.
iii. A hybrid combination involving both conjunctive use mixing and cyclic use of saline and non-saline water is more reasonable for the use of saline-sodic groundwater. Most of these kinds of treatments were associated with decreases in ECe and SAR, and increases in infiltration rate.

Canal Command Scale and Integrated Research Sites

A canal command is potentially a suitable hydrological control unit for: (a) the planning and management of interventions such as drainage (horizontal or vertical, surface or subsurface), and (b) the monitoring and evaluation of the interventions based on performance indicators. This scale also provides the opportunity to assess the accumulative or combined impacts of farm-scale and canal command scale interventions. Canal command areas in Indus Basin vary from a few thousand to more than a hundred thousand hectares, and they offer flexibility for up- and down-scaling as needed. Based on a field experiment covering 500 ha in the Surezai area near Peshawar, Sarwar et al. (2007) concluded that the rehabilitation of an open collector drain by farmers helped lower the water-table, made land cultivation possible and increased crop yields.

The BVDP introduced the concept of integrated research sites (IRS) and tested various livelihood options in salt-affected soils with farmers. At the IRS Kasilain in Punjab, the abandoned and salt-affected land was successfully used for improving grazing capacity rather than regular crops (ICARDA 2006). The Soil Salinity Research Institute (SSRI) Punjab was a research partner in the IRS, Kasilian with farmers. Soils in the area had ECe values between 4 and 39 dS/m. There was encouraging survival of a range of different shrub species including: Acacia nilotica (94%), Iple Iple (90%), Atriplex nummularia (78%), and Atriplex modesta (78%). After 3 years (2003-2006), the average pruned material was 1.09 kg per plant. The plant height of Acacia nilotica varied from 14.5 to 5.6 m (14.6–18.3 feet), and the biomass varied from 135 to 231 kg for all the three fields at the IRS, which was a good success. The farmers' trials on crops (cotton, rice, sorghum, millet) using marginal quality groundwater also showed modest success. The farmers obtained the following yields: cotton (2.1 t/ha); rice (1.9 t/ha); sorghum (8 t/ha), and millet (7.8 t/ha). Unfortunately, water and soil quality data were not available due to the termination of the project and with the closing of the IRS, the long-term effect of saline groundwater use could not be assessed.

[12] The author's experience of these projects.

[13] Caution: reduction in soil properties (ECe, SAR, infiltration rate) was noted in most of the treatments.

River Basin Scale

The River Basin Scale (RBS) is suitable for strategic planning, the assessment of linkage interactions and benefit optimisation. The RBS is important for the improvement of SAWM in the Indus Basin for the disposal of drainage effluent that fits into the existing large-scale and contiguous irrigation system. It also provides the opportunity to assess the downstream impacts of upstream actions. Strategies to improve SAWM in the Indus Basin may benefit from the review/development of the Indus Basin Drainage Plan (IBDP) for medium- to long-term actions. The drainage plan should identify, screen and rank the appropriate interventions at all scales and should be the basis for investment in the drainage subsector.

3.10. Groundwater Management – A Neglected Segment

Groundwater supports almost 50% of irrigation supplies and a large proportion of domestic and industrial needs in the Indus Basin in Punjab. It offers a low-cost water reservoir and acts as a buffer against drought. It enables more equitable access to water and facilitates demand-driven water uses. However, groundwater use requires informed regulation due to the underlying brackish strata, over-pumping and saltwater intrusion, and therefore the possibility of secondary salinisation. Also, much of the groundwater of the Indus Plain can contain dangerous amounts of bicarbonate and sodium, and its indiscriminate use can make soils alkaline and impermeable. It is recommended that tubewells not be installed in areas where the concentration of bicarbonate or sodium is high (Mohammad and Bearing, 1962).

In some parts of Sindh, the abundance of surface water is a disincentive for farmers to use fresh shallow groundwater for irrigation. Recharge of the groundwater from canals therefore continues to occur, causing waterlogging and salinity, decreasing agricultural production and causing health hazards. In 2011, the depth to groundwater was less than 1.0 m on 2.19 Mha area (36% of the 5.96 Mha of irrigated agriculture land), between 1.0 and 1.5 m on 2.04 Mha (33.6%), between 1.5 and 3.0 m on 1.29 Mha (21.2%), and between 3.0 and 4.5 m on 0.34 Mha (5.5%).[14] Flooding in summer, further aggravates the shallow groundwater table. Shallow groundwater combined with flooding can cause salinity, low agricultural production and public health risks. Reallocation of surface water and conjunctive use of both surface and groundwater can free up some of the surface water for other uses, lower the water-table, reduce salinity, increase agricultural production and reduce health risks (Lashari et al., 2015).

The key disadvantages of the unmanaged and unregulated conjunctive use of groundwater are that upstream areas experience a rising water-table whereas tail-end areas are exposed to increased secondary salinity problems due to the excessive use of poor quality groundwater (Qureshi, 2014). Unfortunately, groundwater management is grossly neglected. There is no strong ownership, no or little technical guidance regarding aquifers in use, and no regulatory framework or enforcement of groundwater laws. A couple of assessments under various projects and initiatives have been carried out which strongly suggest a need for new technical, institutional and policy and legal frameworks leading to the better management of aquifers. This is critical from both water and salinity perspectives.

On a positive note, Punjab is developing a groundwater legal and regulatory framework, which is presently at the stage of review and approval. This is one step forward and should be appreciated. However, the framework has not been backed by a comprehensive assessment and policy, and the weakness of the regulatory framework will become clear during implementation. Further institutional arrangements for the management of groundwater remain sketchy. A comprehensive assessment of groundwater monitoring and management in the Indus Basin is required. Qureshi (2015) examined the benefits of groundwater development, institutional approaches and resource management, and concluded that groundwater management in Pakistan requires multifaceted actions focusing both on supply- and demand-side solutions, including stabilising aquifers, revisiting conjunctive use of surface and groundwater, increasing the productivity of groundwater use and improving groundwater governance.

[14] Lashari et al. (2015) with source from SCARP monitoring organisation.

4. Summary of Key Lessons Learned and Future Directions

Salinity is more than a biophysical problem. Salinity is a socio-economic, environmental and human 'well-being' problem. It degrades land, reduces agricultural productivity and causes health hazards. In Pakistan, salinity affects 40% of irrigated land, which is twice the World average of 20%. In the Indus Basin, groundwater induced secondary salinisation is causing the abandonment of 40,000 ha each year (WAPDA, 1989). The country is suffering from high costs because of waterlogging and salinity: crop yields on salt-affected soils are typically 25-40% of the yields on normal soils (Ahmad, 1968). Land degradation (of which salinity is a part) is causing an estimated loss of $250 million per year (Qureshi, 2011), and a total damage cost of about $2.0 billion (waterlogging = $0.5 billion; salinity = $1.5 billion (Anjum et al., 2010). In this assessment, costs due to poor living standards, health hazards, declined livelihood opportunities and forced migration have not been counted.

Factors causing salinity are interlinked in a complex manner. Salinity is caused in natural settings, through inappropriate management actions and flawed farmer practices. The main factors causing salinity are: (i) salt in the original soil profile, (ii) the irrigation-induced accumulation of an additional 14.4 Mt of salts in the soil profile and groundwater annually (NESPAK and MMI, 1993)[15], and (iii) the use of low quality groundwater for irrigation. Marginal quality groundwater use adds 100 Mt of salts to the soil surface every year (ICID, 1991). The application of surface water through canals adds an additional 50 Mt of salts to the system every year (Qureshi, 1993).[16] On average each hectare of irrigated land receives about 1 t of salt per year (NESPAK and MMI, 1993).

Water and salinity are linked with natural, socio-economic and environmental factors and processes in a complex manner. For example, irrigation from surface or groundwater accelerates soil salinity but over-irrigation may be needed to leach the existing salts deeper into the soil profile. The main concern of farmers is that water should be available for irrigation when needed, with no or low attention to water quality. The main concern of water managers is the lack of flexibility in the supply-driven canal irrigation system. The main concern of policy-makers is priority setting and the allocation of water for the production of food, energy and household water security, and water safety. The main concern of governments is low agricultural productivity, food shortages and unrest. Finding workable and sustainable solutions is challenging.

Salinity and agricultural water management has been challenging. The SAWM approach has been viewed through related policies, strategies and investments in infrastructure. The 2012 Draft of the National Water Policy recognises the main focus areas as being the salt build up in irrigated agriculture, increased intrusion of saline water in the Indus Delta, groundwater management planning and regulatory zones, secondary salinisation, waterlogging, and research. Amongst other factors, the Pakistan Water Sector Strategy (Government of Pakistan, 2002) identifies the main issues to be: the deteriorating irrigation and drainage infrastructure and water quality, waterlogging and salinity, and disposal of saline drainage effluents. As the main objectives, it emphasises IWRM, regulating groundwater, improving water quality, reducing waterlogging on 2.8 Mha, and providing a long-term safe solution for the disposal of saline drainage effluents. The strategy also prepared short-, medium-, and long-term action plans. So far, implementation of the strategy action plan remains weak. Of the planned investment of $11 billion, hardly any significant work on waterlogging and salinity, drainage and groundwater was completed during the strategy period from 2002 to 2017.[17]

With some exceptions, institutions did not meet the requirements of a changing environment. With an inability to evolve and with decreased capacity, most of these institutions have become non-responsive and irrelevant with time. Some of the best institutions from the past are now struggling for survival. Water and salinity related legislation has been insufficient and its enforcement weak. The mega projects had some early

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[15] Of an average annual salt inflow of 33 million tonnes to the Indus Basin, around 16.4 million tonnes is washed out to sea and the remaining 16.6 million tonnes remains within the system. Only 2.2 million tonnes is deposited in series of evaporation ponds. A balance of about 14.4 million tonnes of salt accumulates in the soil profile, underlying strata and the aquifer of the Indus Basin.
[16] The two references [NESPAK and MMI, 1993 and Qureshi, 1993] shows a large difference of annual salt accumulation but both signify the issue.
[17] The strategy period runs from 2002 through to 2025.

success, but have now become liabilities due to their inadequate MOM. After the failure of the NDP in 2002, groundwater and drainage have remained a low priority. The infrastructure-based approach of SAWM dominated and masked the potential of participatory and community-based approaches. The main lessons learned from SAWM are as follows:

General

1. In the Indus Basin, salinity persists and continues to affect water and land productivity and accelerates land degradation.
2. The costs of land degradation induced by waterlogging and salinity are high and negatively impact food security and economic development.
3. Seasonal fluctuations in the extent of the saline area depend on several factors including the use of groundwater, the availability of water for leaching, rainfall, drought, floods, soil treatment, crops and management practices. Reported differences in the area of salt-affected land is therefore explainable.
4. The Implementation of Strategy (2025) may require an immediate mid-term review; particularly for SAWM. This may help in restructuring the action plan and incorporating the lessons learned.
5. Improved water management is vitally important for the management of salt-affected land. Conjunctive use of surface water and groundwater can be part of the solution, if appropriately implemented.
6. Groundwater management is critical for the management of salt-affected land but little attention has been paid to this important resource. Improving the governance around groundwater is vitally important given its importance in: (i) the management of salt affected land, (ii) minimising the impacts of drought, (iii) acting as buffer against climate change impacts, (iv) improving land and water productivity, and (v) meeting social needs.
7. Punjab's efforts in preparing laws regarding the use and protection of groundwater is appreciated, but in the absence of a proper assessment and knowledge base, it may face implementation difficulties. A parallel assessment and groundwater information system may help in effective implementation. Appropriate institutional arrangements for groundwater management are absolutely necessary. The ADB's on-going capacity development assistances for the revival of the River Ravi and for institutional transformation and the upcoming TA loan may help and complement the other parallel efforts for effective SAWM.[18]
8. Sustained production from irrigated agriculture requires technical knowhow and skills in surface water and groundwater, soil, crops and climate. For example; shallow groundwater can be advantageous for sub-irrigation, if it does not constrain the plant root zone. So managed groundwater aquifer is important. It means that the costs of irrigation can be decreased with no decline in crop yield.
9. Maintenance and operational management (MOM) has been a generic problem associated with almost all public sector projects and should be duly considered in investment planning.

Farm-Scale interventions

1. Several farm-scale interventions have shown good results including the use of gypsum, leaching, deep ploughing, adding animal manure, the growth of salt tolerant crops and grasses, and biological drainage. These experiences can be successfully adapted in similar geographical and socio-economic environments. For upscaling, agro-climatic, hydro-ecological and socio-economic characterisation, ranking and bundling can help improve adoption. The interventions that increase farmers' profitability are more likely to have high adoption.
2. Farmers advisory and information systems (irrigation, weather, soil-moisture, market, disaster) may help in the better management of water and salt-affected soils. Field level interventions such as land levelling for the uniform application of irrigation water can help in reducing the danger of over- or under-irrigation and can therefore improve crop water use efficiency.

Mega Projects

1. The mega projects had comparative advantages: resource availability, political will and an immediate development focus. Some of the mega projects such as the SCARP, SCARP transition and Punjab groundwater development projects were largely successful, achieving their specific objectives. The LBOD was partially successful and the NDP was unsuccessful.
2. Implementation of the mega projects faced several challenges. The main reasons why mega projects were unsuccessful are: problems in project quality at the start, project complexity and the lack of cooperation of stakeholders and low institutional capacity. Other weaknesses of the mega projects

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[18] ADB approved the capacity development technical assistances: institutional transformation in 2016 and revival of Ravi basin in 2017. A technical assistance loan to prepare future irrigation, drainage and water sector projects is in process of approval in 2018.

include: (i) high investment costs, (ii) ineffectual maintenance and operational management, (iii) inflexible to change and innovate, and (iv) low sustainability. The impacts of these projects has continued to decline. Groundwater governance has been very weak lacking a regulatory framework and enforcing mechanisms at the levels of policy, strategy and operational levels. The NDP failed due to a flawed design.

3. The mega projects have had mixed impacts at the farm-, canal command- and basin-scales. For example, at farm-scale, SCARPs in fresh groundwater areas increased cropping intensity, crop yields and farmers' incomes. At the canal command-scale, the SCARPs lowered groundwater levels reduced waterlogging and salinity, augmented canal flows contributing to a more reliable irrigation supply, and increased agricultural production. At basin-scale, these reduced land degradation, stabilised agricultural production and contributed to water and food security.

Future Directions

1. The NDP was unsuccessful, but it drafted the drainage sector strategic research and development plan (SRDP). Exposing weaknesses, it has set the pathway for future institutional reforms.[19] A better foundation for sustainably improved SAWM in the Indus Basin could be achieved by updating the SRDP for groundwater, salinity and drainage, by educating stakeholders, and by building a broad-based consensus.
2. Combating salinity does not necessarily mean eradicating salinity. Indeed, this may not be a cost-effective solution. The SAWM needs to be viewed in the context of improving community livelihood opportunities while reducing the risks to the land and people living in salt-affected areas. Learning to live with salt-affected soils should be one of the management options. Farmers need alternate options to increase the profitability of saline land. A part of future investment in SAWM may be guided through the concepts of 'living with salinity', reducing risks and improving livelihoods of people. This may require investments in awareness raising and the capacity building of people.
3. The Indus Basin's water, salinity and drainage issue are complex and have generated many unsuccessful stories. A least-harm, cost-effective and early impact approach for SAWM is needed. An informed SRDP should guide future investment in SAWM in the Indus Basin over the medium- to long-term. However, in the short-term, well-planned, farm-scale and farm-based interventions in partnership with farmers may help in achieving immediate benefits for land, water and people.
4. Identifying 'bright spots' and best land practices within the Indus Basin, and characterising, screening and ranking them for upscaling could be one of the most efficient and cost effective ways to approach the salinity problem.
5. Basin-based investment and management planning, strategic framework for MOM and establishing, monitoring, evaluation and feedback mechanisms may help sustainably improve the management of water and the salt-affected soils. Combinations of basin-based planning, command area-based monitoring and farm-scale interventions or local actions could be better strategies to address the issue.

[19] SRDP can be part of a broad-based Indus Basin Plan. The Plan may cover cross-sectoral water interactions including identifying strengths and weaknesses, possible conflicts or threats and synergies, and management planning that paint Indus Basin's global picture and is flexible to allow conducive actions at local or regional scales.

5. Conclusion – Designing Research for Living with Salinity

This report was commissioned to provide evidence to support a new approach to research involving salinity in Pakistan. It contributes to the design of such research, and the ACIAR funded project being proposed in particular. To identify the best approach for such a new project, this report's contribution has been to:

1. Better understand the issues being faced.
2. Review past actions, especially of past projects, that sought to address these issues.
3. Provide a critical summary of the results of past actions and lessons to be learned.

In the Indus Basin, waterlogging and salinity have resulted from:

1. The extensive irrigation system.
2. Rising groundwater tables.
3. Salt inflow and accumulation.

In the second half of the 20th century, waterlogging and salinity dominated debates and management actions, and several mega projects were implemented. The success rate of these mega projects was low, and their sustainability has been questioned. Reasons for this include their large size and complexity coupled with low institutional capacity to implement such projects effectively. They lacked farmer participation, had high operating costs, and fell far short of their overambitious targets. With some variations, salinity continued to persist, productivity declined, and communities suffered.

This report therefore recommends a new more holistic approach with a change of focus. The focus for future research should shift from 'eradicating salinity' to 'living better with salinity'. My recommendation for a future project focused on living better with salinity is that it should have an SSPP approach: it should be Simple, involve Small-scale case studies, be Participatory and involve Pilot-testing (see Figure 7). In brief, the research should be undertaken through co-design and with stakeholder consensus, it should be community-based with low cost and direct benefits, where technologies and methodologies are tested with and by farmers, where indigenous practices are blended with innovativeness, involve capacity building, and have a plan and characterisation for both out-scaling and up-scaling.

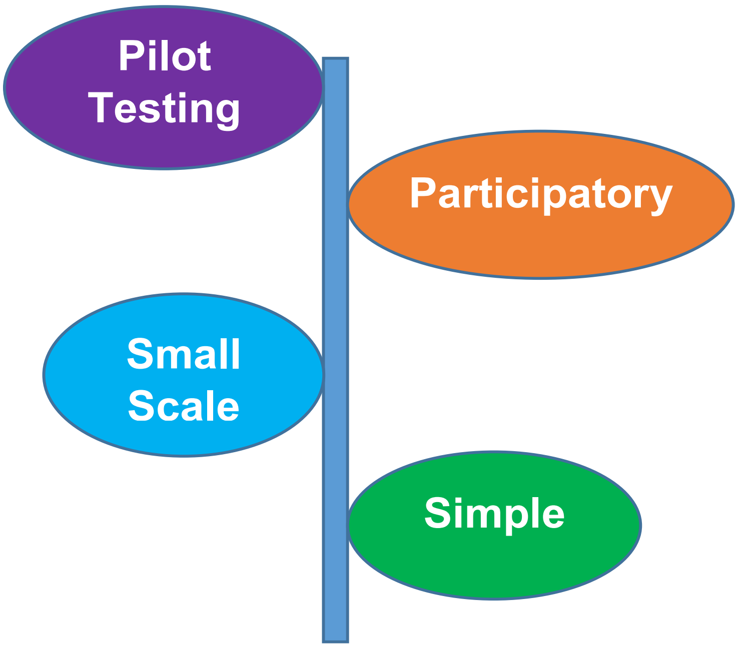

Figure 7: Main Elements of SSPP Research Approach

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Gulbali Institute
Agriculture, Water and Environment

Charles Sturt University
Boorooma Street
Locked Bag 588
Wagga Wagga NSW 2678

1800 275 278 (free call within Australia)
+61 1800 275 278 (callers outside Australia)

gulbali@csu.edu.au

gulbaliinstitute

gulbali_inst

gulbaliinstitute

charlessturtuni

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