Paper No.149

ROLE OF SALINITY MAPPING IN CONTROL OF DESERTIFICATION PROGRESS AND ACCELERATING LAND RESTORATION

Raheel Mustafa Gondal,
Muhammad Basharat,
Shakeel Ahmad,
Muhammad Masood Ahmed Soomro

Role of Salinity Mapping in control of Desertification Progress and Accelerating Land Restoration

By

Raheel Mustafa Gondal[1], Muhammad Basharat[2], Shakeel Ahmad[3], and Muhammad Masood Ahmed Soomro[4]

Land being the guarantor of food security of any country is a precious resource. This precious resource is being degraded or lost due to desertification and salinization. Desertification is reported to affect over three billion hectares of rangeland, 172 million hectares of rain fed crop land and 27 million hectares of irrigated land, in arid areas. Ten percent of the world's land surface is estimated to be affected by salinity & sodicity (Szabolcz 1991). It is estimated that 20 million hectares of land deteriorate to zero or negative productivity each year in addition to that already affected.

Salinity & Waterlogging is a major contributor to the degradation and desertification of agricultural land across the globe & particularly in Pakistan. It was estimated in the late 1990s that about 6.2 Mha (35–40% of the total irrigated area) in Pakistan was affected due to the twin problems of waterlogging and salinity (Government of Pakistan, 1997; Ali, 2018).

The more recent data from the 2000s suggest that 4.5 Mha across the Indus Basin is affected by salinity (WAPDA, 2007). This variation in estimates emphasizes a desperate need for updated and regular assessment of the presence of salinity across the Indus Basin. This paper explores the role of salinity mapping as a crucial tool in combatting desertification and facilitating land restoration efforts in Pakistan. Salinity mapping provides essential data on soil salinity levels, which directly impact land degradation and desertification. By analyzing existing literature, remote sensing techniques, and case studies from Pakistan, this paper evaluates how accurate salinity mapping contributes to understanding desertification dynamics.

The Indus River and its tributaries bring about 31.6 million metric tons (Mt) of salts annually. Salinity is wide spread in Lower Indus part of IBIS. The previous surveys indicate that areas under S2 and S3 in irrigated areas of

[1] Director Salinity & Environment, IWASRI, WAPDA, Corresponding author's email: raheelmustafagondal@gmail.com

[2] Addl. Chief Engineer, (Drainage) IWASRI, WAPDA, Pakistan

[3] Director General, IWASRI, WAPDA, Pakistan

[4] General Manager (Central), WAPDA, Pakistan

Lower Indus has increased from 1979-81 to 2001-03. That is, the non-saline area has decreased from 54% in the previous survey to 49% in 2001-03. Thus, in Lower Indus deterioration has been taken place in almost all categories of surface salinity, and the salt affected area has increased. salinity mapping helps planning for implementing a long-term salinity management strategy facilitating for educating farmers living with the salinity and a ready reference for all the R&D organizations.

1. Introduction

1.1 What is Desertification?

Desertification is the process by which fertile land becomes desert, typically as a result of various factors, including climatic changes and human activities. Annually about 12 million hectares of land is lost due to desertification, affecting over 1.5 billion (UNCCD, 2017). Decrease in vegetation, extra pumping of water and overgrazing are the major cause of desertification which increases the soil erosion, soil salinity, saline water and also cause of siltation in reservoirs. Rapid growth in population and inefficient agricultural practices are the manmade cause of increase in desertification. Desertification, characterized by land degradation in arid, semi-arid, and dry sub-humid areas, is a pressing issue in Pakistan, exacerbated by factors such as climate change, unsustainable land use practices, and water scarcity. In Pakistan where 80% area is semi-arid and arid and 168 million populations depend on dry land to support their livelihood through agriculture. Out of 79.6 million hectares of land area of Pakistan, 62.4 million hectares are susceptible to desertification, as only 4.2% of the total land is under forests. In view of the aridity, 60% of the country is classed as rangelands, 48% of these rangelands are degraded (Zahid et al,2012).

Salinity and waterlogging, two manifestations of the salt-affected soils, are a serious threat to food fuel and fiber production in the world. On a global basis, about one-third of all agricultural lands are becoming saline. The problem, which extends to more than 100 countries, is encountered in all types of climate and is a consequence of both natural processes and human interference.

1.2 Types of Salt Affected Soils:

There are two main types of salt-affected soils. The first are saline soils, which contain sufficiently high levels of sodium chloride (NaCl), sodium sulfate (NaSO4), or, more rarely, other neutral salts, to inhibit the growth of crop plants. The second type of salt affected soils, are sodic, or alkaline, clay soils. They generally have low levels of total salts but contain enough

of the alkali salt sodium carbonate to damage heavy soils. Sodium carbonate (Na2CO3) causes the clay particles in soil to disperse, or deflocculate, by ion exchange processes, resulting in a deterioration of soil structure. A sodic soil has a low permeability to water and air and a pH above 8.2. Plant growth is inhibited by negative effects of sodium on the soil and by the high pH, which reduces nutrient availability to the plant. Soils can become saline or sodic through natural processes or human-induced processes.

Saline soils (without Sodium salts) and Sodic soils (called 'alkaline soils) are most wide spread in irrigated areas in arid and semi-arid regions, but also occur in the more humid climates especially in coastal areas. The salts (other than sodium) or exchangeable sodium in saline and sodic soils hinder crop growth. For efficient crop production, these salts must be leached from the root zone (Ritzema, 1994). But, in water scarce-regions, the leaching is difficult due to a shortage of fresh water. It is true that waterlogging and salinity is still a serious issue in all of IBIS.

Classification of salt-affected soils Salt-affected soils are classified according to the types of salt and intensity of the salt problems. Classification of the types of salt-affected soils was first proposed by Richard (1954) based on electrical conductivity (EC), pH and exchangeable sodium percent (ESP) or sodium adsorption ratio (SAR). According to this scheme, there are three types of salt-affected soils **Saline:** soils with excess soluble salts in which EC > 4 dS/m, pH < 8.5, and ESP < 15 (or SAR 8.5, and ESP>15 (SAR>13) • **Saline-sodic soils**: soils with high content of soluble salts and appreciable quantity of sodium ions capable of alkaline hydrolysis. **Sodic Soils:** The soils have EC>4 dS/m, pH < 8.5 and ESP >15 (or SAR > 13) Many proposals have been proposed in the literature on the limits given by Richards (1954). Abrol et al. (1988) proposed pH limit of 8.2 instead of 8.5 for the three classes of salt-affected soils.

1.3 Drivers or causes of salt problems:

Drivers of the soils problems can be grouped into two: primary and secondary drivers. Primary drivers are the natural sources of mineral elements contributing to the salt problems or the natural conditions that favor development of salt-affected soils. Secondary drivers are factors that exacerbate salt problems in the soils. They are largely associated with human intervention on the natural environment.

1.4 Major Causes of Salinity in Indus Basin:

Researchers have highlighted three main sources of salinity in the Indus basin:

1. Soil salinity is inherent in the Indus Basin due to its flat topography, aridity and diversion of natural river courses for the expansion of the irrigation system (Tarar, 2002).
2. The Indus River and its tributaries bring about 31.6 million metric tons (Mt) of salts annually. Out of the total salts, about 19.95 Mt are deposited in the canal commands at the rate of 1.25 tons per hectare. About 8.81 Mt of salts are drained below Kotri. The remaining 2.8 Mt of salts are retained in either wetlands or join the underlying aquifer through seepage (Saiqa *et al.*, 2022).
3. Another source of salts in the Indus Basin is the use of groundwater. In Sindh, the groundwater quality is generally worse but groundwater use for irrigation is considerably lower than in Punjab (Ahmad *et al.,* 1998; Young *et al*., 2019). With more pumping of groundwater, there are more chances of salinity build-up in the soil. Irrigating with low or marginal quality groundwater aggravates the accumulation of salts in the soil profile and plant root zone, causing secondary salinization, land degradation, and reducing agricultural production (Ali, 2018).

Table-1: Crop Yields from Normal & Salt-Affected Soils of Pakistan

Crops	**Average yield on normal soils ($t\ ha^{-1}$)**	**Average yield on Salt-affected soils ($t\ ha^{-1}$)**	**Loss in yield (%)**
Rice	2.82	1.35	48
Wheat	2.77	0.88	32
Sugarcane	70.00	26.60	35
Cotton	1.12	0.50	45

1.5 Status of Salinity & Land Degradation in IBIS-Pakistan:

The salt-affected soils in irrigated and non-irrigated areas of Pakistan are about 6 million hectares (Ghafoor et al. 2004) The latest surveys (2001-2003) by SMO, WAPDA indicate that 27 percent soils have surface salinity and 39 percent soils have profile salinity problem in Pakistan (WRPI & IWASRI, 2005).

Salinity, a key indicator of soil health and degradation, often accelerates desertification processes by rendering land unsuitable for agriculture and other productive uses. Effective management of soil salinity requires

accurate and timely data, which can be obtained through salinity mapping techniques.

2. Historical Perspective

Salinization and waterlogging in the Indus Basin were first formally documented in 1851 in the Western Jammu Command, and was followed by similar reports from other Punjab commands. During 1850–1950, the only known reason for waterlogging and salinity was the expansion of the unlined canal system (Bhutta and Smedema, 2007). Mohammad and Bering (1962) reported that Roger's report to the President of Pakistan indicated an average rise of the groundwater table at a rate of 0.6 m per year. This rise in the water table was linked to 45 to 54% water loss during water conveyance and application. It was reported that out of average annual water diversions of 92.5 billion cubic meters (Bm^3) to canals, only 42 to 50 Bm^3 was available for crops-5. Literature suggests that waterlogging and salinity problems in Pakistan were approached through different strategies, projects and programs. Starting in 1960s, it was recognized that some of the waterlogging and salinity problems were related to policy/institutional shortcomings and could be alleviated to a certain extent by adopting appropriate reforms (World Bank, 1994). to WAPDA's Revised Action Plan (RAP) in 1977 (WAPDA, 1979).

Table-2. An overview of the Surveys, policy and research evolution since the 1960s

S.#	Name of Survey	Year	Agency	Methods	Findings
1	Reconnaissance Survey under Colombo Plan	1952-53	Colombo Plan co-operative Project	Mapping is based on aerial imagery at the scale of 1:40,000	Predominantly waterlogged: 18,783 Sq.mile Predominantly severely saline: 7852 Sq.mile Areas with common saline patches: 17,692 Sq.mile
2	Surveys by water and soils investigation division, WAPDA	1960	Water and Soil Investigation Division (WASID)	Enlargement of aerial images 1:15,840. The survey of 4-6 bore holes per square mile to a depth of 304 cm.	Soil survey conducted in Punjab on Doab level; 24% was found to be salt-affected.

S.#	Name of Survey	Year	Agency	Methods	Findings
3	Lower Indus Project Survey	1966	M/S Hunting Technical Services and MacDonald's and Partners	Electrical conductivity survey of soil from 0-450 cm top-soil layers	Non-cultivable: 40 thousand hectares Moderately salt-affected: 0.384 Mha Seasonal swamps: 0.091 Mha Severely salt-affected: 0.521 Mha
4	Surveys by Project Consultants	1974-76	Multiple Consultants	Mostly relied on data collected by Water and Soil Investigation Division	Project specific surveys conducted for various projects and through different methods. Results not found
5	Reconnaissance Survey by Soil Survey of Pakistan	1978	Soil Survey of Pakistan	Aerial imagery of 1:40,000 scale along with topographic sheets of 1:50,000 and 1: 250,000	5.8 Mha (23%) of land is salt-affected in total Indus plains
6	Revised Action Plan (RAP)	1979	Master Planning and Review Division, WAPDA	A combination of fresh aerial photography at the scale of 1:30,000 along with field survey	Salinity and sodicity profile of soil (8.55 Mha) 0-15 cm = 28% saline, saline-sodic 15-45 cm = 24% saline, saline-sodic 45-90 cm = 25% saline, saline-sodic 90-180cm = 22% saline and saline-sodic
7	Salinity Survey of Indus Basin	2001-03	IWASRI & SMO, WAPDA	Remote Sensing & Field Survey	Salinity Atlas of IBIS produced

3. Methods for mapping salt-affected soils

Maps of salt-affected soils contain spatial information of the distribution of types and intensity of salt problems in the soils. They are developed by considering the drivers, indicators, prevalence of salt-affected soils in the

landscape and mapping tools and resources (Figure-1). Input data on the drivers and indicators provide the evidence of occurrence of salt problems in the soil. They influence the type of mapping tools for information mining and representation of the final maps. Some of the commonly used mapping tools include Geographic Information Systems (GIS), statistical modeling, stereoscopes, etc. Besides the input data and mapping tools, mapping methods are also influenced by resource requirements, such as expertise, computing facility, and funding.

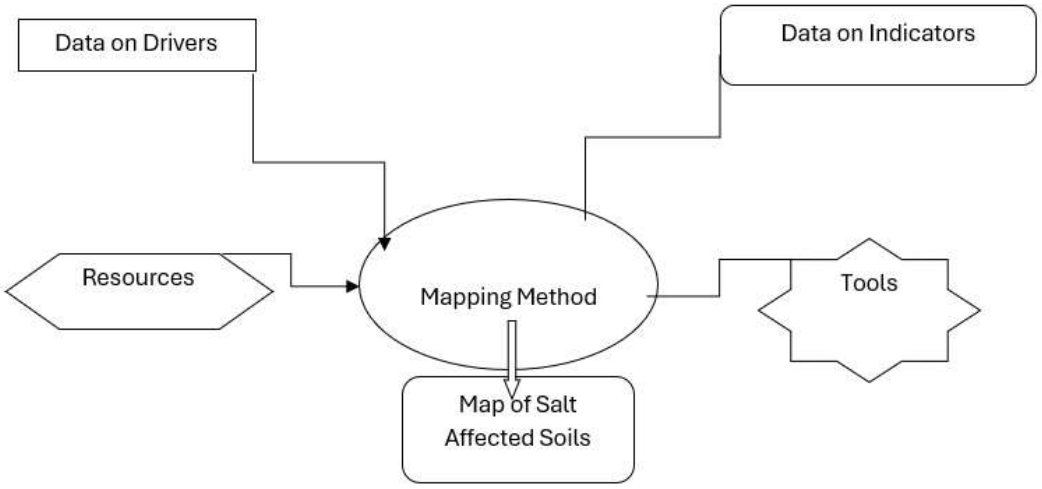


Figure-1: Framework for developing mapping methods for salt-affected soil

3.1 Using remote sensing application:

Remote sensing application has been used in agriculture and environment for many years. The technology provides spatial and temporal information about the land cover, soil cover characteristics, climate, and atmospheric conditions, which are of importance in soil and agriculture resources management. It relies on the interaction of the electromagnetic radiations with soil and vegetation to produce characteristic signatures in the reflected radiations. The reflected signatures are then modeled to extract soil and vegetation features. Two broad categories of radiations are discernible with this technology: radiations from the sun (also called passive radiations) or radiations from the sensor (active radiation). They are further classified according to the type of sensors detecting the radiations: 1) proximal sensors, which are put on the soil surface or a few meters from the soil surface; 2) sub-atmosphere cameras, which are carried by low lying aircrafts or aerial vehicles; and 3) satellites

Remote sensing applications in mapping salt-affected soils target land surface evidence of salt problems in the soil. Examples of proximal sensors often used are electromagnetic induction (EMI), geophysical sounding, and reflect meters. These sensors are mostly used to determine bulk soil electrical conductivity (Lesch et al., 1992). Low-altitude sensors such as Unmanned Arial Vehicles (UAV) are also gaining traction in mapping salt-affected soils (Hu et al., 2019; Ivusking et al., 2019). Hu et al. (2019) tested hyper spectral camera mounted on UAV and EMI in mapping salinity and found UAV as the most promising method for high-resolution identification of soil surface salinity characteristics.

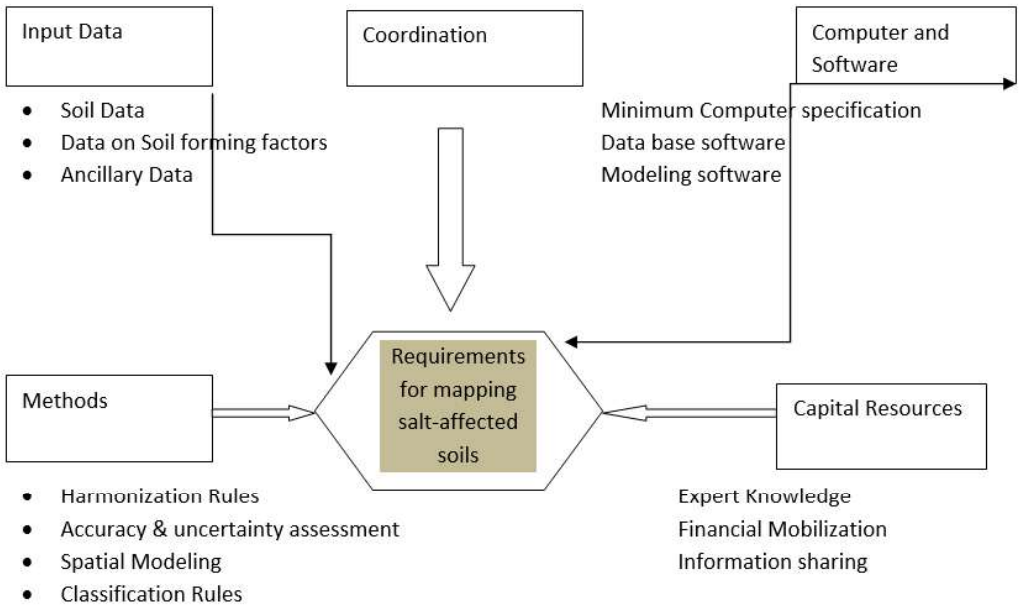


Figure-2: Requirements for multistage mapping of salt-affected soils

4. Policies and Strategies

The National Water Policy was approved in 2018 which also recognized the problem of waterlogging and salinity. The policy vowed to make future infrastructural development in consultation with the provinces in a holistic manner. A pledge for a "National Drainage System" is also a feature of the policy. Watercourse lining is to be promoted in saline and semi-saline areas to avoid conveyance losses. Harvesting of rainwater to flush out salts and to avoid accumulation of rainwater runoff into surface drains was also highlighted. The evident limited understanding of the scale of the problem reveals the extent the inherent salinity problem has been neglected. This might be due to non-availability of sufficient data and information for policy and decision makers. In drainage projects, strategies were lacking to tackle

the drainage effluent, as evidenced in the SCARP VI project where effluent drained into evaporation ponds 41 is now contaminating the command area of the Rainee Canal. Earlier research had strongly discouraged the use of evaporation ponds for effluent management (Chandio and Majeed, 2002; Tarar, 2002). The SCARP VI project was intended to be a solution to waterlogging caused by the aftermath of the 1973 flood, which in turn was an outcome of poor and politically influenced decision-making involving the breaching of the Panjnad section. The 18th Amendment of the Constitution and associated incomplete devolution of powers represented a final blow to already weakened policies and strategies. Conflicts between WAPDA and PIDs remained unsettled on taking over these systems and carrying out operation and maintenance, resulting in poor post construction maintenance. Under-funding and departmental hierarchy in budget allocation has been the main constraints resulting in poor maintenance. 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 groundwater table, reduce salinity, increase agricultural production and reduce health risks.

4.1 Institutional Constraints:

There are a number of success stories but they have not been disseminated or upscale to be used as "lessons learnt" or "best practices". One of the key reasons is that there is a lack of integration among organizations involved. Organizations like IWASRI, SMO, and LIM are still functioning in project mode. Therefore, their scope depends on bite-size allocations from the federal budget. For instance, SMO used to work on soil salinity data collection until 2004 but afterwards, this aspect was eliminated from its scope. Presently, the organization is only provided with funds to collect data and develop an analysis report. It lacks funding to manage the existing 2,000 observation wells or to install new wells. SMO reports that it does not monitor SCARP operations; they only collect groundwater samples from the observation wells. 42 In addition to gaps in data collection, there are only limited numbers of organizations who have worked on salinity. The Soil Survey of Pakistan is no longer collecting waterlogging and salinity data since its devolution after the 18th Amendment. Current departmental mandates are limited to collection of data on soil physical properties. Surveys of agricultural soil and chemical characteristics of soil is the responsibility of Soil Fertility laboratories in Sindh and Punjab. In Sindh, the department has laboratories in only 12 districts whereas Punjab has laboratories in all districts. These laboratories only provide services to farmers on their requests, and the consequent inability to take full ownership

for the problem of salinity has jeopardized farmers' trust in these organizations. This low organizational capacity also highlights where the strategic priorities of the provincial governments lie and the limited vision of the organization's leadership. Another key reason for data gaps is that data among the organizations is not being shared. This undermines the quality and authenticity of data and leads to poor quality of reporting. There is non-compliance of the standard operating procedures of projects and reluctance or no strategy for open data sharing. As for compliance, the PC-V lessons learnt assessment forms required by Pakistan's Planning Commission for each public sector development project have rarely been collected from the organizations involved. Also, organizations such as NIAB, NIA and agricultural research departments, who claimed to have conducted relevant research in soil salinity, are reluctant to share their reports and books. Data restriction in NIAB is so excessive that important pieces of information are censured on the web page leading to poor readability and understanding. During FGDs, NIA and agriculture department officials mentioned some knowledge products on salinity management but they were reluctant to share their reports. The case of organizations such as WAPDA, including its allied institutes, and PCRWR is different. Their data, project reports and publications of post 1960s are freely available for researchers. IWASRI consistently published a catalogue of research conducted relevant to salinity until 2004. That is why these organizations have always remained a strong supporter of establishing a consolidated database for sharing the project recommendations and to avoid the repetition of work.

5. Proposed research study - Soil Salinity Mapping of Indus Plain for Spatio-temporal Variation Assessment Using Remote Sensing and GIS

Recently (March-2022) PCRWR carried out a study titled: "*Adapting to Salinity in the Southern Indus Basin (ASSIB)*" in collaboration with Australian Centre for International Agricultural Research (ACIAR) and other Pakistani as well as international organizations with the key objective to review the policies and strategies relevant to salinity management in the southern Indus Basin. It was one of the recommendations of consortium that there was a need to conduct regular surveys to determine the extent of waterlogging and salinity, particularly for the southern Indus Basin, with detailed survey to be conducted at 10-year intervals, now about 20 years have passed that no salinity survey could be conducted.

As such, following study was designed to aim at fresh soil salinity mapping of the whole Indus Basin to know current situation of salinity in the Indus plain, employing advanced remote sensing techniques, GIS and machine-

learning algorithms etc. The results of this study will help planning for implementing a long-term salinity management strategy facilitating for educating farmers living with the salinity and a ready reference for all the R&D organizations for better planning for controlling land degradation.

5.1 Objectives:

The proposed study is designed to achieve the following objectives.

- To check the current status of soil (surface & profile) salinity in the irrigated areas of IBIS;
- To assess the spatial and temporal changes in soil salinity in comparison with the last surveys; and
- To classify irrigated areas of whole IBIS based on the severity of soil salinity for remedial measures, and recommending appropriate land use options.

5.2 Study Area:

The study area would be entire irrigated canal command area of IBIS, to be surveyed by IWASRI and its field formations as tabulated in Table No. 3 and also shown in Figure-3.

Table-3: Study Area along with Canal Commands

Office Conducting Study	Canal Name	Province	Command Area (Ha)
IWASRI	Marala Ravi Link Canal	Punjab	88872.04
	Raya Branch Canal	Punjab	213554.19
	Jhang Branch Canal	Punjab	816139.94
	Upper Chenab Canal	Punjab	467878.32
	Jhang Branch Canal	Punjab	816139.94
	Central Bari Doab	Punjab	389420.35
	Upper Depalpur	Punjab	143188.67
	Lower Depalpur	Punjab	289933.59

Office Conducting Study	Canal Name	Province	Command Area (Ha)
	Gugera Canal Command	Punjab	715132.13
	Lower Bari Doab	Punjab	792436.81
	Pakpattan Canal	Punjab	505983.68
	Fordwah Canal	Punjab	224270.61
	Sadiqia Canal	Punjab	497955.04
	Mailsi Canal	Punjab	464679.34
	Sidhnai Canal	Punjab	370931.09
	Bahawal Qaim	Punjab	456215.79
	Abbasia Canal	Punjab	125359.51
	Panjnad Canal	Punjab	617674.05
MREP	Upper Sawat Canal	KPK	114053.02
	Lower Sawat Canal	KPK	82696.39
	Warsak High Level	KPK	595128.68
	Landi Dak	KPK	8741.21
	Katch Kot	KPK	23471.76
	Upper Jhelum Canal	Punjab	291349.42
	Lower Jhelum Canal	Punjab	696545.38
	CRBC	KPK	278227.48
	Haveli Canal Command	Punjab	81543.64
	Thal Canal Command	Punjab	1157749.32
	Rangpur	Punjab	164652.89
	Muzaffargarh	Punjab	345766.37
	DG Khan	Punjab	431248.53

Office Conducting Study	Canal Name	Province	Command Area (Ha)
	Desert Canal Command	Balochistan	188111
LIM	Patfeeder Canal	Balochistan	264103
	Bagari Sindh Feeder	Sindh	479272
	Ghotki Canal Command	Sindh	398543
	North West Canal	Sindh	405909
	Khairpur West Canal	Sindh	121870
	Rice Canal Command	Sindh	243609
	Khairpur East Canal	Sindh	196015
	Dadu Canal Command	Sindh	243555
	Rohri North	Sindh	554948
	Rohri South	Sindh	619141
	Nara Canal	Sindh	977760.92
	Lined (Gaja)	Sindh	45939.7
	Fuleli Canal Command	Sindh	423104
	Lined (Tando Bago)	Sindh	162667
	KB Feeder Canal	Sindh	333745
	Pinyari Canal Command	Sindh	397091

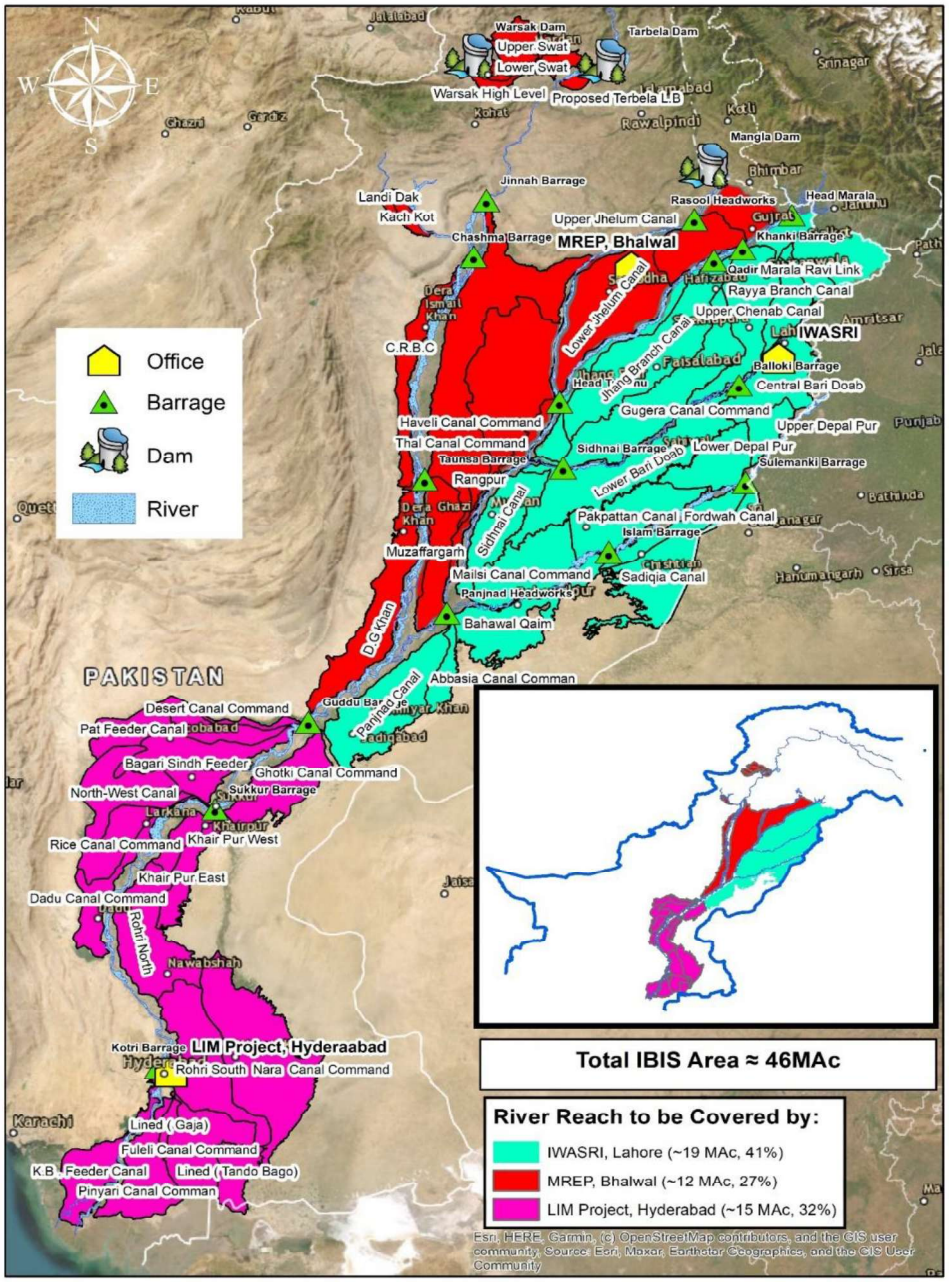


Figure-3: Delineation of Canal Command Areas of IBIS to be surveyed by IWASRI and its Field offices

5.3 Methodology:

The methodology to be adopted in this study is represented in Figure-4. In the beginning literature for all the past studies is solicited on soil salinity carried out during different time periods in Pakistan and other countries in the world especially South Asian countries, viz; India, Bangladesh, and Iran having irrigation system similar to Pakistan. The next phase consists of extensive field survey for data collection. The whole irrigated area of IBIS (~ 46MAc) will be surveyed at the resolution of one auger bore log @ 1 sq.km for Lower Indus for profile salinity, analyzed in the laboratory and results computerized afterwards, however for Punjnad Barrage and Muzzafagarh canal commands it would be about @ 1.5 sq.km and for rest of the Punjab and KP it would be 2 sq.km for one observation for profile salinity.

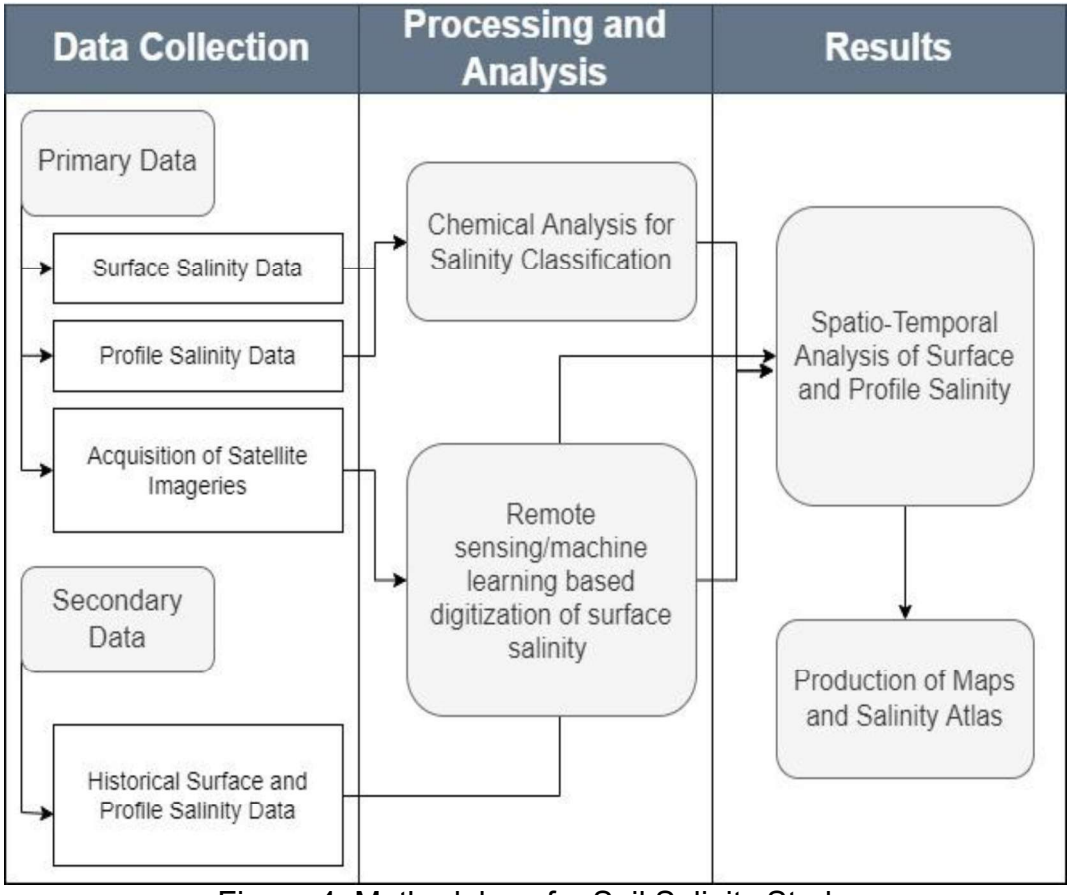


Figure-4: Methodology for Soil Salinity Study

5.3.1 Criteria for Surface Salinity Mapping:

Four categories namely, non-saline (S1), slightly saline (S2), moderately saline (S3), and strongly saline (S4) will be mapped. The criteria for classification of surface salinity categories are based on the Soil Survey Manual Agriculture Handbook No.18 (1993) of USDA as quoted in WAPDA (2001-03).

Table-4: Criteria for Surface Salinity Classification

Soil Class	Mapping Symbol	EC_e(dS/m) at 25°C	Salt (%)
Non Saline	S1	4	≤ 0.2
Slightly Saline	S2	> 4 to ≤ 8	> 0.2 to ≤ 0.5
Moderately Saline	S3	> 8 to ≤ 15	> 0.5 to ≤ 1.0
Strongly Saline	S4	> 15	> 1.0

Table-5: Field Observation Indices for Surface Salinity Classification

Category	Description
S1	No salts are visible on soil surface, plants growth apparently not affected by salinity/sodicity.
S2	25% of the soil surface is affected by patchy salinity. Plant growth is slightly in patches.
S3	Salts visible, on 25-75% of soil surface. Crop growth is in poor to very poor condition.
S4	The area is abandoned, and barren thick salt crust/puff is visible on surface. This type of salinity may generally support presence of very-highly salt tolerant plant species.

5.3.2 Use of Machine Learning Tools (MLT) for Surface Salinity Mapping:

Advancement in remote sensing techniques & machine-learning algorithms has started contributing to fast & large-scale monitoring & mapping of soil salinization throughout the modern world. In this research, satellite imageries from Landsat-8 OLI, Sentinel-2A and Dynamic World is to be

acquired to be processed on Google Earth Engine (GEE) platform. The training dataset in the form of field survey will be fed to the modeling environment. Classification and Regression Trees (CART), Random Forest (RF), and Support Vector Regression (SVR) methods will be implemented to create a correlation between ground measurements and satellite-derived environmental variables or spectral indices. The reason for selecting above mentioned satellite imageries is that they are free source and are available at high resolution with low return period. The characteristics of these imageries are shown in Table-6.

Table-6: Characteristics of Satellite Imageries

Sr. No.	Satellite Mission Name	Resolution		Coverage		Bands	Controlling Agency
		Spatial	Temporal	Spatial	Temporal		
1	Copernicus Sentinel-2	10m	10 Days	83°N to 56°S	Since Jun-2015	13 No Spectral Bands	European Space Agency (ESA)
2	Landsat-8 OLI	30m	16 Days	82°N to 82°S	Since Feb-2013	09 No Spectral Bands	NASA/USGS
3	Dynamic World	10m	2-5 Days	83°N to 56°S	Since Jun-2015	13 No Spectral Bands	Google-WRI JV

After selecting the optimum variables including wetness band, four soil salinity indices, and one vegetation index; soil salinity maps will be generated in three machine-learning algorithms.

5.3.3 Grid Size Selection - Criteria for Profile Salinity Mapping:

Salts keep on fluctuating from surface to ground water and vice versa through the soil profile, depending upon rainfall, canal water and groundwater usage and quality. Soils can be highly variable, even over short distances. Because of this variability, it is often insufficient to collect soil at just one location. Instead, it is preferable to collect so-called composite samples. Composite samples are a mixture of individual samples, or subsamples, generally collected from multiple locations and mixed together to form a single composite sample. By combining multiple subsamples into a single composite sample, we can minimize the effects of soil variability by averaging the soil properties over larger areas. Composite samples are less sensitive to unusually high or low soil test values that might occur due to concentrated fertilizer applications (e.g. banded applications) or natural soil variation. It is, therefore, necessary to select a

suitable grid size for salinity survey of whole IBIS therein considering two major constraints namely cost & time.

Selection of optimized grid size is very important in order to obtain quality results of survey for which data of historically carried out soil salinity surveys can be used as initial guideline. During 2001-03 IWASRI carried out basin wide salinity survey @ 2Km X 2Km under NDP (National Drainage Programme) and updated soil salinity Atlas.

In this study different parts of IBIS will be surveyed considering different grid sizes @ 2Km, 5Km & 10Km and impact of its variation on quality of results is to be checked. Table below represents number of sites, samples and time required for survey with a particular grid size.

Table-7: Statistics of Samples & Duration for Salinity Survey Using Different Grid Sizes

Sr. No.	Grid Size	Samples		Duration
		Sites	Nos	
1	2Km x 2Km	94322	377286	1Y 11M
2	5Km x 5Km	37729	150914	0Y 9M
3	10Km x 10Km	18864	75457	0Y 4M

Table-8: Soil Profile Salinity Classification

Soil Salinity Class	ECe (dS/m) at 25°C	SAR
Non Saline – Non Sodic (**NS-NS**)	≤ 4	≤ 13
Saline – Non Sodic (**S-NS**)	> 4	≤ 13
Saline – Sodic (**S-S**)	> 4	>13
Non Saline – Sodic (**NS-S**)	≤ 4	>13

In order to study the distribution of salts and sodic conditions in the soil profiles, one auger hole per Cell have to be made up to 180 cm depth or to the sloughing material whichever is shallower. Soil samples will be collected in four sectional depths viz. 0 to 15, 15 to 45, 45 to 90 and 90 to 180 cm as per USDA. These samples will be tested for pH, ECe and SAR in the laboratory for classification of soil profiles. Moreover; as USDA derived relationship between SAR/ESP based on USA's soil, similarly, SAR-ESP

relationship will be derived from soil samples based on Pakistan's soil and climatic conditions. The soil samples will be classified according to the criteria laid down in USDA Handbook No.60 as given below. Location of each bore site will be determined using Global Positioning System (GPS) by the field party. This will facilitate and ensure location of observation point for GIS maps production at four different depths as explained above.

5.4 Comparison of Previous Surveys

The comparison of surface salinity survey 2001-2003 of the four provinces, with the previous survey conducted in 1976-79 is carried out. The comparison of the two surveys shows a remarkable improvement in S2, S3 and S4 categories in Punjab Pakistan, which have been converted into non-saline, i.e. non-saline areas increased from 86% in 1976-79 to 93% in 2001-03, as shown in Figures 5 and 6. This is quite logical, the reason being that after completion of Tarbela reservoir in 1976-77, the canal head withdrawals in the Indus increased to 124.6 BCM just after the Tarbela Dam and reached the peak of 133.2 BCM in 1979. Thereafter, canal withdrawals then stagnated at this level up to 1989-90 and have now declined to around 125.8 BCM due to reduction in reservoir capacities (4.37 MAF, 28%, by the year 2012) caused by progressive sedimentation (Ahmad et al., 2012). That is why there is about 30% reduction in Rabi supplies to Punjab, during 2001-09 due to online storage loss and Low River flows during drought period (Basharat et al., 2014). Increased fresh water supply to agricultural lands is a major factor, in leaching down the salts or otherwise salinity build up. Therefore, it is hypothesized (in the absence of fresh survey and reduced canal supplies during last many years) that profile salinity has also increased in Punjab. Therefore, leaching of salts is now an emerging issue in many of the areas in Punjab.

On the other hand in Lower Indus part of the IBIS, the non-saline area has decreased from 54% in the previous survey to 49% in 2002-03 survey. Thus, in Lower Indus part deterioration has been noticed in almost all categories, and the salt affected area has increased. One of the most obvious reasons for this contrasting behavior, in changes in surface salinity, in Punjab and Lower Indus, is lowering of water table in Punjab. On the other hand, increased waterlogging conditions in Lower Indus, particularly after the provision of higher canal supplies after commissioning of Mangla and Tarbela Dams, and the absence of conjunctive use of canal and groundwater leading to lack of drainage in the root zone, had been the major factors for increase in surface salinity. The map of latest available surface salinity survey (2002-03) carried out by WAPDA, for the IBIS, is shown in Figure-4.

Table-9: Surface salinity status of IBIS surveyed by WAPDA

AREA SURVEYED 1976-79 (millions hectare)					
Province	**Non-Saline**	**Slightly Saline**	**Moderately Saline**	**Strongly Saline**	**Area**
NWFP (now KP)	0.526	0.040	0.000	0.000	0.607
Punjab	8.704	0.729	0.445	0.283	10.162
Lower Indus	3.239	1.093	0.607	1.012	5.951
Total	12.510	1.862	1.053	1.336	16.721
AREA SURVEYED 2001-03 (millions hectare)					
NWFP (KP)	1.1	0.01	0.02	0.01	1.14
Punjab	9.789	0.385	0.186	0.162	10.522
Lower Indus	2.964	1.231	0.603	1.247	6.049
Total	13.202	1.619	0.794	1.413	17.032

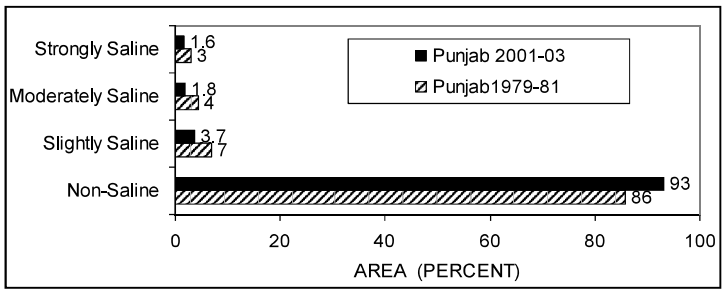


Figure-5: Comparison of surface salinity in Punjab for the periods: 1979-81 and 2001-03

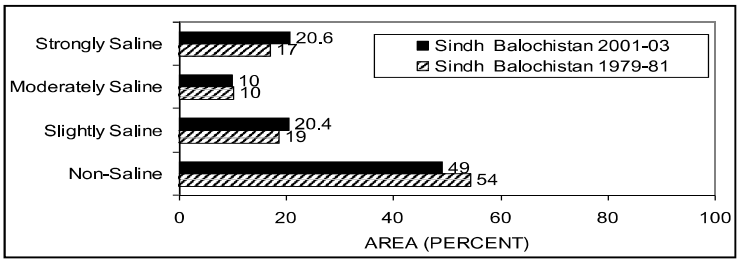


Figure-6: Comparison of surface salinity in Lower Indus for the periods: 1979-81 and 2001-03.

On the other hand, areas under S2 and S3 in irrigated areas of Lower Indus (Sindh and Baluchistan) has

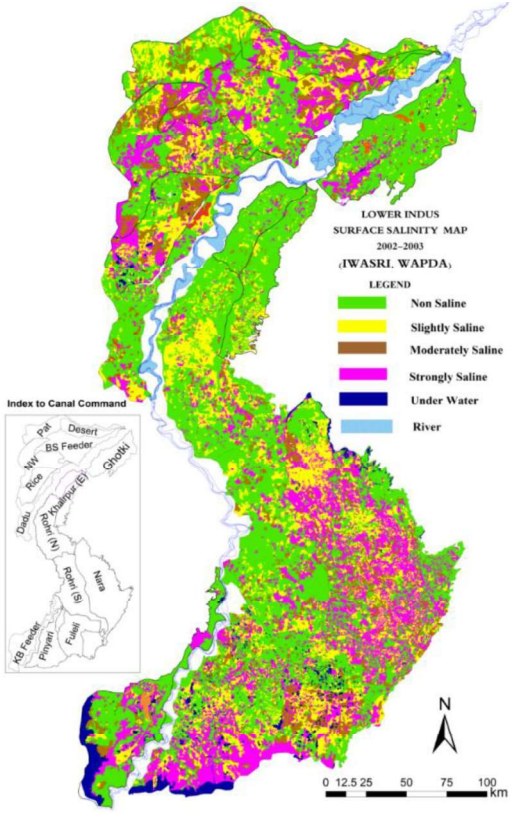


Figure-7: Surface salinity in Lower Indus, as observed during 2002-03 (Basharat et al., 2014).

Increased from 1979-81 to 2001-03. That is, the non-saline area has decreased from 54% in the previous

Survey to 49% in 2001-03. Thus, in Lower Indus deterioration has been taken place in almost all categories of surface salinity, and the salt affected area has increased. One of the most probable reasons for this contrasting behavior, in changes in surface salinity, in Punjab and Lower Indus, is lowering of water table in Punjab. On the other hand, increased waterlogging conditions in Lower Indus, particularly after the provision of higher canal supplies after commissioning of Mangla and Tarbela Dams, and the absence of conjunctive use of canal and groundwater leading to lack of drainage in the root zone, had been the major factors for increase in surface salinity. IWASRI has done an intensive and extensive research regarding salinity management in the IBIS and produced a series of reports. Aslam M. (1998) has concluded that secondary salinization in the Indus Basin is associated with the shallow ground water table and use of marginal to poor quality groundwater for irrigation. Amongst the preventive and curative approaches, the preventive salinity measures pay rich dividends at a much less cost and effort. The aforementioned approach is especially true for the Lower Indus, thus part of the salinity can be managed by lowering water table with proper water management.

5.5 Expected Outcomes:

Following are the expected outcomes of this study:

- The fresh / current status of surface / profile soil salinity in the canal command areas of IBIS.
- The results of this study will help comparing the last survey findings (2001-03 by IWASRI).
- Highlight the severity of soil salinity in different canal-command areas w.r.t. spatio-temporal variation on account of prevalent climate change scenario.
- The findings will be utilized for the zoning of whole Indus Plain based on soil salinity.
- This study will also enable to compute percentage of available fresh water (being applied for agricultural purposes) to leach down salts from saline lands and to develop management plan for converting saline lands to productive lands.

6. Conclusion:

Timely salinity mapping of the whole Indus Basin with the certain objectives is mandatory to know current situation of salinity in the Indus plain. The results of the salinity mapping help for developing policy guidelines for

sustainability and planning for implementing a long-term salinity management strategy, hence control of land degradation and translating manifold economic implications benefitting to national economy.

Overall, salinity mapping plays a crucial role in sustainable resource management, environmental conservation, and climate resilience efforts worldwide. The results of the salinity mapping will help planning for implementing a long-term salinity management strategy facilitating for educating farmers living with the salinity and a ready reference for all the R&D organizations.

References

Abrol I.P., Yadav J.S.P, Massoud F.I. 1988. Salt-affected soils and their management. FAO Soils Bulletin 39. FAO, Rome

Ahmad, B., M. Ahmad, and Z.A Gill. (1998). Restoration of Soil Health for Achieving Sustainable Development Growth in Agriculture. The Pakistan Development Review 37:4, Part II, 997-1015.

Ali, A. (2018). Improving salinity and agricultural water management in the Indus Basin, Pakistan issue, management, and opportunities: A synthesis from a desk-top literature review. Appendix 5 in Final Report for ACIAR LWR/2017/028 Small Research and Development Activity 'Improving Salinity and Agricultural Water Management in the Indus Basin of Pakistan.

Aslam M. 1998. Improved water management practices for the Rice-Wheat system in Lower Indus, Pakistan. IIMI.

Basharat M, S. Umair Ali and Aftab H. Azhar, 2014a. Spatial variation in irrigation demand and supply across canal commands in Punjab: a areal integrated water resources management challenge. Water Policy journal 16(2) 397-421; doi:10.2166/wp.2013.060.

Chandio, B.A. and A. Majeed. (2002). Long term policy for disposal of drainage water effluents. In National Workshop on Drainage system performance in Indus Plain and future strategies, January 28-29. Vol II. Drainage and Reclamation Institute of Pakistan, Tandojam.

Ghafoor, A., M. Qadir and G. Murtaza, 2004. Salt-Affected Soils: Principles of Management. A Book Published by Allied Book Center, Urdu Bazar, Lahore, pp: 304.

Iqbal, N., M. Ashraf, M. Imran, H.A. Salam, F.U. Hasan and A.D. Khan. (2020). Groundwater investigations and mapping in the Lower Indus Plain. Pakistan Council of Research in Water Resources (PCRWR), Islamabad, pp 70.

Ivuskin K., Bartholomeus H., Bregt A.K., Pulatov A., Kempen B., de Sousa L. 2019. Global mapping of soil salinity change. Remote Sensing of Environment, 231: 111260

Lesch S.M., Rhoades J.D., Lund L.J., Corwin D.L. 1992. Mapping soil salinity using calibrated electromagnetic measurements. Soil Science Society of America Journal, 56: 540-548.

M. Qadir, E. Quillerou, V. Nangia, G. Murtaza, M. Singh, R.J. Thomas, P. Drechsel and A.D. Noble. 2014. Economics of Salt-induced land degradation and restoration

Ritzema H.P. ed. 1994. Drainage Principles and Applications, ILRI Publication 16, Second Edition. Wageningen, The Netherlands: International Institute for Land Reclamation and Improvement

Saiqa, I., Hifza, R., and M. Ashraf. (2022). Water Quality Profile of Surface Water Bodies in Pakistan: Situation Analysis and Future Management Strategies. Pakistan Council of Research in Water Resources (PCRWR), pp. 111.

Squires V.R. and Ayoub A.T. (1995). Halophytes as a Resource for Livestock and for Rehabilitation of Degraded Lands. Tasks for Vegetation Science No. 32. Dordrecht: Kluwer Academic. [An examination of the role of halophytes and the potential for development of new crops for saline soils.]

Tarar, N.R. (2002). Drainage System in Indus Plain-An overview. Proceedings of National Workshop on Drainage system performance in Indus plain and future strategies. In National Workshop on Drainage system performance in Indus Plain and Future Strategies, January 28-29. Vol II. Drainage and Reclamation Institute of Pakistan, Tandojam

Water Resources Planning Organization (WRPO) & International Waterlogging & Salinity Research Institute (IWASRI), 2005. Drainage Master Plan of Pakistan. Volume II Main Report.

WAPDA. (1979a). Revised Action Program for Irrigated Agriculture. Main Report Vol. 1. Master Planning Division. Lahore

World Bank. (1994). Pakistan Irrigation and Drainage: Issues and Options. Report # 11884-PAK, Agricultural Operation Division, South Asia Region, World Bank, Washington DC. Copyright.

Young, W, J., Arif, A., Tousif, B., Edoardo, B., Stephen, D., William, R., Garthwaite III, E. Michael, G., Christina, L., Lucy, L., Ian, M., and S.

Basharat. (2019). Pakistan: Getting More from Water. Water Security Diagnostic. World Bank, Washington, DC

Zahid Hussain, Muhammad Irfan, 2012; Sustainable Land Management to Combat Desertification in Pakistan.