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Adapting to Salinity in the Southern Indus Basin: Future Research Road Map for Living with Salinity



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Executive Summary

The Adapting to Salinity in the Southern Indus Basin (ASSIB) project started in March 2021, responding to a recommendation for a holistic approach to resolve the issues related to salt-affected soils in Pakistan (Ali, 2023). Given the nexus between soil salinity and water management, and to provide an effective interface with the intended audience, the project has focused on practical ways for adapting to salinity. The project builds on the assumption that farmer-to-farmer learning combined with the engagement of the scientific research community and practitioners is essential for integrating indigenous knowledge with scientific research to manage salinity. To this end, field investigations involving salinity adaptation options commenced as a co-inquiry with the project's 'bright spot' communities. Using the Stakeholder Engagement for Research and Learning (SERL) approach (Heaney-Mustafa et al., 2023) as an engine, the 'bright spot' communities identified suitable interventions in a co-design mode with the participation of the relevant stakeholders and conducted research investigations in a co-inquiry mode.

The project has gone on to achieve farmer participation in co-inquiry research using SERL, with three 'bright spots' now recognised as demonstration sites: Tippun Dublo and Malwah in Sindh and Jalalpur in South Punjab. These activities will be continued even after the project ends due to the selection of trained farmers as leaders who will take responsibility for scaling out the SERL approach further. This project also integrated the Capability, Risk, plant Adaptation and Mitigation (CRAM) framework (Barrett-Lennard, in press), which emphasises selection of suitable salinity tolerant crops and other relevant management strategies that must align with the conditions of a particular salinity-affected landscape. Other significant legacies of the ASSIB project include the development of a salinity handbook for field practitioners (Barrett-Lennard, in press), the use of a GIS application for characterisation of agriculture and water management and mobile and web-based App for farmer guidance (Khan et al., 2024), and groundwater modelling and monitoring for water resource planning (Ahmed et al., 2024; Jamali et al., 2024; Raheem et al., 2024a; b). Use of all these approaches (SERL, CRAM, GIS and groundwater modelling) were led by early career researchers. These legacies are described in detail in this report. To resolve salinity problems at the community level, a concept note for future salinity research has also been developed (Appendix 1: Nature-Based Salinity Management Solutions for the Southern Indus Basin). This concept note is the way forward for the government to carry out and replicate the ASSIB SERL approach on a large scale.

Irrigation and agriculture departments and farming communities engaged in agriculture and aquaculture are the main actors dealing with salinity issues, including those related to soil salinity, water quality and land and water management. The Barrett-Lennard (in press) salinity handbook is a practical and field-oriented guidebook that will enhance practical advice for these farming communities, supported by the use of associated mobile and web-based applications.

The project's groundwater modelling and GIS applications for the characterisation of agriculture are major and interlinked scientific activities that will support water resource planning by Pakistan's federal and provincial governments. Groundwater modelling with different management and climate change scenarios was developed by staff employed by US-Pakistan Center for Advanced Studies in Water (USPCAS-W) at Mehran University of Education & Technology (MUET) and by MNS University of Agriculture, Multan (MNSUAM). Model outcomes have been discussed at workshops organised with relevant professionals from different departments. Following the outcome of the workshops, a concept note has been developed to carry out this approach for the benefits of irrigated agriculture and salinity management in the province of Sindh (see Appendix 2).

The project's local-scale stakeholder planning and decision-making for various interventions in the agriculture sector have benefited from application by the Australian Centre for International Agricultural Research (ACIAR) 'Groundwater' project (LWR/2015/036) of an integrative and participatory approach known as Representative Agricultural Pathways (RAPs). A concept note has been developed to take up this approach for future projects to be implemented in Pakistan (see Appendix 3).

Contents

Executive Summary	2
Acknowledgments	4
1. Introduction	4
2. An Overview of the ASSIB Project and its Legacies	5
2.1. Background	5
2.2. Overview of the ASSIB Project	5
2.3. Key Legacies of the ASSIB Project for Future Research and Practice	7
2.4. An Overview of Relevant ASSIB Publications to Date	17
2.5. ASSIB Team Recommendations for Ways Forward: Co-inquiry for Nature-Based Salinity Management Solutions	18
3. References.....	20
Appendix 1. Concept Note 1	22
Nature-Based Salinity Management Solutions for the Southern Indus Basin	22
Appendix 2. Concept Note 2	25
Strengthening Groundwater Monitoring in Sindh	25
Appendix 3. Concept Note 3	30
Using RAPs as a Collaborative Planning Tool for Communities Living in Salinity-Affected Areas.....	30

Acknowledgments

The Adapting to Salinity in the Southern Indus Basin project's main achievements (which we called legacies) were highlighted at the International ACIAR Salinity Futures Symposium held in Vietnam in March 2024. These legacies have also been discussed in several other meetings with relevant departments, organisations and donors. This project's way forward for "living with salinity" has been prepared with the support of all project partners. We acknowledge their contributions with profound gratitude.

1. Introduction

This report aims to set an agenda for future research related to salinity management and adaptation in Pakistan. Its intended audience is donors and government agencies working for the enhancement of Pakistan's economy, society and environment through improved land and water resources management. Our agenda for future research builds on the experiences of the ACIAR-funded 'Adapting to Salinity in the Southern Indus Basin' (ASSIB) project. We championed an approach for "living with salinity" – working with those managing and living in salinity-affected areas to investigate and enhance salinity adaptation options for improved livelihoods.

The report begins with an overview of the ASSIB project and its legacies. A key legacy of the project is our promotion of co-inquiry research that we co-designed with salinity-affected communities and other relevant stakeholders. This legacy is taken up in the first concept note (Appendix 1). Other legacies of the ASSIB project are taken up in two subsequent concept notes (Appendices 2 and 3).

2. An Overview of the ASSIB Project and its Legacies

2.1. Background

Soil salinity is a serious issue for irrigated agriculture in Pakistan. It affects at least 4.5 million hectares of land across the country and 54% of the lower part of the Indus Basin (Qureshi et al., 2008). Limited surface water supplies and increased dependence on poor-quality groundwater are accelerating the extent and severity of secondary land salinisation. This 'secondary salinisation' is primarily a result of irrigated agriculture, with one classic estimate suggesting that approximately 15 million tonnes of salt are added annually to the Indus Basin (NESPAK & MMI, 1993). Several efforts have been made over the last few decades to tackle this issue but with limited success. Impacts from climate change are also emerging as a key driver for increased salinisation, especially along the coastal belt of the Indus Basin.

It is increasingly recognised now that salinity is more than a biophysical problem; it is a socio-economic, environmental and human 'well-being' problem (Ali et al., 2023), whereby the farmer occupies a central position as a key stakeholder. A holistic approach is thus needed that recognises that farmers' participation, understanding and ownership are vital to the success of field-level practice change programs.

2.2. Overview of the ASSIB Project

Launched in 2021, the ASSIB project funded by ACIAR focused on learning and adaptation through collaborative planning and action involving farmers and other related stakeholders. The ASSIB project builds on the outputs, practical lessons and professional networks from previous ACIAR-funded projects in Pakistan (Spriggs et al., 2016; Mitchell et al., 2018; Mitchell et al., 2020; Heaney-Mustafa et al., 2021; Punthakey et al., 2021).

The overall objective of ASSIB was to develop and investigate adaptation options and strategies with people managing and living in salinity-affected agricultural landscapes in the southern Indus Basin. It involved the selection of 'bright spots' (Noble et al., 2006) using the criteria described by Mitchell et al. (2020). The term 'bright spots' refers to communities living in salinity-affected landscapes that sustain and perhaps enhance their livelihoods through active community-driven adaptations.

ASSIB project partners and collaborating organisations were invited to nominate 'bright spot' communities using a form that described the communities according to a set of criteria. Five communities were selected at the start of the project (three in Sindh: Malwah, Sujawal and Tippun Dublo; and two in Punjab: Jalalpur Pirwala and Muzaffargarh). Our collaboration with a consortium headed by Sindh Agriculture University (SAU) led to the prospects of two more 'bright spots' being selected in the districts of Tando Muhammad Khan and Mirpurkhas. However, co-inquiry activities could not be taken up on these sites due to disruptions associated with the national flood emergency of 2022, which affected both communities severely. These disruptions also prevented co-inquiry activities from proceeding at Sujawal. The map in Figure 1 shows the locations of the selected bright spots in Punjab and Sindh.

Engagement with the farming communities was facilitated through a workshop process initially referred to as the Farmer Integrated Learning Model (FILM), later updated and built into the Rural Research Engagement and Learning Model (R²EaLM). Given the experience of working with R²EaLM, the name of the process was revised to Stakeholder Engagement for Research and Learning (SERL). SERL acknowledges that all those who have a stake in further improving rural livelihoods and agricultural practices and policies are to be actively engaged in both learning and teaching each other about how these improvements can be achieved (Heaney-Mustafa et al., 2023).

The ASSIB Project model and approach involves: (a) identification of bright spots, (b) engagement with bright spot farming families, (c) identifying stakeholders relevant to the bright spot communities, (d) establishing a stakeholder forum, and (e) conducting SERL workshops which provide a platform in which farming communities and stakeholders jointly discuss, co-design and participate in co-inquiry research plans and activities. Using an asset-based community development (ABCD) approach and SWOT analysis, the SERL workshops identify priority problems in co-design mode with specialist researchers and other

stakeholders. The seasonal interventions were designed based on priority issues identified in co-inquiry mode.

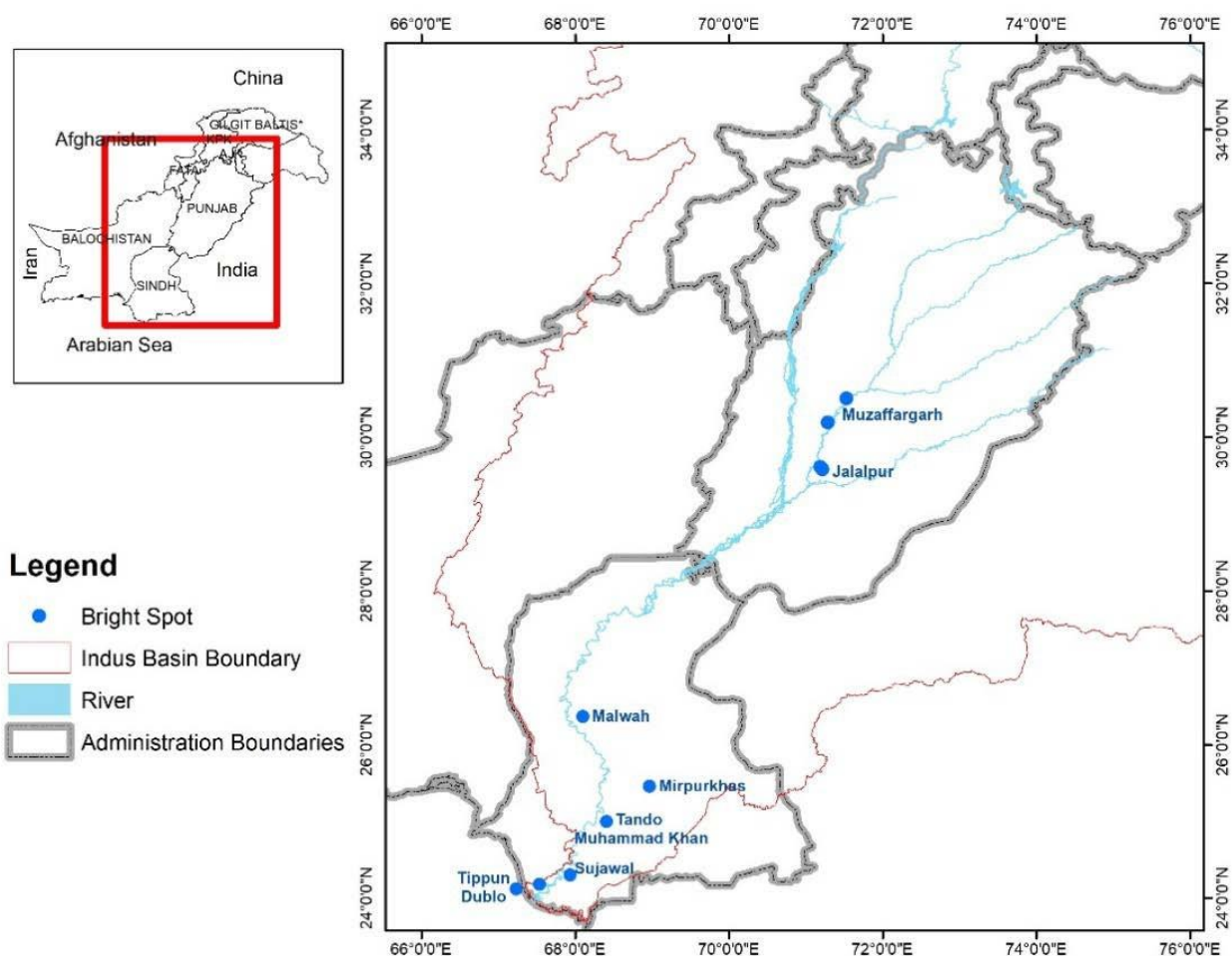


Figure 1. Map showing locations of ASSIB bright spots in Punjab and Sindh

Structured around the SERL model, the co-inquiry approach of ASSIB, with the potential for continual collaborative learning, is not commonly used in Pakistan. The SERL approach encourages and supports learning and adaptations through the co-design of action plans that are implemented in a co-inquiry mode. The experience gained through the ASSIB project over three years (2021-2024) has shown positive results in terms of effective farmer engagement and learning, including the involvement of youth and female farmers, encouraging participation of relevant stakeholders, and improved linkages with service providers. The active involvement of farmers in the entire process as co-researchers has improved their adaptive capacity, leading to the farmers ‘owning’ the results. This experience has, therefore, a strong and positive effect on adaptation and adoption. Furthermore, the farmers are now actively participating as farmer facilitators, leading farmer-to-farmer scaling-out workshops with neighbouring farming communities.

2.3. Key Legacies of the ASSIB Project for Future Research and Practice

2.3.1. Stakeholder Engagement for Research and Learning (SERL) Approach

Stakeholder Engagement for Research and Learning (Heaney-Mustafa et al., 2023) is the process that addresses how adaptive capacity for living with salinity can be built and among whom. It lays the foundation through which affected agricultural communities can be supported and encouraged to choose and plan their futures for adapting well to salinity. The SERL approach engages farmers to co-design and participate in co-inquiry investigations with other researchers on innovative and best practices methods for living with salinity. This approach creates ownership by the stakeholders, including farmers, practitioners and professionals. The SERL approach helps to identify farmers' challenges and engages their enthusiasm, while also building a network with relevant service providers and government officials (Figure 2).

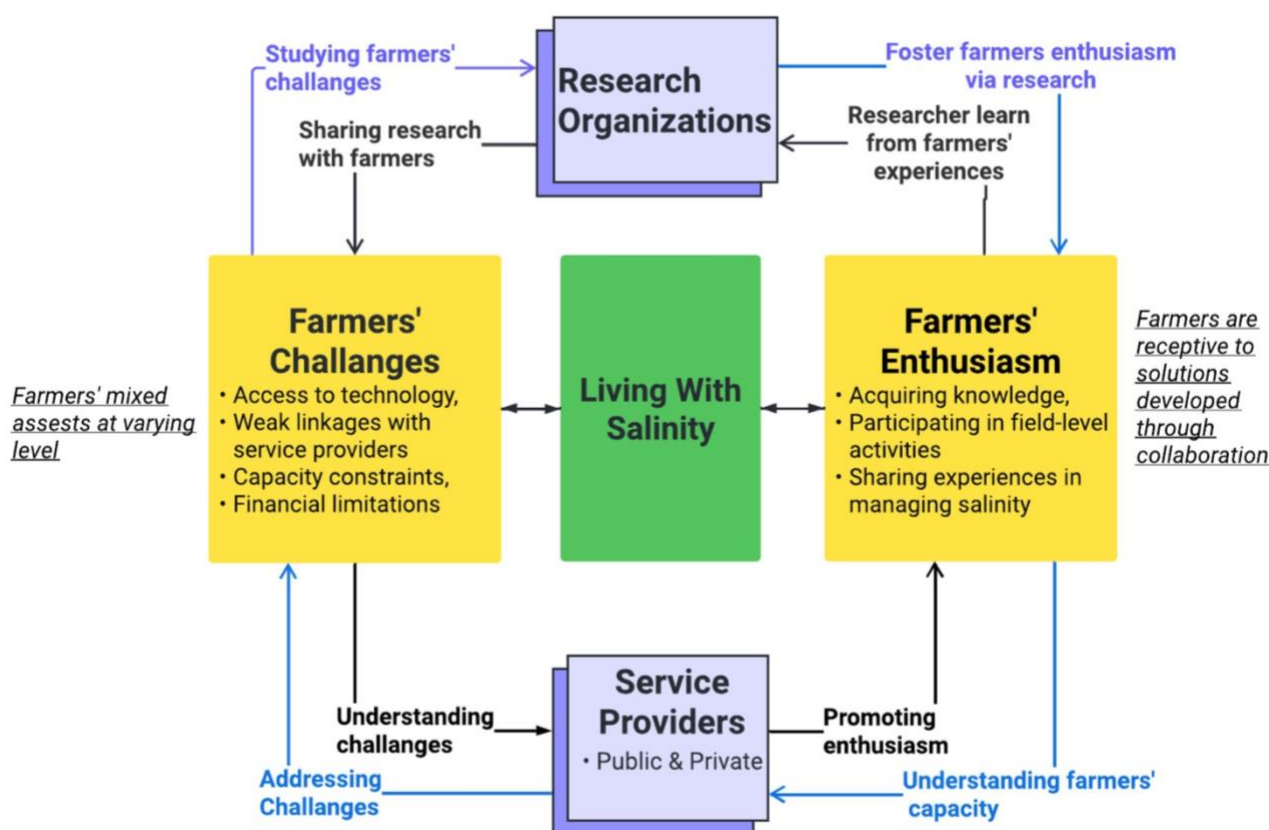


Figure 2. SERL approach for understanding farmer perspectives on salinity management

All stakeholders possess knowledge that, though different, is of equal value. Each stakeholder has an existing capacity worthy of respect. Hence SERL is built on valuing, respecting, and trusting all involved. SERL is also culturally and linguistically sensitive and provides a basis for sustaining change towards improved livelihoods. SERL has three iterative and repeating phases: a pre-research phase, a collaborative workshop, and an action and evaluation phase (Figure 3).

Stakeholder Engagement for Research and Learning (SERL)



Figure 3. Overview of SERL approach (Source: Heaney-Mustafa & Ashraf, 2024)

SERL has given farmers and others confidence, enhanced knowledge and capacity, built lasting networks, and given women a voice. SERL has also been used to upskill men and women farmers in the facilitation of other farmers, allowing it to become a farmer-led, farmer-facilitated, farmer-to-farmer scaling-out strategy (Heaney-Mustafa & Ashraf, 2024).

After successfully implementing the co-inquiry and co-design approach with three bright spot communities (Tippun Dublo, Malwah and Jalalpur), the project team has prepared a concept note to replicate this approach at a larger scale (see Appendix 1).

2.3.2. Salinity Handbook

One of the commitments of the ASSIB project was to develop a database documenting the outcomes of the field activities carried out in 'bright spot' communities. This activity morphed into developing a new 'Salinity Handbook' (Barrett-Lennard, in press) accessible to government and non-government agencies and professionals in identifying potential solutions to the particular salinity problems farmers face in different places.

One of the major issues affecting the practice of saline agriculture is that it is not regarded as a scientific discipline in its own right. The knowledge and skill sets required to practice and provide advice on saline agriculture extend across the disciplines of soil science, agronomy, plant physiology, agricultural extension, and – increasingly – aquaculture and silviculture. This means that researchers and extension agents need an extraordinary breadth of education and experience to provide well-informed advice to farmers and other stakeholders. Unfortunately, young people with this breadth of education are simply not available to take on the range of roles that are to be required. The ASSIB team addressed this issue by writing the book "Living with Salinity: how understanding salt, water and soil can help farmers grow better crops". This book was written with two audiences in mind: (a) extension officers /community facilitators and (b) new research professionals entering the field of saline agriculture. The book provides both these audiences with a grounding in the foundations and practice of saline agriculture. Much of the book's content is based on current knowledge about saline agriculture. This material could potentially be winnowed out of the literature by a committed and tenacious student. However, the penultimate chapter of the book (CRAM) is entirely novel. Here, we developed a new method of improving the fit between land, soil, water, plants and soil management by:

- Defining the capability of saltland in terms of its salinity and water content (from drought to waterlogging/inundation); this information is used to define a 'risk boundary' for a given site.
- Defining the impacts of key land management interventions on the risk boundary.
- Defining the adaptation of plants to land within the risk boundary.

The material in the book has been workshopped with community facilitators and project researchers: we are, therefore, relatively confident of its value to Pakistan. The insights contained in the book, and especially the CRAM chapter, are helping community facilitators provide better-informed advice to farmers about options for 'living with salinity'. This leads us to make the following recommendations:

1. The salinity handbook should be published as soon as possible and widely promoted – not just in Pakistan, but for all countries where ACIAR works.
2. The handbook should be used as the foundation for how young Pakistan-based agricultural and other rural service professionals work with those living in salinity-affected areas to support their investigations into adaptation options and development of their adaptive capacity more broadly.
3. Key messages from the book need to be made accessible to farmers. This will require translation of book materials into local languages and associated development of visual materials.

For the future, we believe that the book and its contents will be highly relevant to many countries in Asia and the Pacific that are experiencing salinity now, or that are expected to experience increased salinity in the future as a consequence of climate change. For example, sea-level rise is an existential threat to many island nations in the Pacific. The book could become an increasingly important resource as these communities re-orientate their agricultural systems to withstand the threat. This uptake would be greatly accelerated through the use of the book as a resource in face-to-face training courses.

2.3.3. Groundwater Monitoring

It is recognised that salinity and water management are interlinked. In many cases, the shortage of canal water is compensated for by the pumping of groundwater for irrigation purposes. This is mostly observed in Punjab. This is because Punjab has better access to good-quality groundwater where groundwater is relatively deep, and seepage from an extensive network of canals and link canals has contributed to a thick layer of relatively fresh groundwater. In contrast, aquifers in Sindh have shallow watertables, which are generally higher in salinity. Consequently, access to fresh groundwater is limited to a thin freshwater lens overlying deeper marginal and brackish groundwater.

A comprehensive assessment of the groundwater budget, including its inflow and outflow, is considered as important in managing salinity and for the development of effective adaptation options.

Findings of groundwater modelling, with special reference to water resources planning and management in South Punjab (Raheem et al., 2024) and southern Sindh (Jamali et al., 2024), are summarised below:

2.3.3.1. SOUTH PUNJAB – GROUNDWATER MODEL

1. The water balance for the study period 2010-2020 indicated that river/canal leakage was the major inflow source, accounting for 53% of the total inflow to the groundwater, with recharge from rainfall and field application losses at 47%.
2. Groundwater pumping was found to be the most significant outflow, comprising 91.9% of the total outflows, which resulted in a decline in net groundwater storage of 517.4 MCM/year. The net loss in groundwater storage indicates that groundwater pumping is impacting groundwater reserves underlying southern Bari Doab Canal Command.
3. The projected increase in groundwater pumping under the climate change scenarios, i.e., SSP2-4.5 and SSP5-8.5, indicated a large area of the top layer of the model would dry out in future in the lower reaches, especially the southern Bari Doab Canal Command. Clearly, this level of pumping will not be sustainable and will have long-term impacts on the quantity and quality of groundwater.
4. The simulated adaptation options for the Southern Bari Doab indicate that despite changing a portion of the high water use crops such as cotton, rice and sugarcane with low delta crops such as mung bean and onions, flood flows and environmental amelioration of the riverine corridors, there will still be a significant loss in net storage in the underlying aquifer of 586.6 MCM/year. A simulation without the recharge option indicated a loss in groundwater storage of 678.9 MCM, which indicates the inclusion of the recharge options by simulating flood flows adds 92.3 MCM/year to groundwater storage.
5. Currently, the Punjab Irrigation Department (PID) monitors around 3,300 piezometers and 4,000 farmer-owned tubewells for groundwater level and quality biannually. Areas that have continuously declining groundwater levels and/or those with emerging water quality issues will require instrumenting bores with water level, temperature and EC loggers. Such a system will provide reliable time-series data, especially at strategic sites where groundwater levels are declining and water quality issues are emerging. Strengthening groundwater monitoring networks to gather accurate and up-to-date data on groundwater levels and quality is essential for making informed decisions.
6. Managed aquifer recharge (MAR) has so far not been widely adopted, and large-scale MAR projects such as the diversion of monsoon flood waters from the Islam Barrage into the Old Mailsi Canal are only recently being considered in Pakistan (Zakir-Hassan, 2023). The new approaches for large-scale rural MAR projects (Zakir-Hassan, 2023) provide a framework for PID to develop these projects in consultation with the farming community for selecting locations best suited for MAR projects. Similarly, strategic sites to replenish the groundwater recharge locally should also be considered, as water stress and climate change exacerbate groundwater availability in Pakistan.
7. Capacity building of farming communities to improve knowledge of on-farm water management, climate-smart agriculture (CSA) and options for managing declining groundwater levels and quality will be essential for adapting to water and climate stress. Engaging with groundwater users and irrigators is necessary to co-design a sustainable future over a specified planning period. An example of this is the use of Representative Agricultural Pathways (RAPs – see Appendix 3), which offers planning tools that can lead, for example, to broader stakeholder acceptance and adoption of

low-delta crops and high-efficiency irrigation systems for fruit trees, such as mango orchards, which are high-value crops (Nasir et al., 2021).

Summary points:

- Increases in groundwater pumping following past trends and scenario modelling are resulting in rapid declines in water levels, which will affect livelihoods in agricultural communities, especially smallholder farmers. In addition, scenarios show climate change poses an existential threat to the sustainability of groundwater use for irrigation and farmers' livelihoods in South Punjab.
- Improved design of monitoring systems and building institutional capacity to map, model and manage groundwater are required.
- There is a need to assess long-term sustainable yields for groundwater management areas and develop water-sharing plans with stakeholder agreement.
- A focus on managing hotspots and adaptive groundwater management of groundwater resources is needed.

2.3.3.2. SOUTHERN SINDH AND COASTAL DISTRICT OF SUJAWAL – GROUNDWATER MODEL

In the district of Sujawal, water tables are generally shallow, which, along with elevated salinity levels, makes the groundwater unsuitable for irrigation. The primary source of irrigation water is from the Pinyari Canal, which is non-perennial. Surface water is available in the Kharif (wet) season, which supports the production of major Kharif crops, i.e. rice and sugarcane. In the Rabi (dry) season, agricultural activities are marginal and rainfall-dependent. Thus, agriculture productivity during the Kharif season is significant in maintaining the livelihoods of smallholder farmers. However, waterlogging and salinity are widespread in parts of the Pinyari Canal Command Area (CCA), hampering the feasible environment for crop development. Along the coast, inflows from sea boundaries pose a risk to coastal ecosystems. By 2150, these risks may extend to the southern edge of Pinyari CCA due to sea level rise and extreme climate events such as the rains in 2022 and possibly tidal surges, which are experienced during peak monsoon. The following points elucidate the output of the groundwater modelling study in Sujawal:

1. The water budget for the calibrated model from October 2010 to September 2020 indicated rainfall recharge and irrigation from field applications are the main sources of recharge to the aquifer, contributing 2,246.3 MCM. Seepage from the Pinyari Canal network and the Indus River also account for significant inflows to the aquifer. Evapotranspiration of 2,199.8 MCM is by far the major outflow from the aquifer owing to shallow watertables and high temperatures in southern Sindh. The high rate of evapotranspiration and marginal to brackish watertables in Sujawal increase the risk of salt transport into the crop root zone, often manifested by salinity onto the surface.
2. Climate change scenarios, including SSP2-4.5 and SSP5-8.5, were simulated to check their effects on groundwater resources. Increased rainfall under climate change predictions induced higher recharge, decreased inflow from the river to the aquifer and enhanced sea level rise exacerbated the quality of the aquifer with high salinity. However, simulating adaptation options in the SSP5-8.5 scenario, which includes the substitution of high delta crops with low delta crops and implementing green barriers in coastal areas, resulted in reduced water logging and salinity issues and enhanced aquifer recharge with fresh water from the river. Nonetheless, the increased risk of sea level rise needs robust adaptation options, including engineered sea barriers and additional support to protect the vulnerability of the coastal areas to seawater intrusion.
3. Exploitation of freshwater lenses will require judicious management to ensure the salinity of these lenses remains within a usable range. Overexploitation will increase salinity due to lateral intrusion from saline areas surrounding these freshwater lenses and the risk of upconing from deeper saline groundwater. It will require the Sindh Irrigation Department (SID) to implement a robust monitoring strategy encompassing marginal quality zones in Sindh and develop guidelines jointly with communities on strategies for the long-term use of these lenses.
4. The coastal zone has already lost about 2.95 million acres (1.194 hectares) due to seawater intrusion and inundation (Khaskheli et al., 2018). This huge loss of land could have provided livelihood opportunities for coastal communities, who are struggling to find alternate livelihood opportunities. A specialised monitoring program is required to improve understanding of the impacts on the unique coastal ecosystems in Sindh and to preserve and enhance the biodiversity of the Indus Delta.

5. The coastal zone contributes to the marine ecosystem, shrimps and fisheries and provides livelihood opportunities for coastal communities. The loss of agricultural lands and livelihoods in the coastal districts of Thatta, Sujawal, and Badin cause significant concern. Findings of the groundwater modelling indicate a substantial risk of seawater intrusion along the coast. These risks will be amplified greatly by rising sea levels between 1.2 and 2.0 metres by 2100.
6. A recent study of the Lower Indus Basin indicates groundwater extractions in Sindh have increased from 1.6 BCM to 19 BCM (Salam et al., 2023). This is concerning as there is a dearth of information about Sindh's groundwater, and the lack of technical capacity in groundwater in SID is a significant barrier to better groundwater management. Although the institutional capacity to manage Sindh's groundwater resources has not been developed, it is recognised in the Sindh Water Policy that groundwater resources need to be monitored and managed as they are vital for food production and farming livelihoods.

The US-Pakistan Center for Advanced Studies in Water (USPCAS-W) of Mehran University of Engineering and Technology (MUET) has been leading the development of this groundwater model, with support from MNS University of Agriculture Multan (MNSUAM). Both institutions are planning to include this model in the curricula and develop training modules for the capacity building of relevant departments. As a scaling-out strategy, the capacity building workshop was organised on 17th May 2024 at USPCAS-W, MUET, for the Sindh Irrigation Department, Sindh Irrigation and Drainage Authority and other research institutions. The outcome of the workshop is given in Appendix 2. A similar scaling-out workshop was organised at MNSUAM, Multan, on 29th May 2024, with the participation of the Punjab Irrigation Department, Punjab Agriculture Department, University of Agriculture Faisalabad, Baha ud Din University of Agriculture Multan, International Water Management Institute Lahore and others. The outcome of these workshops is given in Appendix 3.

2.3.4. Mobile and Web-Based Application

An important output of the project has been the development of a mobile App that provides a decision support system for farmers to enhance crop productivity vis-à-vis the land capability of their farms.

Land capability assessment is paramount for sustainable agriculture production as it assists in making optimal farming decisions. Stakeholders need to plan what crops to grow and where and how these should be grown. These decisions are linked to land capability to allow optimal utilisation of the land and water resources. Such data-driven decisions not only ensure better economic outputs but also enhance sustainability. The stakeholders (farmers, government officials, researchers and policymakers) need substantial data and algorithms and data processing to make optimal plans on how best to use land resources. This mobile and web-based App is an AI-based system for evaluating land and water resources, which accesses the following data sources and performs the following tasks:

Data:

- Stores data entered by users (in case they have their own data sources, e.g. groundwater depth and quality, soil characteristics, and weather).
- Makes available existing data from selected locations already stored in the database and is readily updatable by the users themselves.
- Fetches agrometeorological data from online sources such as World Weather Online, Meteomatics and reanalysis of climate model data.
- Accesses remote sensing (RS) data from the European Satellite Agency's Sentinel 2 and 3 data at 10meter resolution with five-day intervals.

Analyses:

- Location and time-dependent advisories on land operations based on land characteristics viz., soil, weather, and water.
- Water analytics to compute crop water requirement as per FAO's methodology based on the Penman-Monteith algorithm.
- Remote sensing analytics computes indices for crop vigour/health (Normalised Difference Vegetation Index: NDVI), crop moisture (Normalised Difference Moisture Index), crop nitrogen (Normalised Difference Red-edge) and chlorophyll activity (Red-edge Chlorophyll Index).

The architecture of this AI-based system is based on the following components:

Knowledge Base: This is the core component of the ASSIB project's Land and Water application for land assessment. A survey questionnaire (the 'Q&D rapid Land and Water Capability Framework') was developed by the team, which forms the basis of this knowledge base (see Appendix C in Barrett-Lennard, in press). It includes facts, rules, heuristics, and relationships within the land capability assessment and allows the system to provide insights and recommendations on the optimal use of land resources.

Inference Engine: The reasoning mechanism developed applies logical rules to the knowledge base to deduce new information for making decisions. It interprets and processes the data (input by users, data already available in the database, and online resources) and applies reasoning to generate conclusions.

User Interface: The user-friendly interface allows interaction between the system and its users. It enables users to input data, ask questions, and receive suggestions and recommendations from the system.

Database: The raw data that the system uses to make decisions is stored in the database and includes historical data (e.g., soil sampling results) and real-time data streams (or a combination of both), providing a comprehensive data repository for analysis.

Data Processing and Integration Layer: This layer handles the processing and integration of soil, water and weather data from input, database, and online, respectively. It ensures that the data fed into the knowledge base is accurate, consistent, and in the right format for analysis.

The application presented is a mobile and web-based decision support system for enhancing farm production based on the assessment of water (quality and quantity), weather, and soil characteristics. Further, it provides remote sensing-based vegetation health indicators at field scale. The App gathers five kinds of information. Firstly, based on satellite data and databases, farmers are able to assess general crop health, canopy moisture, and nitrogen levels in the leaves. It also provides daily weather data (maximum and

minimum temperatures, humidity, rainfall and windspeed). Secondly, information is supplied on important soil parameters (salinity, organic matter, nitrogen, potassium, phosphorus and pH). Thirdly, groundwater quality (SAR, RSC and EC) and quantity (depth) are provided. Fourthly, the farmers are asked to provide information about their farming operations and cropping patterns. These questions are based on the land and water capability framework, which assists not only in the rapid assessment of land but also in optimal decision-making. Lastly, the developed system integrates the information mentioned above and provides decision support on crop management.

2.3.5. Remote Sensing Characterisation of Agricultural and Water Use Practices in Salinity- affected Canal Commands in the Indus Basin Irrigated System

Regarding salinity management, Pakistan's national water policy highlights the need for "a new approach that tackles the problem in a holistic manner on a basin-wide level". This 'shall be followed for future infrastructure development. In chronic problem areas, canal water allowances shall be reviewed, and water management shall be improved". For this purpose, water managers and policymakers need land use and irrigation performance information at various scales (i.e. field/farm->irrigation system-> basin scale). In practice, such spatially disaggregated information is not readily available, especially below the main administrative units. To overcome this information gap and support better-informed decision-making, this project component evaluated the historical changes in irrigated agriculture using a remote sensing dataset within two salinity-affected regions in the IBIS from 2010 to 2020. The assessment included cropping dynamics (crop types and extents) and water supply and consumption, with the goal of facilitating water balance analyses and monitoring of irrigation management techniques at the sub-canal command level as a key to managing the future.

Cropping practices and water use were assessed spatially and temporally via remote sensing through actual evapotranspiration (ETa) and seasonal crop type classification maps. These data were generated at 30 m spatial resolution at intervals of 10 days for ETa and seasonally (wet summer 'Kharif' from April to September and dry winter 'Rabi' from October to March) for the main crop types of the IBIS. The 10-day frequency was required to match the 10-day period in which adjustments are made to regulate flows to balance shortages in the IBIS's canal commands. This was achieved through the blending of 'low spatial resolution-high temporal frequency' images (having lower detail but taken frequently over time) with 'high spatial resolution-low temporal frequency' images (providing greater detail but taken less frequently). This level of information is suitable for understanding localised changes in land use practices and informed decisions and policymaking at the sub-canal command level. Remotely sensed ETa estimates from the CMRSET model were evaluated against two locally calibrated ETa estimates, showing reasonable agreement both temporally and spatially. Seasonal crop maps, obtained through a Random Forest Mapping model, were evaluated against remotely sensed mapping and agricultural survey statistics on main crop areas, showing reasonable agreement. The 30 m spatial detail of both ETa and crop maps provided important insights into the dynamics of cropping practices and water use.

In Punjab, even though ETa showed relatively low variability from season to season, there were substantial shifts from cotton to rice, other crops, and fish farming. Nonetheless, the total cultivated area within each canal command remained relatively consistent. During the Rabi, ETa and crop area variation were relatively less compared to the Kharif. Again, the total cropped area within each canal command remained relatively stable, with winter cereals being the dominant crop in the Rabi season. The analysis revealed that in south Punjab canal commands, ETa is generally higher than canal supplies, potentially resulting in increased groundwater use for agriculture and aquaculture (fish farms). The gap between ETa is substantially higher during the Rabi than during Kharif, which is one of the main contributors to groundwater decline. To address the issues of the mismatch between supply and consumption, and halt the groundwater decline, potential water management options include:

- (i) Managed aquifer recharge in fresh and declining groundwater areas.
- (ii) On- and off-farm storages to store intermittent surplus canal water supplies and reduce groundwater pumping.
- (iii) Improving canal water allocation to supply additional water.
- (iv) Agricultural policy adjustments to promote low water requirement land uses.

In Sindh, due to its location at the IBIS end-of-system, both ETa and crop areas show more season-to-season variability than in Punjab. Rice areas have increased, notably in the Kharif in 2019 and 2020. Cropping dynamics, both ETa and crop areas in the Rabi season have less crop area variation than during the Kharif. The analysis showed intermittent increases in Kharif canal supplies surpassing ETa, which can further aggravate waterlogging and salinisation. At the same time, there was also a widening gap between ETa and canal water supply during the Rabi. Potential water management options for Sindh include improving irrigation efficiencies to reduce excessive recharge to saline groundwater, reviewing intra-provincial canal water allocations to provide adequate supplies in Rabi, and implementing agricultural policy adjustments to promote low water-requiring salt-tolerant crops.

2.3.5.1. USE OF RS DATASETS DURING THE ASSIB PROJECT

RS results as a time-series gridded ETa (one of the largest water balance components and highly variable across time and space) and land use datasets were shared with the groundwater team. This facilitated the *groundwater model development (activity 1.3)* for the Punjab and Sindh provinces.

2.3.5.2. IDEAS FOR POTENTIAL/FURTHER RESEARCH PROJECTS

Considering the lack of publicly available information, we recommend a similar systematic assessment across all of the IBIS canal commands to guide provincial-scale agriculture and irrigation water management/policy decisions. To achieve this, we propose targeted efforts and investments in enhancing capacity building in Earth Observation (EO) techniques and operationalising the products we developed using cloud computing and geostatistical analysis, which can remain in-country. [We are doing this for Bangladesh; we can tailor it for the Indus/Pakistan.]

Key national partners: Provincial agricultural and irrigation departments, SUPARCO, PCRWR and universities from Punjab (e.g., MNSUAM) and Sindh (e.g. MUET).

2.4. An Overview of Relevant ASSIB Publications to Date

The ASSIB project has published many journal articles and reports. Four of these reports provide useful background to our recommended future research agenda, as summarised below.

1. **Ashraf et al. (2022):** Among other things, the authors have narrated the R&D projects and technology options implemented since 1954. They identified three core gaps contributing to the ineffectiveness of past strategies and programs in arresting soil salinity and waterlogging problems. These gaps are:
 - No policy guidance for sustainability and no planning for long-term strategy implementation.
 - Non-consolidation of data collection and research conducted by various organisations.
 - Lack of farmer participation in decision-making processes.
2. **Ali (2023):** The report has identified a range of past salinity management failings across Pakistan and called for the pursuit of an integrated and holistic approach to implementing available adaptation options through small pilot investigations with the active involvement of farming communities and other stakeholders.
3. **Heaney-Mustafa et al. (2023):** The report covers theoretical underpinnings and facilitator guidelines for implementing SERL to identify priority issues and interventions to address these in co-design and co-inquiry mode. The authors emphasise that respecting and valuing the local is an essential principle in working with communities. One way of possibly overcoming this but not excluding the voices of women is to run the SERL workshops with the women first, get their views, issues and ideas and then take them to the workshops with the men.
4. **Allan et al. (2024):** They have narrated the stories of change from project participants regarding the ASSIB activities undertaken at the three bright spots. They conclude, “the data presented in this report suggest that carefully considered and supported co-inquiry should be considered as a means for transformational change in poorly resourced areas facing salinity, climate change and systemic institutional neglect. Such co-inquiry need not be vastly expensive, but should have sufficient resources to enable facilitation, risk mitigation, and longevity.”

2.5. ASSIB Team Recommendations for Ways Forward: Co-inquiry for Nature-Based Salinity Management Solutions

- A key element of the ASSIB approach is to follow a practically adaptable system for engaging stakeholders in co-design and co-inquiry research investigations in a sustainable manner. Lessons learned during the project period, especially community engagement, enthusiasm, and eagerness for communities to learn and adapt best practices, constitute the basis for future community engagements, including farmer-to-farmer scaling out of the project outcomes.
- For this to happen sustainably, scaling out/up ASSIB outcomes should receive due attention through continual engagement of the bright spot communities.
- Pakistan's provincial agriculture departments are key stakeholders. Formulation of future projects should provide for effective engagement with agriculture and irrigation departments, with strong provisions and appropriately conceived mechanisms for the institutionalisation of the ASSIB Approach.
- A new project should be developed with the participation of the existing consortium of partnering organisations for the benefit of farming communities living in salt-affected landscapes with a strong element for the institutionalisation of the ASSIB approach for co-design and co-inquiry with intervention activities by the concerned government departments.
- We have, therefore, produced a concept note (see Appendix 1) as a starting point for initiating the process based on learnings and experience gained from the ASSIB Project. The objective is to eventually develop a full-fledged project for funding with support from potential donors, including ACIAR.

2.5.1. Institutions Adapting Co-Inquiry Approach

The ASSIB project partners have made efforts to get some projects and use the SERL approach in the projects. Some of the examples are given below. This indicates that ASSIB legacies will continue to be implemented in future in Pakistan.

2.5.5.1. INTERNATIONAL UNION FOR CONSERVATION OF NATURE (IUCN)

Based on what was learned from SERL, IUCN has started implementing a project in the Thar desert in Sindh province. The project, funded by a private sector company, primarily aims to enhance the livelihoods of local communities. Drawing on insights from the ASSIB project, IUCN's Thar initiative, tailored to the desert environment's challenges like water scarcity and high water salinity, prioritised community engagement through consultations and meetings from the outset and, with community support, identified the resources available and their capabilities. Based on extensive community consultation on the adaptation options, livelihood enhancement plans were co-designed with the respective objectives, activities, timescale and monitoring systems in place. Given the arid climate of the desert, adaptation strategies were customised to meet local needs. The ongoing initiative, starting with two pilot backyard ponds, has expanded to five, indicating positive progress. The success of this participatory approach is evident from neighbouring villages' interest in obtaining fish fry and expressing willingness to construct ponds independently if provided with seedlings.

Given the SERL experience of working in saline coastal environments, IUCN has recommended the following ideas for future projects:

1. Utilisation of naturally saline water bodies as an opportunity to obtain livelihoods through saline aquaculture.
2. Implementation of small-scale (backyard) aquaculture for economically valuable species like shellfish, shrimp, etc.
3. Nature-based solutions in aquaculture through establishing floating rafts for:
 - a. Molluscan aquaculture not only supports livelihoods but also serves as a biofiltration system against organic pollutants, thereby contributing to the overall ecosystem health and functioning. Moreover, it has the potential to act as a natural barrier against sea level rise.
 - b. Seaweed aquaculture offers livelihood opportunities while functioning as effective biofilters.

4. Investigation and promotion of cultivating native flora and associated marshy vegetation as nature-based solutions can contribute to mitigating coastal erosion, enhancing shoreline stabilisation, and providing habitat for marine and terrestrial species.
5. In short, using saline water bodies for aquaculture (SDG 1, 2, 13) supports livelihoods, food security, and climate resilience (SDG 14, 15). It fosters economic growth (SDG 8), ensures water quality (SDG 6), and promotes responsible consumption (SDG 12).

2.5.5.2. MUHAMMAD NAWAZ SHARIF UNIVERSITY OF AGRICULTURE MULTAN (MNSUAM)

The MNSUAM team has been able to extend the learnings of the ASSIB project approach, i.e., co-learning and farmer-led experiments in a joint project with Eberswalde University for Sustainable Development (HNEE), Lahore University of Management Sciences (LUMS), titled “Innovations for Resilient Smallholder Production Systems in Punjab, Pakistan”, funded by BLE (Federal Office for Agriculture and Food). The three-year project will start in February 2025. The Jalalpur bright spot community and area have been included in the project design because of the continuous interaction and collaboration of the community and experts. The research project has been designed as a participatory endeavour that systematically connects the stakeholders, from farmers to policymakers, including service providers and experts. The project will use the existing knowledge and capacity of the community (comprised of small landholders) to involve them in more practice-oriented research activities. The project will involve practitioners and policyholders through a series of iterations to engage them with local communities to improve their livelihood through better adoption of technologies and practices.

Earlier, Prof. Irfan Baig was also invited as a Keynote Speaker to the international conference on “Sustainable Food and Biomass Futures - Localised Approaches to Agricultural Change and Bioeconomy” from 22-24 June 2023. The title of his talk was “Transforming Livelihoods Together: Co-inquiry with Rural Communities for Improved on-property Salinity Management in South Punjab”. The talk generated a lot of interest among the participants. It resulted in a proposal for a joint workshop (funded by Co2libri) at MNSUAM from 19-20 August 2024 in collaboration with Prof. Sarah Hultz, Humboldt University, Berlin, University of Peshawar and Quaid-e-Azam University Islamabad. During this workshop, community facilitators from Meerkot and Basti Kulab will share their co-inquiry and on-field experimentation experience with the visiting academia and researchers.

Dr. Irfan Baig was also invited to deliver a lecture on the topic of “Participatory Co-Inquiry in Salinity Management in Pakistan” to the students of HNEE (Eberswalde University for Sustainable Development). The lecture took place online on May 30, 2024, as part of the course “Extension Methods in International Cooperation” for the post-graduate study program “International Forest Ecosystem Management.”

The project teams at MNSUAM and MUET have also used their capacity developed in groundwater modelling through the ASSIB project. The teams have been able to successfully compete and win grants for groundwater modelling in Punjab and Sindh under the FAO-GCF project. The competitive grant was for one year and included the calibration, development and estimation of hydrological modelling, design and development of information products, and training of Punjab Irrigation Department and On Farm Water Management Wing officials.

3. References

- Ahmed, W., Punthakey, J. F., Jamali, S., Qureshi, A. L., & Shaik, S. (2024b). *Assessing groundwater monitoring in Sujawal and guidance for strengthening groundwater monitoring across Sindh (Gulbali Report No. 8)*. Gulbali Institute, Charles Sturt University. <https://www.csu.edu.au/research/gulbali/about-us/publications/>
- Ali, A. (2023). *Improving salinity and agricultural water management in the Indus Basin, Pakistan: issues, management and opportunities: a synthesis from a desk-top literature review (Gulbali Report No. 1)*. Gulbali Institute, Charles Sturt University. <https://www.csu.edu.au/research/gulbali/about-us/publications/>
- Ashraf, M., Fatima, B., Hasan, F. u., & Salam, H. A. (2022). *Adapting to salinity in the southern Indus Basin: policy review*. Islamabad, Pakistan: Pakistan Council for Research in Water Resources. <https://pcrwr.gov.pk/water-management-reports/>
- Barrett-Lennard, E. G. (in press). Living with salinity: how understanding salt, water and soil can help farmers grow better crops. ACIAR, Canberra.
- Heaney-Mustafa, S., Stirzaker, R., ul Hasan, F., Fatima, B., Jabeen, N., Anwar, Z., Afzal, M., Hussain, I., Memnon, F., & Riaz, F. (2021). *Developing approaches to enhance farmer water management skills in Balochistan, Punjab and Sindh in Pakistan: final report*. (ACIAR Report No. FR2021-055). ACIAR. <https://www.aciar.gov.au/project/lwr-2014-074>
- Heaney-Mustafa, S., Channa, M. Y., Baloch, T., Channa, M. A., Kumbhar, B., Mohiuddin, I. Riaz, M. F., Rubab, A., Samoo, A. H., Zahid, S. M. A., & Zaman, B. (2023). *Stakeholder engagement for research and learning (SERL): theoretical underpinnings and guidelines for facilitators (Gulbali Institute Report No. 3)*. Gulbali Institute, Charles Sturt University. <https://www.csu.edu.au/research/gulbali/about-us/publications>
- Heaney-Mustafa, S., & Ashraf, M. (2024). *Building and scaling out knowledge: the practice of co-learning with farmers (Gulbali Institute Report No. 11)*. Gulbali Institute, Charles Sturt University. <https://www.csu.edu.au/research/gulbali/about-us/publications>
- Jamali, S., Punthakey, J. F., Ahmed, W., Qureshi, A. L., Raheem, A., & Ahmed, M. (2024). *Modelling climate change impacts and adaptation strategies for managing groundwater resources in Pinyari Canal Command Area and coastal Sujawal, Sindh (Gulbali Institute Report No. 7)*. Gulbali Institute, Charles Sturt University. <https://www.csu.edu.au/research/gulbali/about-us/publications>
- Khan, M. R., Barrett-Lennard, E. G., & Punthakey, J. F. (2024). *Mobile and web applications for land and water evaluation (Gulbali Institute Report No. 12)*. Gulbali Institute, Charles Sturt University. <https://www.csu.edu.au/research/gulbali/about-us/publications>
- Khaskheli, N., Kalhoro, N. A., Wang, J. U. N., He, Z., Xu, D., Tunio, G. R., Shahani, K., & Hussain, F. S. (2018). Impacts of tidal link drain, along the coastal areas of districts Badin and Sujawal in Indus deltaic region, Sindh Pakistan. *MAUSAM*, 69(4), 535-542. <https://doi.org/10.54302/mausam.v69i4.394>
- Mitchell, M., Punthakey, J., Barrett-Lennard, E. G., Allan, C., Culas, R. J., & Finlayson, C. M. (2018). *Improving salinity and agricultural water management in the Indus Basin of Pakistan: final report*. ACIAR. <https://www.aciar.gov.au/project/LWR-2017-028>
- Mitchell, M., Allan, C., Punthakey, J. F., Barrett-Lennard, E. G., Heaney-Mustafa, S., Lashari, B. K., Baig, I. A., Hussain, I. (2020). *Living with salinity in the Indus Basin: SRA 2: final report*. ACIAR. <https://www.aciar.gov.au/project/WAC-2019-102>
- Nasir, J., Ashfaq, M., Baig, I. A., Punthakey, J. F., Culas, R., Ali, A., & Hassan, F. u. (2021). Socioeconomic impact assessment of water resources conservation and management to protect groundwater in Punjab, Pakistan. *Water*, 13(19), 2672. <https://doi.org/10.3390/w13192672>
- NESPAK & MMI. (1993). *Feasibility study of National Drainage Program I*. National Engineering Services of Pakistan and Mott MacDonald International, Pakistan.
- Noble, A. D., Bossio, D. A., Penning de Vries, F. W. T., Pretty, J., & Thiyagarajan, T. M. (2006). *Intensifying agricultural sustainability: an analysis of impacts and drivers in the development of 'bright spots'*.

(Comprehensive Assessment of Water Management in Agriculture Research Report No. 13). Colombo Sri Lanka: Comprehensive Assessment Secretariat.

- Punthakey, J. F., Ashfaq, M., Allan, C., & Mitchell, M. (2021). *Improving groundwater management to enhance agriculture and farming livelihoods in Pakistan: final report* (ACIAR Report No. FR2021-056). ACIAR. <https://www.aciar.gov.au/project/lwr-2015-036>
- Qureshi, A. S., McCornick, P. G., Qadir, M., & Aslam, Z. (2008). Managing salinity and waterlogging in the Indus Basin of Pakistan. *Agricultural Water Management*, 95(1), 1-10. <https://doi.org/10.1016/j.agwat.2007.09.014>
- Raheem, A., Saifullah, M., Punthakey, J. F., Zakir-Hassan, G., & Baig, I. A. (2024a). *Modelling climate change impacts and adaptation strategies for managing groundwater resources in southern Punjab (Gulbali Report No. 5)*. Gulbali Institute, Charles Sturt University. <https://www.csu.edu.au/research/gulbali/about-us/publications/>
- Raheem, A., Saifullah, M., Punthakey, J. F., & Baig, I. A. (2024b). *Assessing groundwater monitoring in the Southern Bari Doab and guidance for strengthening groundwater monitoring across Punjab (Gulbali Report No. 6)*. Gulbali Institute, Charles Sturt University. <https://www.csu.edu.au/research/gulbali/about-us/publications/>
- Salam, H. A., Ashraf, M., Iqbal, N., Gul, N., Farooque, M., & Memon, S. (2023). *Exploring groundwater dynamics: a comprehensive investigation and spatial mapping in canal command areas of Sindh*. Islamabad, Pakistan: Pakistan Council of Research in Water Resources (PCRWR).
- Spriggs, J., Chambers, B., Heaney-Mustafa, S., & Fitzgerald, R. (2016). Social research to foster effective collaboration and strengthen pro-poor value chains. (ACIAR Report No. FR2016-29). ACIAR. <https://www.aciar.gov.au/publication/technical-publications/social-research-foster-effective-collaboration-and-strengthen-pro-poor-value-chains>
- Zakir-Hassan, G. (2023). *Improving sustainable groundwater management: a case study of managed aquifer recharge in Punjab, Pakistan*. PhD Dissertation, School of Agricultural, Environmental and Veterinary Sciences, Charles Sturt University, Albury NSW.

Appendix 1. Concept Note 1

Nature-Based Salinity Management Solutions for the Southern Indus Basin

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Background

Modern agricultural practices have led to significant environmental challenges, including soil degradation, decreased biodiversity, and climate change impacts. Regenerative agriculture offers a solution by promoting practices that restore the land and enhance ecological health. Regenerative agriculture also promotes nature-based salinity management solutions, which seeks to address these challenges by educating and empowering farmers to adopt these sustainable practices.

Aims

- Build the adaptive capacity of the rural communities in salinity-affected areas through a self-learning process of co-creation of knowledge with the help of experts.
- Facilitate small-farmer communities to enhance the productivity of salt-affected soils thereby reducing poverty and improving livelihoods and resilience across the southern Indus Basin.
- Promote nature-based solutions for salinity management among marginal land communities.

Objectives

- Engage 12-16 communities across the Southern Indus Basin in the process of setting up and executing experiments.
- Develop capacity of 25 male and 25 female smallholder farmers on the principles and benefits of regenerative agriculture through workshops and field days so that they can engage the communities on a sustainable basis.
- Establish 10 demonstration plots to provide hands-on experience with regenerative techniques.
- Develop a farmer-to-farmer mentorship program, pairing 50 new farmers with experienced practitioners.
- Increase soil health in participating farms, as measured by organic matter content by 10-20% within two years.
- Involve young graduates and scientists in the farmer experimentation process to help them master community-level communication and carry out research in regenerative agriculture for improving farming livelihoods.

Activities

Management strategies based upon the contextual review, options selection, and implementation mapping:

- Co-inquiry approach as a foundation.
- Integrated salinity management strategies:
 - Selection of zone-based salt-tolerant crop varieties and regenerative agriculture practices.
 - Initiating aquaponics techniques to facilitate circular use of resources.
 - Using mulching for salt tolerance induction.
 - Crop growth stage-based irrigation and nutrient management strategies.
- Stakeholder engagement strategy.
- Farmer engagements/ networking/ institutionalisation.
- Climate-smart saline agriculture.
- Scaling out strategies.
- Knowledge generation and dissemination.
- Groundwater modelling and implementation.
- GIS and remote sensing technique integration.
- Technology development, introduction, and implementation like sensors, apps:
 - Revamping of extension services.
 - Technology-based capacity building.
 - Village-based facilitators.
- Market linkages.
- Environmental assets and their values.
 - Land and water/ river flow/ demand for environmental flow and distribution patterns, particularly for managing seawater intrusion.

Potential Project Partners

- Mehran University of Engineering and Technology (MUET).
- Muhammad Nawaz Sharif University of Agriculture, Multan (MNSUAM).
- Sindh Agriculture University (SAU).
- Society of Facilitators and Trainers (SOFT).
- International Union for Conservation of Nature (IUCN) Pakistan.
- Pakistan Council of Research in Water Resources (PCRWR).
- Pakistan Agriculture Research Council (PARC).
- Provincial Agriculture Departments.
- Provincial Irrigation Departments.
- NGOs.

Potential International Project Partners

- Charles Sturt University (CSU).
- Commonwealth Scientific and Industrial Research Organisation (CSIRO).
- Murdoch University.

- University of Canberra (UC).
- International Center for Biosaline Agriculture (ICBA).
- Pakistan Council of Research in Water Resources (PCRWR).
- ECOSEAL.
- Landcare network.
- Others.

Possible Funding Sources

National Level

- Federal government.
- Provincial governments.

International Level

- ACIAR, USAID, ADB, WB, FAO-UN, IsDB.

Duration

- 5 years.

Appendix 2. Concept Note 2

Strengthening Groundwater Monitoring in Sindh

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Background

There are growing issues with groundwater quality and quantity worldwide, including in regions of South Asia, where groundwater use plays a crucial role in advancing human wellbeing and in enhancing food security for smallholder farmers. This proposal aims to build a collaborative partnership with key institutions of Sindh Pakistan such as Sindh Irrigation Department (SID) for assessing the impact of salinity, waterlogging, excessive exploitation of groundwater in freshwater zones of Sindh and seawater intrusion in coastal Sindh. It also investigates how these issues affect communities and their livelihoods, especially under various climate change scenarios.

Development of agricultural enterprises that use water wisely and judiciously are vital for improving water productivity and food security in Pakistan. In the past groundwater use for irrigation in Sindh was minimal. However, with the increase in population and increasing needs for food security cropping intensities in Sindh have increased from 67 percent to about 120 percent. The increase in cropping intensity has been achieved by increasing exploitation of groundwater for irrigation which requires urgent attention for its sustainable management. The major impediment to improving management of groundwater resources in Sindh is the lack of knowledge on groundwater resources and conditions due to an inadequate groundwater monitoring structure. Groundwater in Sindh is under increasing pressure due to overexploitation of its fragile freshwater lenses, leading to secondary salinisation from upconing and lateral migration of deep brackish groundwater. In Coastal Sindh, farmers prioritise surface water over groundwater for irrigation purposes as the underlying shallow groundwater is generally brackish. This threat is further intensified by the impact of sea water intrusion and coastal flooding which requires the efficient monitoring networks to improve management and to design adaptation strategies.

Various studies have been conducted on improving the groundwater monitoring in Sindh. In the 1960s, the Lower Indus Project (LIP) was initiated by the Water and Power Development Authority (WAPDA) which included extensive drilling of deep boreholes for hydrogeological investigations and pumping tests and to understand the shallow groundwater quality and its impact on agricultural production. In the Lower Indus Basin, the availability of good quality groundwater is found adjacent to the river and major canals and its quality deteriorates with increasing salinity away from the river and major canals. There are some regions in Rohri canal command area including Khairpur, Naushero Feroze, and parts of Shaheed Benazirabad districts that have thick lenses of freshwater due to significant seepage from canals and rivers. The right bank of the river has poor groundwater quality due to limestone hills and Piedmont plains. Shallow watertables and marginal to brackish groundwater are widespread in the Indus Delta however, shallow freshwater lenses are accessed by hand pumps for meeting drinking water needs. There is little monitoring outside canal commands such as in the fresh groundwater pockets in coastal areas which are not mapped. In the Indus Basin, the topographic gradient decreases, and the proportion of finer sediments increase in a southerly direction towards the Arabian sea. This contributes to drainage issues, causing waterlogging and salinisation, which are further exacerbated by high evapotranspiration rate from shallow ground groundwater resulting in salinity mobilisation and land degradation. According to the LIP investigation, it was estimated

that 71% of Sindh's irrigated area has groundwater that is marginal to highly saline which results in widespread waterlogging and salinisation in Sindh.

A recent study conducted by PCRWR 2023 researchers and the Sindh Irrigation Department mapped the fresh groundwater pockets across 14 canal command areas. This study provided interesting insights of significant variation in soil salinity and groundwater quality and indicated the availability of fresh groundwater in areas such as Ghotki and Khairpur, while southern regions exhibited high salinity due to impending impact of seawater intrusion and inadequate drainage system. It emphasised sustainable groundwater extraction and improved canal lining to address seepage losses to avoid waterlogging and salinity in Sindh. Moreover, two groundwater modelling studies have been done in Sindh to understand the impact of over-extraction from freshwater pockets in Rohri canal command and seawater intrusion in coastal Sindh. These groundwater models can be further used for assessing the impact of policy changes, climate change scenarios and devising a feasible adaptation option to deal with groundwater challenges in Sindh.

Challenges of Groundwater in Sindh

- Groundwater in Sindh is negatively affected by elevated levels of salinity from marginal to saline and serious waterlogging. In Sindh, 78% of the area has poor groundwater quality, compared to 23% in Punjab. Unplanned exploitation of such poor groundwater quality leads to secondary salinisation. Furthermore, about 35% of the total area in Sindh has shallow groundwater tables within 1.5m leading to waterlogging issues in extensive parts of Sindh.
- Shortage of surface water coupled with increasing demand for irrigation compels people to use freshwater lenses in Sindh. This leads to overexploitation of freshwater lenses along the left bank of the Indus River. This increases the risk of lateral intrusion of marginal groundwater and upconing of deeper saline water into freshwater zones.
- Shallow saline water tables is prevalent in the coastal region of Sindh and consequently people prefer canal water for irrigation purposes due to high groundwater salinity. Moreover, seawater intrusion is also a significant threat to agriculture and fisheries and groundwater resources in the coastal areas of Sindh. However, due to lack of monitoring networks, much is unknown about groundwater conditions in coastal Sindh.
- Lack of integrated institutional framework and capacity within the Sindh irrigation department enhances the problems of groundwater monitoring and management.

Aim

The aim of the proposed project is to establish a robust groundwater quantity and quality monitoring program in Sindh to assist in developing sustainable management strategies for groundwater resources in Sindh, and to build capacity of key stakeholders to improve monitoring, mapping and management of groundwater resources, and to extend knowledge of improved conjunctive use practices for farming communities for sustainable groundwater use and to enhance agricultural production.

Objectives

- Establish a comprehensive groundwater monitoring network across Sindh to deal with the challenges of serious waterlogging issues, elevated levels of salinity and overexploitation of freshwater lenses and to obtain high frequency data of water levels and salinity.
- Promote sustainable groundwater use practices for managing freshwater lenses and addressing salinity intrusion through policy driven interventions and stakeholder engagements (policy options could include nature-based solutions, crop substitutions, and improved irrigation management).
- Develop capacity in groundwater monitoring, mapping groundwater resources, and its sustainable management in government institutions to assist decision making for effective groundwater management in support of Sindh water policy.

Methodology

Sustainable use of groundwater resources will be achieved by:

- (i) Designing and implementing a groundwater monitoring system for Sindh with a focus on the freshwater zones.
- (ii) Provision of knowledge products for the farming community to improve knowledge and skills amongst groundwater users.
- (iii) Enabling government stakeholders to engage with communities to improve the management of groundwater for enhancing agricultural production, leading to improved livelihood outcomes.
- (iv) Engaging communities and key stakeholders to design effective adaptation strategies to mitigate risk from overexploitation of the freshwater lens, and waterlogging and salinisation.
- (v) Supporting institutions to implement a framework for sustainable groundwater management in Sindh.

Activities – Sindh in General

- Development of a new institutional structure in the Indus Basin aquifer in Sindh to effectively monitor the groundwater from local to provincial levels with dedicated units focused on groundwater and follows the principle of integrated management.
- Establishing a strategic groundwater monitoring network across Sindh to improve mapping of overexploitation of groundwater and its impact on the freshwater lenses in irrigated areas, and to map waterlogging and elevated levels of salinity.
- Introducing a program of establishing monitoring bores with CTD loggers to monitor the depth to water table (DTW), water quality and temperature of aquifers which assist institutions to check drawdown variation in groundwater and water quality hotspots.
- Installation of loggers in piezometers/monitoring bores to acquire data at more frequent intervals (e.g. every 12 hours or daily) – this will require a budget for drilling, purchasing loggers and for field monitoring and archiving data. A system of logging bores will also need to be established while drilling new piezometers to provide information on hydrogeological conditions of aquifer including soil and rocks, and training will need to be provided to drillers on bore construction and logging bore details.
- Development of groundwater databases, hydrogeological and groundwater maps to map freshwater lenses, shallow aquifers and water quality zones.
- Development of a program to digitise all tubewells (similar to the program undertaken by the Punjab Irrigation Department's geotagging of 1.2 million tubewells).
- Identifying large groundwater users and undertaking strategic assessment of impacts on groundwater and surface water resources, and where possible undertaking strategic metering of production bores.
- Developing a program within SID to undertake rehabilitation of the existing SCARP Monitoring Organization (SMO), to instrument SMO bores with CTD loggers, and to introduce nested piezometers to assess the distribution of salinity at various depth intervals.
- Establishing the means for integrating existing data from different studies and thus start building a knowledge base of groundwater in Sindh that can provide a partial picture of groundwater status in Sindh to guide future monitoring and mapping activities.
- Establishing a strategic regional monitoring approach by identifying Groundwater Potential Zones to assess the probability of aquifers available in Sindh through GIS and remote sensing approaches, including identification of vulnerable groundwater zones/ hotspot zones where freshwater lenses are over-exploited.
- Establishing clear pumping thresholds with stakeholders in hotspot/vulnerable zones to ensure long-term sustainability of aquifers.
- Developing practical advice to improve conjunctive use of groundwater and surface water to avoid depletion of freshwater lenses in groundwater in Sindh.

- Promotion of high-efficiency irrigation techniques and development of appropriate groundwater use regulation strategies to encourage sustainable groundwater use; the latter may include strategies involving pricing where such a strategy is deemed necessary and feasible (in which case a pilot study could be established).
- Capacity building of relevant government officials and other stakeholders through structured professional training in groundwater monitoring, mapping and modelling at different proficiency levels. This includes basic training for foundational knowledge (Level 1), advanced training in hydrogeological mapping and modelling of groundwater resources (Level 2), and planning and management of groundwater and practical application of developed tools for decision-making (Level 3).
- Further development of groundwater models to understand the impact of groundwater use in Rohri canal command and waterlogging and salinity in Pinyari canal command including coastal Sindh. Establishing a groundwater modelling and hydrogeology unit would assist extensive usage of these models to benefit the community of groundwater users, industry, and the environment. These projects have trained many SID engineers, MUET students, and engineers from SMO Sindh in groundwater monitoring and modelling, marking the initial steps towards capacity building in Sindh. It is crucial to build on these efforts to monitor and manage groundwater resources to benefit Sindh's groundwater users in the future.
- Promotion of sustainable groundwater use practices for managing freshwater lenses and addressing salinity intrusion through policy driven interventions and stakeholder engagements.

Activities – Monitoring Coastal Sindh

- Improving monitoring programs in coastal Sindh including Sujawal, Badin and Thatta is integral, requiring mapping of marginal quality groundwater, its exploitation with best practices and sharing this key knowledge with stakeholders are essential to protect coastal agricultural lands, and supporting livelihoods in the region.
- To mitigate the impact of seawater intrusion, a specialised monitoring program such as installation of sentinel bores for consolidating early warning system of sea level rise to develop strategies for protecting coastal ecosystems.
- Implementation of nature-based solutions, including plantation of mangroves, salt bushes and native trees in coastal lands to reduce the impact of seawater intrusion.

Addressing Capacity Development to Improve Groundwater Management in Sindh

The significant gap in institutional capacity to monitor, map, model and manage groundwater resources will need to be addressed to allow the SID to transition into the role of resource management. This will require significant multidisciplinary skills encompassing hydrogeological modelling, water quality monitoring and modelling, and strengthening skills in social and community engagement to reach out to groundwater irrigators to improve resource use management. The lack of data on groundwater in Sindh and the lack of technical capacity within SID is a major impediment to improving management of groundwater. The absence of a Groundwater Directorate within SID or Sindh Government has further consolidated groundwater capacity issues.

The water policy in Sindh highlights the significance of managing water resources holistically, emphasising the need to achieve a more sustainable use of groundwater. Although the institutional capacity to manage Sindh's groundwater resources has not been developed, it is recognised in the Sindh Water Policy that groundwater resources need to be monitored and managed as they are vital for food production and farming livelihoods and an important source of potable water for rural communities. The following additional activities are to be considered for development:

- Enhancement of capacity-building efforts by providing structured professional training in groundwater monitoring and modelling at different proficiency levels. This includes basic training for foundational knowledge (Level 1), advanced scenario modelling for predictive analysis (Level 2), and practical application of developed tools for decision-making (Level 3).
- Development of a roadmap for SID to establish a Water Resources Directorate with the specific mandate to improve the monitoring and management of surface and groundwater resources in Sindh and focus on an integrated water resource management approach.

- Facilitating knowledge exchange, collaboration, collaboration and data-sharing to bridge the gap between academia and government organisations.

Potential Project Partners

- Mehran University of Engineering and Technology (MUET).
- Muhammad Nawaz Sharif University of Agriculture, Multan (MNSUAM).
- Sindh Agriculture University (SAU).
- Society of Facilitators and Trainers (SOFT).
- International Union for Conservation of Nature (IUCN) Pakistan.
- Pakistan Council of Research in Water Resources (PCRWR).
- Pakistan Agriculture Research Council (PARC).
- Provincial Agriculture Departments.
- Provincial Irrigation Departments.
- NGOs.

Potential International Project Partners

- Charles Sturt University (CSU).
- Commonwealth Scientific and Industrial Research Organisation (CSIRO).
- Murdoch University.
- University of Canberra (UC).
- International Center for Biosaline Agriculture (ICBA).
- Pakistan Council of Research in Water Resources (PCRWR).
- ECOSEAL.
- Landcare network.
- Others.

Possible Funding Sources

National Level

- Federal government.
- Provincial governments.

International Level

- ACIAR, USAID, ADB, WB, FAO-UN, IsDB.

Duration

- 5 years.

Appendix 3. Concept Note 3

Using RAPs as a Collaborative Planning Tool for Communities Living in Salinity-Affected Areas

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Background

Stakeholder planning and decision-making for various interventions in the agriculture sector have benefited from application by the ACIAR 'Groundwater' project (LWR/2015/036) of an integrative and participatory approach known as Representative Agricultural Pathways (RAPs). The ACIAR 'Adapting to Salinity in the Southern Indus Basin' (ASSIB) project also started using RAPs to support planning with some of its 'bright spot' communities. A process to support stakeholder engagement with planning and to finalise interventions is very useful for ASSIB communities and should be continued. A comprehensive adaptation package was developed but all the adaptations could not be implemented and analysed at the same time for economic analysis. The researchers tried to run the model on the available data but that was not sufficient to draw any meaningful conclusions. The team undertook RAPs sessions with community/stakeholders, developed the adaptation packages, and the DevRap matrix. Our agenda is to continue working with the communities who have become engaged with the RAPs process to finalise collection of data about adoption of interventions and then analysing that data using the TOA-MD approach to assess the socio-economic impacts on the farming communities affected by salinity.

Aims

The proposed project aims to:

1. Work closely with the rural communities (farmers, youth, and females farm representatives) in salinity-affected areas using RAPs for building scenarios and future short, medium and long run strategic planning.
2. Enhance farm productivity of salt-affected farmers using proposed adaptation packages and interventions for increasing net farm returns, reducing poverty and improving livelihood and resilience in the southern Indus Basin.
3. Upscale the RAPs based solutions for salinity management and enabling the communities to live with it in the project areas and beyond.
4. Enlighten policymakers on the crucial role of policy interventions in sustainable salinity management agricultural practices.

Objectives

1. Organise RAPs sessions with communities and stakeholders.
2. Incorporate the recommendations into co-designed research with ASSIB bright spot and other communities in saline areas.

3. Improve the RAPs process and adaptation packages for ASSIB bright spot and other extended communities.
4. Organise training workshop(s), outreach activities and mini conference(s) regarding proposed adaptations.
5. Assess the socio-economic impact of the interventions proposed and implemented in the past and current project for living with salinity in the selected areas.

Activities

- Continuous engagements with communities for co-learning and co-development regarding RAPs and site-specific adaptation packages.
- RAPs sessions with stakeholders, following all its protocols.
- Development of scenarios, adaptation packages and then key interventions.
- Finalisation of RAPs process using the DevRAP matrix.
- Sharing of RAPs results and adaptation packages with experts for further refinement on certain variables.
- Collection of data from farming households who adopted interventions in the past.
- Combining survey data, RAPs, and secondary data about farm indicators in TOA-MD for economic analysis of proposed adaptation.
- Analysis of data using TOA-MD model for assessing the socio-economic impact of the interventions proposed and implemented in the past and future on farm welfare indicators (cost benefits analysis, impact on net farm returns, poverty etc.).
- Production of reports and research papers for publication.

Potential Project Partners

- Mehran University of Engineering and Technology (MUET).
- Muhammad Nawaz Sharif University of Agriculture, Multan (MNSUAM).
- The University of Faisalabad (TUF).
- Sindh Agriculture University (SAU).
- University of Agriculture, Faisalabad (UAF).
- Society of Facilitators and Trainers (SOFT).
- Pakistan Agriculture Research Council (PARC).
- Provincial Agriculture Departments.
- Provincial Irrigation Departments.
- NGOs, stakeholder forums.

Potential International Project Partners

- Charles Sturt University (CSU).
- Commonwealth Scientific and Industrial Research Organisation (CSIRO).
- Murdoch University.
- International Center for Biosaline Agriculture (ICBA).
- ECOSEAL.

- Others.

Possible Funding Sources

National Level

- Federal government.
- Provincial governments.

International Level


- ACIAR, USAID, ADB, WB, FAO-UN, IsDB, JICA.

Duration

- 5 years.

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