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Integrated Socioeconomic Assessment of Seawater Intrusion in the Coastal Districts of Sindh, Pakistan



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Pakistan Council of Research in Water Resources (PCRWR)
2026

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Disclaimer:

The socioeconomic findings presented in this report are based on structured household surveys conducted in the coastal areas of Sindh and reflect the perceptions, experiences, and opinions of the respondents at the time of the survey. These findings are intended to complement the scientific assessment and should not be interpreted as independently verified conclusions or as the official views, policy positions, or administrative statements of PCRWR, NIO, the Government of Pakistan, or any other government institution.

ISBN: 978-627-7725-08-2

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Foreword



Coastal regions represent both an ecological asset and a socioeconomic lifeline for Pakistan. Along the Sindh coast, millions of people depend on fragile land and water systems for agriculture, fisheries, livestock rearing and related livelihoods. In recent decades, however, these systems have come under increasing stress due to seawater intrusion, declining freshwater availability, climate variability and growing development pressures. Addressing these challenges requires not only scientific understanding of environmental processes, but also a clear appreciation of how such changes affect communities, livelihoods, health and social structures.

It is in this context that this study on Monitoring the Impacts of Seawater Intrusion on Coastal Communities of Sindh has been undertaken under the PSDP project "*Monitoring the Sea Water Intrusion, Sea Level Rise, Coastal Erosion and Land Subsidence along Sindh and Balochistan Coast"*. The report represents a timely and important contribution to evidence based planning and policy dialogue by integrating hydrogeological monitoring with socioeconomic and community level analysis across the coastal districts of Badin, Sujawal, Thatta and Tando Muhammad Khan.

What distinguishes this study is its integrated and multidisciplinary approach. By combining data from a network of piezometers monitoring groundwater salinity and water levels with household surveys and focus group discussions, the study moves beyond sectoral silos. It provides a holistic picture of how seawater intrusion translates from a physical process into tangible development risks affecting drinking water security, agricultural productivity, livelihoods, health outcomes, gender roles and migration patterns. Such integrated evidence is essential for informed decision making in complex coastal environments.

The findings underscore that seawater intrusion is not merely an environmental concern, but a cross sector development challenge with cumulative and reinforcing impacts. Declining freshwater quality, soil salinization, livelihood instability and health burdens interact in ways that disproportionately affect vulnerable groups, including women, youth, landless households and small scale fishing communities. At the same time, the study documents the resilience and adaptive responses of coastal communities, highlighting both indigenous knowledge and coping strategies, while also revealing the structural constraints that limit their effectiveness.

Importantly, this report does not stop at diagnosis. It offers practical, phased recommendations ranging from immediate measures to protect drinking water and health, to medium and long term strategies for climate resilient agriculture, livelihood diversification and integrated coastal zone management. The proposed monitoring, evaluation and knowledge management framework provides a foundation for sustained learning and adaptive planning, aligning local action with provincial and national development priorities.

From an institutional perspective, the study demonstrates the value of investing in data driven, participatory approaches. The integration of scientific monitoring with community perspectives strengthens accountability, enhances relevance and ensures that policy responses are grounded in both measured conditions and lived realities. Such approaches are increasingly essential in the face of climate change and growing pressure on natural resources.

I commend the research team and all stakeholders involved for their dedication and rigor in carrying out this important work. The insights presented in this report will be valuable to policymakers, planners, development partners, researchers and practitioners engaged in coastal management, water security and climate resilience. It is my hope that the findings and recommendations contained herein will inform concrete actions to safeguard livelihoods, improve water security and promote inclusive and sustainable development along the Sindh coast.

Dr. Ibrahim Zia
Principal Scientific Officer (NIO)

Acknowledgment

The authors express their sincere gratitude to all individuals and organizations whose dedication, expertise, and support contributed to the successful completion of this study.

We are especially grateful to Dr. Hifza Rasheed, Director General, PCRWR, for her valuable guidance in developing the socioeconomic survey questionnaire and for her continuous encouragement and support throughout the implementation of the study.

Our heartfelt appreciation goes to the PCRWR field team, particularly Mr. Abdul Ghaffar Solangi (Research Officer), Mr. Mir Tasleem Akhtar (Field Assistant), Mr. Muhammad Amin Mallah (Assistant Scientific Officer), Mr. Abdul Rahim Soomro (LDC), Mr. Anwar Ali Chang (Laboratory Assistant), Mr. Noor Muhammad Lakho (Field Assistant), Mr. Muhammad Amjad Baloch, and Mr. Farooque Ahmed (Drivers), for their dedicated efforts in conducting field surveys, monitoring the Multilevel Observation Wells (MLOWs), and collecting groundwater samples under challenging coastal field conditions.

We sincerely acknowledge Mr. Muhammad Yousif Abro (Environmental Engineering Specialist), Directorate of Agriculture Research, Soil & Water Testing Laboratory (DRIP), Tandojam, for conducting the Electrical Resistivity Sounding (ERS) surveys and providing valuable technical support for aquifer characterization.

The authors also appreciate the contributions of Ms. Nazia Sattar, Ms. Nasreen Pathan, Mr. Noorzaman Shar, Mr. Pervaiz Ahmed Soomro (Assistant Scientific Officers), Mr. Abdul Shakoor, and Mr. Shuhab-ud-Din Babar (Laboratory Assistants) for their meticulous laboratory analysis of groundwater samples. We are equally thankful to Mr. Abdul Jabbar Pathan (Assistant Director Ex.), Mr. Asghar Ali Chang (Assistant Scientific Officer), and Mr. Muhammad Ali (Laboratory Assistant), Soil & Water Testing Laboratory, DRIP, Tandojam, for carrying out the laboratory analysis of soil samples collected during the installation of Multilevel Observation Wells.

We gratefully acknowledge Mr. Farooque Ahmed Vighio (Assistant Director), Mr. Karmullah Khawaja (Assistant), Mr. Papu Kumar, and Mr. Muhammad Murad (LDCs) of PCRWR Regional Office Karachi and DRIP Tandojam for their dedicated support in administrative, financial, and project account management throughout the study. Our sincere thanks are extended to Mr. Muhammad Moosa Jagirani (Sub-Divisional Officer) and the transport team for efficiently coordinating transportation and logistical support, for the successful execution of extensive field activities.

We are particularly grateful to Hafiz Abdul Salam Memon, Regional Director, DRIP Tandojam, for his continuous cooperation, guidance, and assistance in coordinating field activities and facilitating project implementation whenever required.

The authors wish to express their sincere appreciation to the Director General/Project Director, National Institute of Oceanography (NIO), Karachi, for his leadership and valuable technical support throughout the planning, implementation, and coordination of the project.

Special thanks are also extended to Mr. Abdul Ghafoor Palepoto, Mr. Asghar Ali Sujawali, Mr. Abdullah Saraz, and Mr. Ali Akbar Qambrani for their valuable assistance in organizing the Focus Group Discussions (FGDs) in the districts of Thatta, Sujawal, and Badin.

Finally, the authors extend their heartfelt gratitude to all community members, household respondents, key informants, and participants who generously shared their time, knowledge, and experiences during the socioeconomic survey. Their cooperation and valuable insights formed an essential foundation of this study. We also acknowledge Mr. Zeeshan Munwar for his dedicated efforts in formatting and finalizing this report.

EXECUTIVE SUMMARY

Seawater intrusion (SWI) has become a critical environmental and development challenge along the Sindh coast, with far reaching implications for freshwater security, agriculture, livelihoods, health and social stability. This study presents an integrated assessment of the socioeconomic and environmental impacts of seawater intrusion in the coastal districts of Badin, Sujawal, Thatta and Tando Muhammad Khan, combining scientific monitoring with community-level evidence. The assessment draws on three complementary data sources: (i) hydrochemical monitoring from 100 piezometers installed across coastal grids, with repeated sampling during 2023-2025; (ii) a household level socioeconomic survey of approximately 300 households; and (iii) focus group discussions capturing community perspectives, indigenous knowledge and coping strategies. Secondary data from national and provincial institutions were used to contextualize findings within broader demographic, climatic and development trends.

Hydrogeological monitoring confirms widespread and persistent groundwater salinization across the coastal aquifer system. Most sampled locations fall within saline to highly saline categories, exceeding guideline values suitable for drinking and irrigation. Salinity occurs across both shallow and intermediate aquifers, indicating that seawater intrusion is a regional hydrogeological process rather than isolated local contamination. These scientific findings are consistent with community perceptions, with nearly three quarters of surveyed households reporting that their drinking water is saline or brackish. Respondents further indicated that access to "sweet water" is primarily associated with seasonally available surface water rather than groundwater. According to the household survey, the availability of "sweet water" is generally limited to certain periods of the year, after which many households rely on saline groundwater, ponds, or purchased water for their daily needs. While this seasonal availability provides temporary relief, it does not represent a sustainable or reliable source of freshwater.

Agriculture remains a central livelihood pillar, with >70% of surveyed households reporting ownership of agricultural land. However, this structural dependence is increasingly undermined by salinity stress. An overwhelming 94% of households reported increasing soil salinity, and nearly nine out of ten households reported worsening crop yields over time. Freshwater for irrigation is limited and seasonal, and the use of saline groundwater further accelerates soil degradation. Farmers report reduced germination, declining crop vigor and shrinking harvests, prompting shifts toward low value salt tolerant crops, fallowing of land, or complete abandonment of cultivation in severely affected areas. These trends pose serious risks to food security, rural incomes and long term agricultural viability.

Livestock and fisheries serve as important secondary or alternative livelihoods, particularly where agriculture fails. Survey responses and qualitative discussions indicate that saline water adversely affects livestock health and productivity, while changes in coastal and estuarine salinity regimes are perceived to reduce fish quality and alter species composition. As a result, traditional livelihood buffers are weakening across much of the coastal zone.

Across sectors, households face direct income losses from declining production alongside indirect costs, including purchasing drinking water, medical expenses and increased time spent accessing basic services. These pressures erode savings, increase indebtedness and weaken adaptive capacity, particularly among landless households and small scale fishers.

Health impacts linked to saline and unsafe water are widespread. More than 80% of surveyed households reported negative health effects, including skin conditions, gastrointestinal illness and other water related ailments. Women and children bear a disproportionate share of caregiving responsibilities, especially in districts with limited health infrastructure. Chronic exposure to poor quality water,

combined with sanitation constraints, reinforces cycles of vulnerability through lost labor productivity and rising out of pocket health expenditures.

Migration is increasingly used as a coping strategy. Approximately 28% of households reported that at least one member had migrated, with higher incidence in districts experiencing greater livelihood stress and water insecurity. Reported drivers include poverty, employment loss, declining agricultural viability, lack of drinking water and health concerns. Migration is predominantly seasonal or circular, but persistent environmental stress raises the risk of longer-term displacement, social fragmentation and demographic imbalance, particularly among youth.

The impacts of SWI are unequally distributed. Women bear a disproportionate burden of water collection, often spending 2-3 additional hours per day during canal closure periods, limiting participation in income generating activities and education. Youth face rising employment stress as traditional livelihoods decline, increasing reliance on informal labor and migration. Vulnerable groups including landless agricultural laborers, small scale fishers, elderly persons, and female-headed households exhibit the lowest adaptive capacity, characterized by limited savings, weak institutional linkages and minimal access to formal support mechanisms.

Community awareness of environmental change is high. Most households perceive declining groundwater quality, reduced freshwater availability and increasing salinity impacts on land and livelihoods. While communities employ a range of coping strategies such as water purchasing, crop adjustments, livelihood diversification, and temporary migration many practices identified as "working" provide only short-term relief. Structurally unsustainable responses, including pumping saline groundwater, remain widespread due to limited alternatives. Key constraints to effective adaptation include financial limitations, weak technical support and limited institutional engagement**.**

Overall, the evidence demonstrates that seawater intrusion in coastal Sindh is not only an environmental issue but a cross-sector development risk, affecting water security, agriculture, health, livelihoods, gender equity, and migration in mutually reinforcing ways. The study underscores the importance of evidence based and integrated planning, combining scientific monitoring with community level data and institutional learning. Without coordinated and sustained action, seawater intrusion will continue to erode development gains and deepen vulnerability among coastal populations.

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List of Acronyms

SWI	Sea Water Intrusion
GW	Ground Water
FAO	Food and Agriculture Organization
PBS	Pakistan Bureau of Statistics
MICS	Multiple Indicator Cluster Survey
WHO	World Health Organization
EC	Electrical Conductivity
TDS	Total Dissolved Solids
DTW	Depth to Water Table
KM	Knowledge Management
FGDs	Focus Group Discussions
IPCC	Intergovernmental Panel on Climate Change
UNDP	United Nations Development Programme
UNICEF	United Nations Children' Fund

CHAPTER

1

INTRODUCTION

Chapter 1.
INTRODUCTION

1.1 Background

Coastal regions worldwide are increasingly exposed to sea water intrusion (SWI) as a consequence of sea level rise, reduced freshwater inflows, ground water (GW) over extraction, and climate induced hydrological change. SWI is now recognized as a major threat to freshwater security, agricultural productivity, ecosystem integrity and human wellbeing in low lying deltaic systems. Globally, more than one billion people living in coastal zones are estimated to be at risk from salinization of land and water resources, with impacts expected to intensify under projected climate change scenarios (IPCC, 2021; World Bank, 2020).

South Asia is among the most vulnerable regions globally to salinity intrusion and water insecurity due to the convergence of extensive low-lying deltaic systems, exceptionally high population densities, rapid urbanization and a heavy reliance on GW based irrigation and domestic water supplies. Major river deltas such as the Indus, Ganges-Brahmaputra-Meghna and Mahanadi support hundreds of millions of people but are increasingly exposed to reduced upstream freshwater flows, sea level rise and over extraction of aquifers. These pressures have intensified SWI into coastal aquifers, degraded soil and water quality and heightened risks to food security, livelihoods and public health, particularly in rural and agrarian communities (FAO, 2019; World Bank, 2020; IPCC, 2021). GW abstraction accounts for more than half of irrigation water use in South Asia, making the region especially sensitive to salinity-related degradation of freshwater resources (Shah et al., 2007; FAO, 2020).

The Indus Delta is one of Pakistan's most environmentally vulnerable coastal regions, where groundwater resources are increasingly influenced by the combined effects of climatic variability, sea level rise, coastal hydrogeological processes, and growing pressure on freshwater resources. Changes in freshwater availability within the deltaic system, together with rising sea levels and intensive groundwater abstraction, have increased the susceptibility of coastal aquifers to saline water intrusion. These interacting natural and anthropogenic factors contribute to the progressive evolution of groundwater salinity through both surface and subsurface pathways, while land subsidence may further enhance saline intrusion in parts of the lower delta (IPCC, 2021; World Bank Group, 2022).

The coastal districts of Badin, Sujawal, Thatta and Tando Muhammad Khan (T. M. Khan) are particularly exposed due to their low lying, flat geomorphology, close proximity to the Arabian Sea and high dependence on climate sensitive livelihoods such as irrigated agriculture, livestock rearing and coastal fisheries. Persistent GW salinization in these districts has reduced access to potable water, degraded agricultural soils and undermined household income sources, increasing vulnerability among rural, landless and fishing communities. National and regional assessments consistently identify the lower Indus Basin as one of South Asia's most severely affected deltas in terms of SWI and salinity related livelihood risks (FAO, 2020; PCRWR, 2018; IPCC, 2021). While the biophysical dimensions of SWI such as GW salinity, soil degradation, and ecosystem change have been documented in various technical studies, the socioeconomic consequences of SWI remain under represented in planning and policy discourse. In practice, SWI is not only an environmental process but a cross sector development challenge that directly affects drinking water access, household health, income stability, gender equity and migration dynamics. The impacts are unevenly distributed, disproportionately affecting poor, landless and socially vulnerable groups, including women, youth and small scale fishing communities.

In coastal Sindh, declining freshwater availability has increased household dependence on saline GW and seasonal canal supplies, with implications for health and daily labor burdens. Agricultural productivity is increasingly constrained by soil salinity and unreliable irrigation, while fisheries and livestock often viewed as livelihood buffers are themselves being stressed by changing salinity regimes and ecosystem degradation. These interacting pressures contribute to income loss, rising household expenditures, indebtedness and distress migration, reinforcing cycles of poverty and vulnerability.

Despite the scale of the challenge, policy responses have often relied on fragmented sectoral data, with limited integration of community level socioeconomic evidence. This gap underscores the need for systematic, ground level assessment that links physical measurements of SWI with lived experiences and coping responses of affected populations.

To address this need, the present study undertakes a household based socioeconomic survey across coastal Sindh, integrated with hydrogeological monitoring and qualitative insights from community consultations. The survey captures district wise data on water access, agriculture, livelihoods, health, gendered burdens, migration and adaptive practices. By combining scientific monitoring with community reported evidence, the study provides an integrated understanding of how SWI translates into tangible development risks.

The outputs of this assessment are intended to support evidence based planning, improve targeting of mitigation and adaptation investments and inform inclusive, climate resilient development strategies for Pakistan's coastal zones. In doing so, the study contributes to national priorities and aligns with international commitments on climate adaptation, water security and sustainable development.

CHAPTER

2

RESEARCH OBJECTIVES & SCOPE

Chapter 2.
RESEARCH OBJECTIVES & SCOPE

2.1 Overall Objective

The main objective of the research study was to assess the socioeconomic and environmental impacts of SWI in the coastal districts of Badin, Thatta, Sujawal and T. M. Khan. The research was designed to move beyond purely physical measurements of salinity by situating environmental change within the everyday realities of coastal households.

By integrating hydrogeological evidence with household level socioeconomic data and community perspectives, the study aimed to translate complex environmental risks into clear policy relevant insights to support planners, development practitioners, and government institutions in designing targeted interventions that protect livelihoods, safeguard freshwater resources, and strengthen long term resilience in coastal Sindh.

2.2 Specific Objectives

The specific objectives of the study were to;

i. Assess the extent and characteristics of SWI and its impacts on GW quality, freshwater availability, soil salinity and coastal ecosystems, with particular emphasis on drinking water security and irrigation reliability.
ii. Analyze the socioeconomic consequences of SWI, including impacts on agricultural productivity, livestock and fisheries, household income, employment patterns, health outcomes, and poverty dynamics across coastal communities.
iii. Examine livelihood transitions and migration responses associated with declining water quality and environmental stress, including the drivers, patterns and implications of seasonal and longer term migration.
iv. Document community perceptions, indigenous knowledge and coping strategies related to SWI and evaluate the effectiveness and limitations of existing household level adaptation practices.
v. Identify differential vulnerabilities and adaptive capacity gaps among women, youth and socially vulnerable groups, highlighting equity and inclusion dimensions of SWI impacts.

vi. Develop evidence-based policy and planning recommendations to support sustainable water management, climate resilient livelihoods and integrated coastal development, grounded in scientific monitoring and community level evidence.

2.3 Scope of the Study

The study is geographically limited to four highly exposed coastal districts of Sindh: Badin, Thatta, Sujawal, and Tando Muhammad Khan. These districts represent diverse livelihood systems, ecological conditions, and degrees of salinity intrusion, allowing for comparative analysis across varying exposure contexts.

i. The analytical scope of the research encompasses three interconnected dimensions:
ii. the hydrogeological characteristics of groundwater salinity,
iii. household level socioeconomic conditions and livelihood systems, and
iv. community perspective, responses, and institutional constraints.

While the study does not claim statistical representativeness for the entire coastal population of Sindh, it provides an analytically representative assessment of key vulnerability patterns and response pathways. The findings are therefore intended to inform policy prioritization, program design, and future research rather than to generate population wide estimates.

2.4 Conceptual Framing

The study adopts a pressure → exposure → impact → response framework. In this model, seawater intrusion acts as an environmental pressure that alters groundwater quality and agricultural soils (exposure). These changes affect livelihoods, health, and food security (impacts), prompting households and communities to adopt coping and adaptation strategies (responses). Feedback loops such as poverty driven groundwater over extraction further intensify vulnerability.

This framing allows the study to link physical processes with social outcomes and to position seawater intrusion not only as an environmental issue, but as a multidimensional development challenge.

CHAPTER 3

METHODOLOGY

Chapter 3.
METHODOLOGY

3.1 Introduction

This study adopted a convergent mixed methods research design to examine the socioeconomic and environmental impacts of seawater intrusion (SWI) in the coastal districts of Sindh. Recognizing that SWI is both a physical and social phenomenon, the methodology was designed to integrate hydrogeological measurements with household level socioeconomic data and community perspectives. This approach allowed the study to capture not only the extent of salinity intrusion, but also how it translates into livelihood stress, health risks, water insecurity, and migration pressures.

The study is grounded in a Pressure → Exposure → Impact → Response (PEIR) analytical framework to systematically examine the multidimensional consequences of seawater intrusion. This framework enables an integrated assessment of environmental processes and their socioeconomic implications within vulnerable coastal contexts.

In this structure, seawater intrusion constitutes the primary environmental pressure. It exerts stress on natural resource systems by degrading groundwater quality and increasing salinity in agricultural soils. These biophysical alterations represent the exposure dimension, as they directly affect household water sources, irrigation systems, and land-use practices in coastal communities.

The exposure conditions subsequently generate socioeconomic impacts. These include reduced agricultural productivity, declining household incomes, drinking water insecurity, health complications associated with saline water consumption, food insecurity, and shifts in employment patterns, including seasonal or permanent migration.

The response dimension captures the coping and adaptation strategies adopted by households and communities. These responses range from switching crops and modifying irrigation practices to increased reliance on alternative water sources, livelihood diversification, and migration. Institutional and policy-level responses are also considered where relevant.

The framework further acknowledges feedback mechanisms. For example, poverty-driven groundwater over-extraction may intensify aquifer depletion and salinization, thereby reinforcing environmental pressure and increasing vulnerability over time.

Empirical data were collected from four highly exposed coastal districts i.e. Badin, Thatta, Sujawal, and Tando Muhammad Khan. These districts were selected due to their documented vulnerability to seawater intrusion and associated socioeconomic stressors. The PEIR framework thus provides a coherent structure for linking hydro environmental dynamics with household level outcomes and adaptive behavior

3.2 Study Area

The study was conducted in the coastal belt of Sindh, Pakistan, encompassing the districts of Badin, Thatta, Sujawal, and Tando Muhammad Khan. These districts were selected due to their high vulnerability to seawater intrusion, dependence on groundwater for domestic and agricultural use, and recurring exposure to climate related stresses such as cyclones, flooding, and prolonged droughts.

The region is characterized by low lying deltaic terrain, extensive irrigation networks, and fragile coastal ecosystems. Salinity ingress has increasingly compromised freshwater aquifers and agricultural soils, undermining traditional livelihoods and accelerating out-migration. The four districts represent diverse livelihood systems and varying degrees of salinity exposure, making them suitable for comparative analysis.

3.3 Research Design

The research study was guided by a fundamental principle: environmental challenges like SWI do not unfold in isolation. The intrusion of seawater into freshwater systems did not stop at aquifers or farmlands; it moved through households, shaped health outcomes, altered livelihoods, and gradually transformed social and cultural life. Capturing this reality required a research approach that could measure physical change while also giving voice to the people living with its consequences.

For this reason, the study adopted a convergent mixed methods design, in which quantitative and qualitative data were collected and analyzed in parallel and then brought together through systematic triangulation. This approach was chosen deliberately to reflect the complexity of seawater intrusion, which could not be fully understood through numbers alone, nor through narratives in isolation. Quantitative data made it possible to trace patterns of salinity, water access, income loss, and health stress, while qualitative accounts revealed how these changes were experienced, interpreted, and managed in everyday life.

By integrating these two streams, the study moved beyond fragmented evidence and developed a more coherent understanding of risk, vulnerability, and response. In this way, the methodology was not only a technical choice, but a reflection of the study's core aim: to link scientific measurement with human experience and translate that combined knowledge into insights that could inform practical, people-centered policy.

3.3.1 Rationale for the Convergent Mixed Methods Design

Seawater intrusion in Sindh's coastal belt is a dynamic and evolving crisis driven by sea level rise, reduced freshwater inflows from the Indus River, over extraction of aquifers, and climate variability. It is not merely a hydrological issue; it is intersected with poverty, gender roles, migration patterns, and public health in ways that demanded a multidimensional analytical lens. A traditional cross-sectional design while useful for capturing a snapshot of prevailing conditions but would have limited the analysis to surface level associations, such as simple correlations between salinity levels and income loss, without exploring the underlying social and behavioral mechanisms. For example, why some households migrated while others remained and adapted, or what cultural meanings communities attached to "salty water" beyond its chemical composition, could not have been adequately explained through a single method.

Similarly, a purely qualitative approach, though rich in narrative depth, would have overlooked broader patterns essential for policy relevance, such as the proportion of households affected or the spatial distribution of salinity hotspots. The convergent mixed methods design addressed these gaps by giving equal priority to quantitative and qualitative strands. The quantitative strand was designed to provide breadth and analytical generalization, while the qualitative strand offered depth and contextual understanding; both were collected concurrently during the 2023-2025 period. This parallel structure ensured that insights from one strand could immediately inform the other, reducing the risk of methodological silos.

The design drew upon established mixed-methods traditions, particularly Creswell and Plano Clark's (2017) convergent parallel model, which emphasized integration at the interpretation stage to enhance validity through triangulation. In this study, triangulation served multiple purposes: convergence, where findings aligned to confirm patterns; complementarity, where one strand helped explain the other; and divergence, where discrepancies revealed hidden complexities, such as social desirability bias in self-reported health data. For instance, when quantitative surveys indicated low adoption of adaptation strategies, qualitative focus group discussions revealed structural and gender based barriers, prompting a re-examination of the statistical results.

This approach proved particularly well suited to seawater intrusion research in vulnerable coastal contexts. As highlighted in recent climate adaptation literature, mixed-methods designs were especially effective in socio-environmental studies because they linked biophysical data, such as groundwater salinity, with social indicators, including livelihood stress and resilience strategies. In this case, the design enabled a deeper understanding of how past events such as the 2010 floods that accelerated salinity intrusion interacted with present day realities, embedding historical context within a contemporary analytical framework.

3.4 Key Components of the Research Design

The convergent mix methods research design is structured around three interconnected phases: (i) parallel data collection, (ii) independent analysis, and (iii) integrated interpretation. Each phase is tailored to the study's objectives, ensuring that environmental, socioeconomic, and resilience dimensions are examined holistically.

3.4.1 Parallel Data Collection

Data collection occurred concurrently across the four districts, with quantitative and qualitative efforts running side by side to capture real time synergies. This simultaneity allowed field teams to cross reference emerging patterns. For instance, noting a high salinity reading from a piezometer and immediately probing nearby households for perceived impacts.

3.4.1.1 The Quantitative Strand: Measuring Exposure and Impact

The quantitative strand focused on generating objective, scalable indicators of SWI's extent and effects. Key elements included:

- **Hydrogeological Monitoring:** GW conditions were assessed through a network of 100 piezometers, installed to depths of up to approximately 60 feet across the study districts. Monitoring focused on key hydrochemical and physical parameters, including:

    a) Electrical Conductivity (EC)
    b) Total Dissolved Solids (TDS)
    c) pH
    d) Depth to Water Table (DTW)
    e) Cation +Anion Analysis

Sampling was conducted during 2023-2025, covering multiple seasonal rounds to capture temporal variability. This dataset provides an objective basis for identifying salinity classes, spatial patterns, and persistence of saline conditions within the coastal aquifer system.

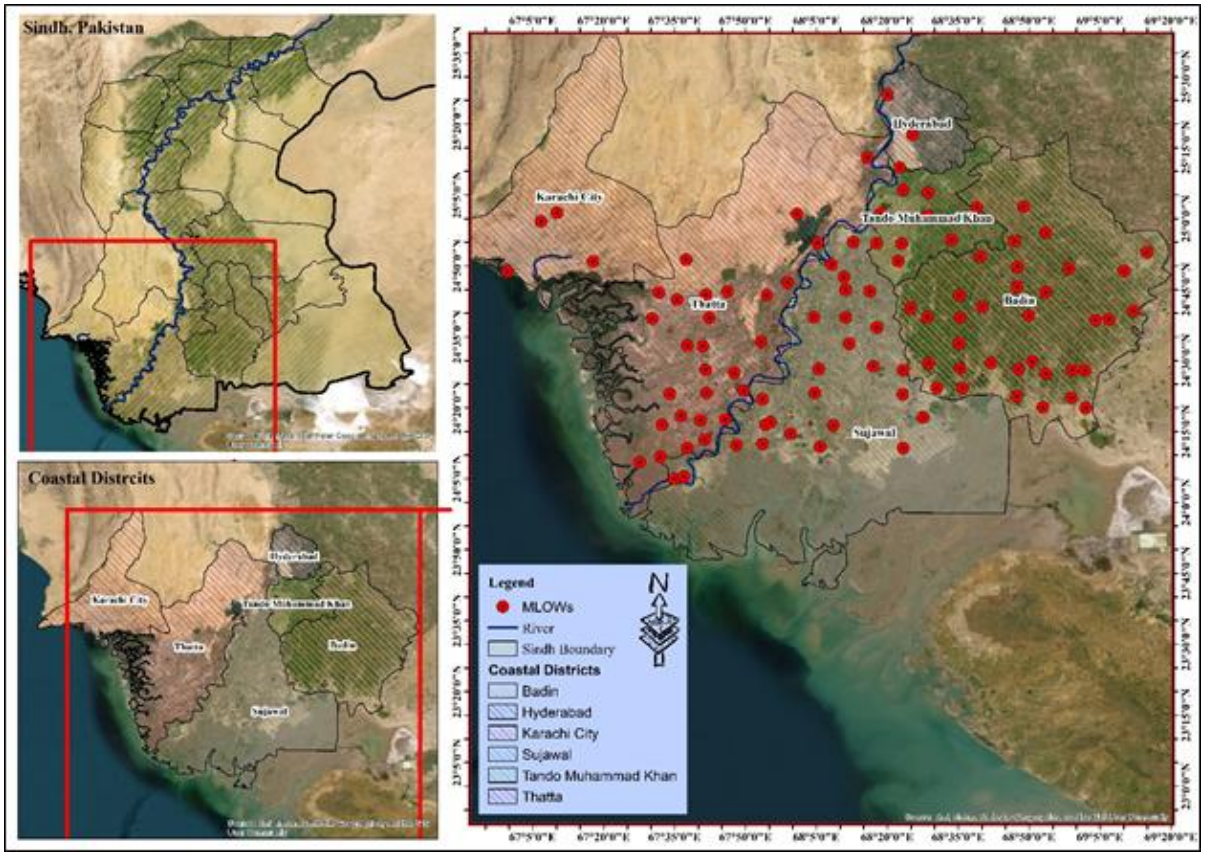


***Figure* 3.1:** *Location Map of MLOWs installed in coastal Sindh, Pakistan*

Household Surveys: A central component of the data collection process was the administration of structured household surveys to 300 households across the four coastal districts. To ensure that the sample reflected the diversity of exposure contexts, a stratified random sampling approach was adopted. Households were stratified by district, proximity to the coastline, dominant livelihood type (agriculture, fisheries, or wage labor), and settlement size. This strategy was selected to capture variations in salinity exposure and socioeconomic vulnerability across different ecological and livelihood zones, while reducing selection bias and enhancing analytical comparability between groups.

The structured questionnaire was designed to generate quantitative evidence on both the physical and social dimensions of seawater intrusion. It assessed not only the extent of salinity exposure but also how households perceived and experienced its impacts on land, water, health, and livelihoods. In doing so, the survey captured the ways in which environmental change translated into everyday risks and decisions at the household level. Specifically, the instrument collected data on:

- **Water security:** Primary drinking water sources, seasonal availability, and perceived water quality (sweet versus saline).
- **Socioeconomic conditions:** Education levels, income sources, agricultural land ownership, crop productivity, and employment shifts.
- **Health and migration:** Self-reported health symptoms linked to water quality (such as skin and gastrointestinal conditions) and migration incidence, including intra-provincial, inter-provincial, and international movements.
- **Adaptation and coping strategies:** Household responses such as rainwater harvesting, water filtration, crop diversification, and livelihood shifts.

By combining objective indicators with household perceptions, the survey enabled the study to quantify not only the scale of seawater intrusion, but also its social meaning and practical consequences. This approach strengthened the ability of the research to inform policies that are responsive to both environmental risk and human experience. To enhance statistical rigor and spatial accuracy, GPS coordinates were recorded for sampled locations, and standardized chain of custody procedures were followed during groundwater sampling. Together, these measures ensured the reliability, traceability, and policy relevance of the quantitative evidence generated on the scale and distribution of seawater intrusion.

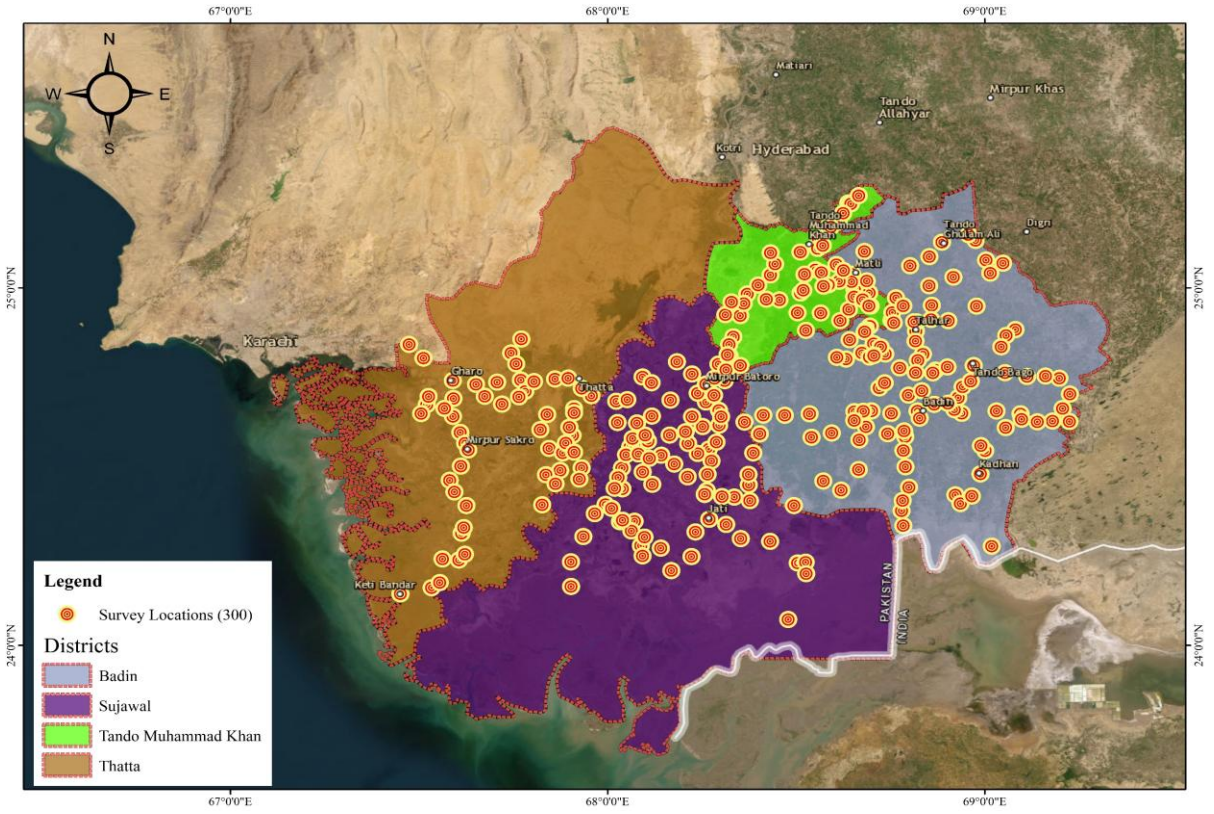


Figure 3.2: *House Hold Survey Location Map of Coastal districts of Sindh*

- **Secondary Quantitative Data:** Secondary quantitative data were integrated from national and provincial sources, including the Pakistan Bureau of Statistics (PBS), and climate records from the Pakistan Meteorological Department (PMD). These datasets provided historical benchmarks and contextual trends, such as long-term rainfall variability, declining agricultural yields, and shifts in population and livelihood patterns. In particular, rainfall records over the past two decades indicated a substantial decline, supporting the analysis of climate related stressors contributing to seawater intrusion. This secondary data stream strengthened the analytical foundation of the study by enabling trend-based comparisons and external validation of field findings.

3.4.1.2 The Qualitative Strand: Community Experiences and Perspectives

The qualitative strand explored the lived experiences of communities and the ways in which households interpreted, navigated, and responded to seawater intrusion and complemented the quantitative evidence. This component was designed to capture the social meanings, emotional dimensions, and cultural understandings that could not be fully revealed through numerical data alone. By giving space to community voices, the qualitative inquiry deepened the analysis and revealed how environmental change was perceived, negotiated, and managed in everyday life.

- **Focus Group Discussions:** Focus group discussions (FGDs) were conducted to capture the nuanced perspectives of different stakeholder groups within the affected communities. These discussions were particularly valuable for understanding how collective attitudes and behaviours shape community responses to the challenges posed by SWI. Engaging participants across various demographics such as age, social status and professional background allowed to gather rich qualitative insights into local knowledge, experiences and coping mechanisms. Each FGD served as a vital platform for community members to articulate their concerns and develop a shared understanding of the challenges and opportunities that lie ahead, ultimately contributing to more informed and effective interventions. This qualitative component of the research not only complemented the quantitative data obtained from household surveys but also added depth to the analysis, enriching the overall understanding of how environmental changes impact these communities.

- **FGD 1 (Sujawal):** In Sujawal, the FGD convened community representatives from diverse backgrounds, including community leaders, social workers, health practitioners and youth, in a localized setting that catered to their accessibility and comfort. This location was chosen for its strategic importance, as Sujawal is one of the frontline districts heavily impacted by SWI. Discussions emphasized the shared challenges of accessing clean water and healthcare, with participants detailing localized strategies to address resource scarcity. The dialogue underscored the importance of social cohesion, showcasing how collective efforts both formal and informal are mobilized to manage shared resources like water and land. Participants expressed a strong sense of community solidarity, though they acknowledged the strains that environmental changes have placed on these social ties. Knowledge sharing regarding climate change adaptation strategies emerged as a recurrent theme, with many participants noting gaps in awareness about effective practices to mitigate adverse effects.



- **FGD 2 (Golarchi**): Similarly, the FGD in Golarchi engaged a diverse group of stakeholders, including local farmers, educators and youth activists, who brought their experiences and perspectives to the table. Golarchi, with its unique socioeconomic dynamics, provided a fertile ground for discussing agricultural practices and their changes over time due to SWI. Participants pointed out the drastic impacts on crop yields and livelihoods, and the discussions turned to community led initiatives aimed at sustainable farming practices. Local



leaders highlighted efforts to educate farmers about alternative crops that are more resilient to saline conditions, showcasing a proactive stance despite the adversity. The FGD also explored the role of youth in driving awareness campaigns about climate change and adaptation strategies. This exchange fostered an atmosphere of hope and ingenuity, as participants shared stories of successful grassroots initiatives aimed at resource management and ecological resilience.

- **FGD 3 (Badin):** The FGD conducted in Badin produced equally compelling insights, reflecting the area's historical significance and diverse population. In this district, particular emphasis was placed on health impacts related to SWI, with health workers participating actively in the discussions. They conveyed their experiences regarding increased cases of waterborne diseases and the challenges in providing adequate healthcare in light of deteriorating water quality. Participants discussed collective strategies for managing healthcare resources, focusing on the need for enhanced training for local healthcare providers and better access to medical facilities.



The discussion also tackled issues of social cohesion, as participants acknowledged the diversities within their communities including various ethnic and sectarian groups and how these dynamics influence collective action toward adaptation to climate change. Many emphasized the importance of inclusivity in decision making processes, advocating for greater representation of marginalized voices in conversations regarding resource management and climate adaptation.

- **Secondary Qualitative Data**: Secondary qualitative data were also incorporated to situate primary field narratives within a broader regional and historical context. These materials were drawn from published research reports, environmental impact assessments, policy documents, and archival sources, including documented oral histories from earlier coastal studies. Such sources provided insight into long-term patterns of environmental change, displacement, and livelihood transformation in Sindh’s coastal belt.

Integrating these materials allowed the study to compare present day experiences with earlier documented accounts of salinity intrusion, water scarcity, and ecological degradation. This historical layering strengthened the interpretive depth of the analysis by identifying continuities and shifts over time, and by situating household testimonies within a wider trajectory of environmental stress and adaptation. In doing so, the qualitative strand moved beyond isolated narratives and contributed to a more grounded and policy relevant understanding of vulnerability in the coastal region

3.4.2 Independent Data Analysis: Establishing Analytical Foundations

Following data collection, the quantitative and qualitative strands were analyzed independently to preserve methodological rigor prior to integration. This sequential independence ensured that each dataset retained its internal validity and analytical strength before being brought together through triangulation.

The quantitative data were analyzed using SPSS (Version 28) to generate both descriptive and inferential insights. Descriptive statistics, including means, frequencies, and cross tabulations, were used to summarize household characteristics, water sources, health conditions, and livelihood patterns. Inferential techniques, including linear and logistic regression models, were employed to examine associations between salinity exposure and selected outcomes such as migration incidence and income variability. Spatial analysis was conducted using ArcGIS to identify geographic clustering and salinity hotspots. To facilitate comparative analysis across households, composite measures were constructed, including an SWI Exposure Index combining electrical conductivity, total dissolved solids, and dependence on affected water sources.

The qualitative data were analyzed using NVivo (Version 14) following a systematic thematic analysis approach. Transcripts from focus group discussions and interviews underwent open coding to identify emerging themes, such as shifting perceptions of water quality and the social meaning of environmental change. Axial coding was then used to group related codes into broader analytical categories, including adaptation burdens, gendered responsibilities, and livelihood transformation. Finally, selective coding distilled overarching narratives that framed seawater intrusion as a multidimensional socio-environmental disruptor. To enhance credibility, approximately 20 percent of transcripts were double coded, and discrepancies were resolved through team deliberation to ensure interpretive consistency.

By analyzing each strand independently, the study preserved the precision of statistical modeling alongside the contextual richness of narrative inquiry. This phase strengthened the analytical foundation and prepared the datasets for systematic integration in the subsequent stage of interpretation.

3.4.3 Integrated Interpretation: Triangulation and Meta Inferences

The defining feature of the convergent mixed-methods design was the systematic integration of quantitative and qualitative findings through triangulation. After independent analyses were completed, results were compared using joint displays, including analytical matrices that aligned statistical indicators with corresponding thematic insights. This structured comparison enabled the identification of patterns of convergence, complementarity, and divergence across data sources.

Convergence was observed where quantitative and qualitative findings aligned to reinforce exposure patterns. For instance, elevated TDS measurements in specific locations corresponded with focus group discussions describing the abandonment of wells due to increasing salinity, thereby confirming both physical and experiential dimensions of intrusion. Complementarity emerged when one strand provided explanatory depth to patterns identified in the other. Regression models indicated that education functioned as a buffer against distress migration; qualitative discussions further clarified that educated youth were more likely to access urban employment networks, reducing vulnerability. Divergence was also analytically valuable. In some areas, moderate salinity readings were accompanied by strong qualitative expressions of fear, including references to “salt in the blood,” suggesting that perceptual and cultural thresholds of risk extended beyond objective measurements.

From this triangulated analysis, broader meta inferences were derived. These holistic interpretations moved beyond isolated indicators to reveal systemic dynamics, such as the ways in which seawater intrusion intensified existing gender inequalities. Quantitative findings showed a significant increase in women’s labor time related to water collection and household adjustments, while qualitative narratives described heightened emotional and physical burdens. Integration also illuminated pathways of resilience, including informal water-sharing arrangements and collective coping mechanisms that buffered households against economic shocks.

Through this process, integration did not merely validate findings across methods; it deepened understanding, reduced interpretive bias, and strengthened the policy relevance of the study by linking measurable trends with lived realities.

3.5 Ethical Considerations, Strengths, and Study Limitations

3.5.1 Ethical Considerations

Ethical integrity was maintained throughout the research process. Prior to participation, informed consent was obtained from all respondents. The purpose of the study, data collection procedures, expected duration of participation, and the voluntary nature of involvement were clearly explained in accessible language. Participants were informed of their right to decline any question or withdraw from the study at any stage without consequence.

Confidentiality was treated as a fundamental obligation. Personal identifiers were removed from datasets, and all digital and physical records were securely stored to prevent unauthorized access. Findings were reported in aggregate form to ensure that no individual household or respondent could be identified.

The research team adopted systematic data collection and analytical protocols to minimize bias. Enumerators were trained to maintain neutrality during interviews and discussions. During analysis, reflexive review sessions were conducted to examine potential interpretive biases, particularly when integrating qualitative narratives with quantitative findings. These measures strengthened the credibility and ethical robustness of the study.

3.5.2 Strengths and Suitability of the Research Design

The convergent mixed-methods design proved particularly well suited to studying seawater intrusion, given its interconnected environmental and social dimensions. By examining linkages between hydrogeological indicators (such as salinity levels and water availability) and socioeconomic outcomes (including income shifts, health access, and migration), the study was able to capture both structural patterns and lived realities.

A key strength of the design was its capacity to foreground community agency alongside environmental exposure. While quantitative analysis identified the extent of salinity and its statistical associations with livelihood stress, qualitative inquiry revealed how households interpreted these changes, negotiated constraints, and developed coping strategies. In practice, parallel data collection enhanced community engagement, as participants observed

both scientific monitoring of water quality and structured opportunities to share their experiences.

Although primary data collection followed a cross-sectional framework, meaning that household surveys, groundwater testing, and qualitative discussions were conducted within a defined study period, it incorporated retrospective insights through historical climate records, secondary datasets, and elders' accounts of ecological change. This approach extended the analytical horizon beyond a single moment in time, embedding current vulnerabilities within longer-term processes such as delta erosion and reduced freshwater inflows since the 1990s. In this sense, the research offered not merely a snapshot, but a contextualized assessment informed by memory and documented trends.

3.5.3 Limitations and Mitigation Strategies

Despite its strengths, several limitations must be acknowledged to appropriately interpret the findings. First, the study relied in part on self-reported data, particularly regarding health symptoms, income changes, and perceptions of water quality. Such data are inherently subjective and may be influenced by recall bias or social desirability effects. To mitigate this limitation, self-reported responses were triangulated with groundwater measurements, secondary statistics, and qualitative discussions to enhance reliability.

Second, the cross-sectional nature of the SES limited its ability to capture long-term or seasonal dynamics of seawater intrusion. SWI is an evolving process shaped by climatic variability, hydrological shifts, and socio-political responses over time. Although the study included secondary data spanning approximately two decades to infer broader trends, it did not constitute a longitudinal monitoring system. Future research incorporating panel data or repeated seasonal measurements would strengthen temporal analysis.

Third, the availability of comprehensive secondary data particularly on groundwater salinity baselines and migration flows was limited. This constraint necessitated greater reliance on primary data collection. While this approach produced rich and context-specific evidence, it reduced opportunities for standardized benchmarking across regions.

Fourth, the concurrent implementation of quantitative and qualitative strands required careful coordination and resource allocation. To manage this complexity, data collection was phased within districts, and local enumerators were engaged to facilitate logistics and cultural familiarity.

Finally, integrating different forms of data presented interpretive challenges. There is always a risk of oversimplifying narratives to fit statistical patterns or overemphasizing isolated testimonies. To address this, structured integration protocols, including joint display matrices and team based reflexive discussions, were used to preserve methodological balance.

CHAPTER

4

PHYSICAL AND ENVIRONMENTAL BASELINE OF THE SINDH COASTAL REGION

Chapter 4.
PHYSICAL AND ENVIRONMENTAL BASELINE OF THE SINDH COASTAL REGION

4.1 Introduction and Scope

This chapter establishes a rigorous physical and environmental baseline for the Sindh coastal region to support interpretation of SWI processes and their observed impacts. This chapter is diagnostic in nature and integrates reported datasets, peer reviewed literature and institutional assessments to describe the underlying climatic, hydrological, hydrogeological and environmental conditions that control salinity dynamics along the coast.

4.2 Regional Physiography and Coastal Morphology

The Sindh coastline extends approximately 350 km along the Arabian Sea and is dominated by the Indus Delta, historically one of the largest deltaic systems in the world. Elevations across large parts of the delta plain are typically below 2 m above mean sea level, with extensive intertidal mudflats, tidal creeks and abandoned distributaries. Low relief and weak natural drainage result in prolonged waterlogging and facilitate inland penetration of saline water during high tides and storm surges. Remote sensing-based studies indicate sustained shoreline retreat and erosion in several coastal segments over recent decades (World Bank Group, 2020). The study area/coastal districts Sindh shown in Figure 4.1.

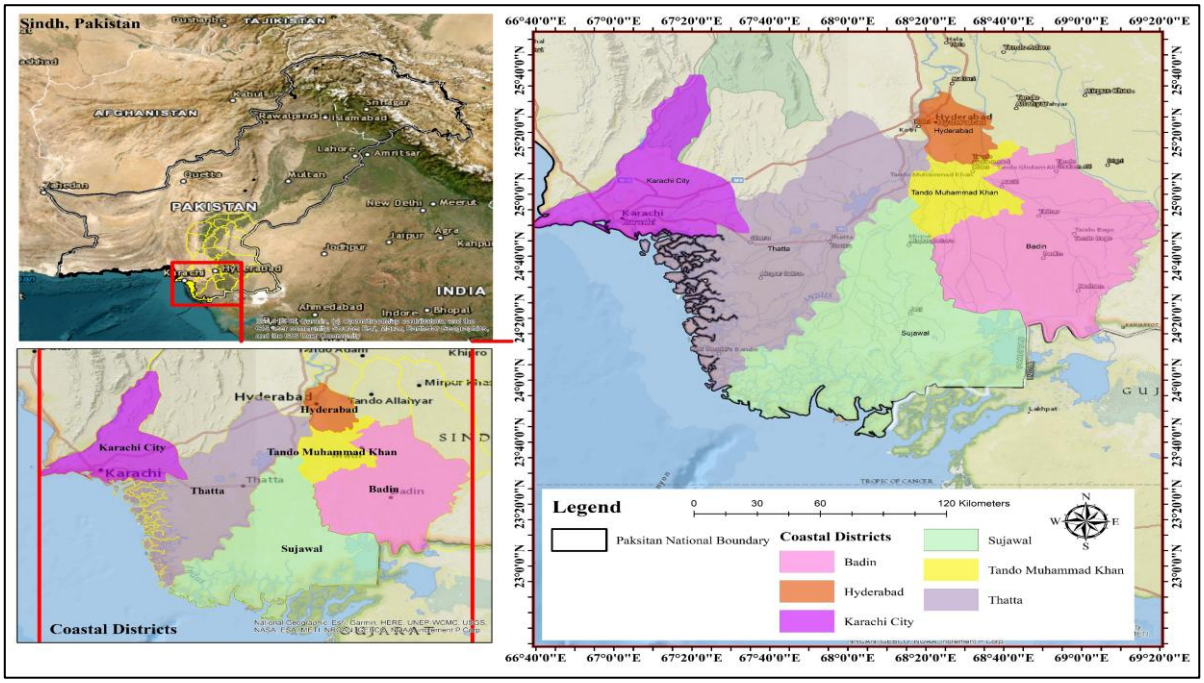


Figure 4.1: *Location of Sindh coastal districts along the Arabian Sea, dominated by the Indus Delta*

4.3 Climate and Hydro-meteorological Conditions

The coastal districts of Sindh fall within an arid to semi-arid climatic zone. Long term meteorological records indicate mean annual rainfall generally ranging from 150 to 300 mm, with over 60-70% occurring during the southwest monsoon (July-September). Potential evapotranspiration significantly exceeds rainfall for most of the year, resulting in a persistent climatic water deficit. Observed warming trends of approximately 0.5-1.0 °C over recent decades, coupled with increased frequency of heatwaves and intense rainfall events, are consistent with regional climate change projections (IPCC, 2021). Cyclonic storms in the Arabian Sea, though infrequent, pose a significant risk due to storm surges and saline inundation of low lying areas.

4.3.1 Rainfall Seasonality and Recharge Implications

Rainfall in the Sindh coastal region exhibits pronounced seasonality, with the majority of annual precipitation concentrated within a short monsoon period between July and September, as illustrated in Figure 4.2. Average monthly rainfall during these months is several times higher than during the remainder of the year, while extended dry conditions prevail for most of the annual cycle. This strong seasonal concentration of rainfall limits opportunities for sustained GW recharge and results in a prolonged reliance on canal supplies and GW abstraction outside the monsoon season.

The dominance of a short, intense rainfall window, combined with high evapotranspiration rates, reduces the effectiveness of rainfall as a reliable recharge mechanism for coastal aquifers. Consequently, GW systems remain highly sensitive to reductions in surface water availability and are particularly vulnerable to salinity intrusion during prolonged dry periods. These climatic characteristics reinforce the structural vulnerability of the coastal aquifer system and contribute to the persistence of saline GW conditions observed across the region (PMD 2013; FAO, 2020; World Bank Group, 2020; IPCC, 2021).

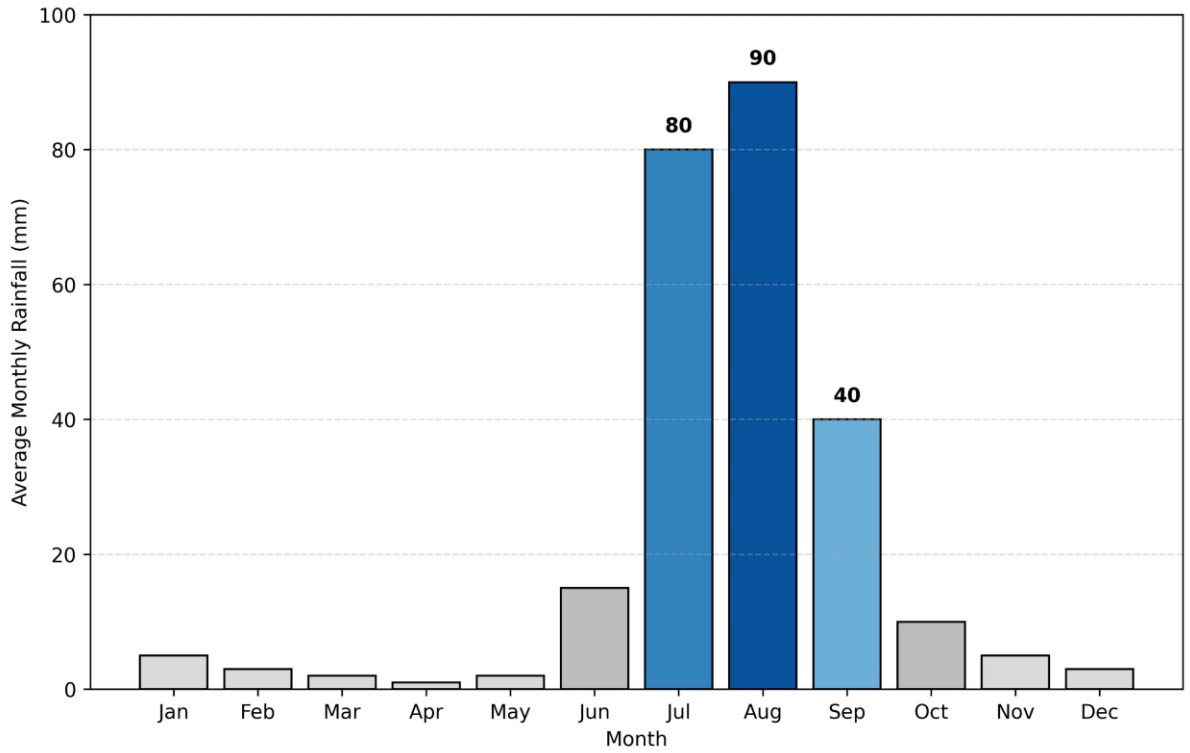


Figure 4.2: *Seasonal Distribution of Average Monthly Rainfall in the Sindh Coastal Region Source: Based on climatological normals reported by PMD (2015), FAO (2020), World Bank (2022), and IPCC (2021).*

4.3.2 Seasonal Temperature Variability and Evapotranspiration Stress

The Sindh coastal region experiences pronounced seasonal variability in air temperature, with average monthly temperatures increasing steadily from winter months to peak summer conditions between May and June, as illustrated in Figure 4.3. During this period, average temperatures commonly exceed 34-36 °C, coinciding with the pre-monsoon dry season. Elevated temperatures significantly increase potential evapotranspiration rates, intensifying soil moisture loss and reducing the effectiveness of rainfall and surface water supplies for GW recharge.

High summer temperatures also drive increased domestic and agricultural water demand, leading to intensified GW abstraction during periods of limited surface water availability. This seasonal imbalance between water demand and natural recharge amplifies stress on coastal aquifer systems and accelerates salinity intrusion processes. When considered alongside rainfall seasonality (Figure 4.2), temperature variability provides critical insight into the climatic drivers underlying persistent GW stress and salinity conditions in the Sindh coastal region (PMD 2013; FAO, 2020; World Bank Group, 2020; IPCC, 2021).

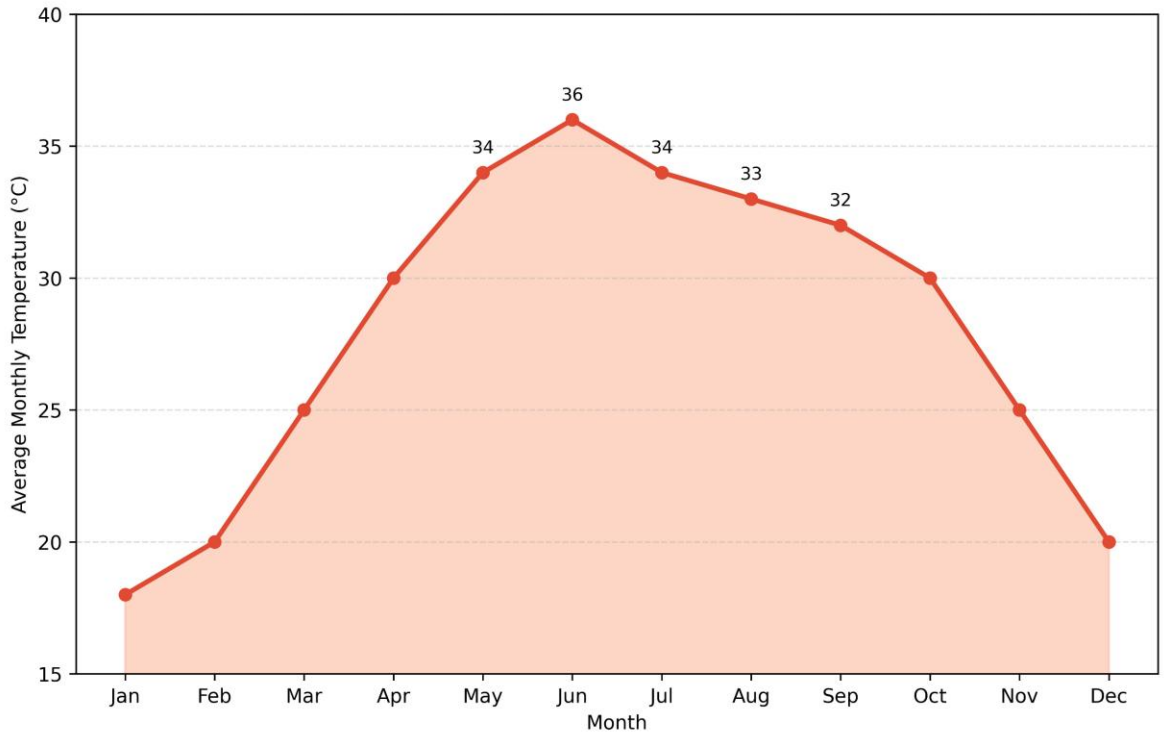


***Figure 4.3**: Seasonal Variation of Average Monthly Temperature in the Sindh Coastal Region (Source: Based on reported climatological normals and regional climate assessments (PMD, 2015; World Bank Group, 2020; IPCC, 2021).*

4.4 Indus River Flows and Surface Water System

The Indus River is the principal freshwater source for the Sindh coastal region and plays a vital role in maintaining the natural hydraulic balance between freshwater and seawater within the Indus Delta. The hydrogeological conditions of the delta are influenced by the interaction of freshwater availability, tidal processes, groundwater abstraction, sea level rise, and local geological heterogeneity. Variations in these interacting factors can alter the freshwater–seawater equilibrium and, consequently, influence the extent and distribution of groundwater salinization across the coastal aquifer system (FAO, 2020; World Bank Group, 2020). Canal water supplies in Badin, Sujawal and Thatta are highly seasonal and unevenly distributed, resulting in extended dry periods during which communities depend on GW or marginal water sources. Fresh water flows into Indus delta shown in figure 4.4.

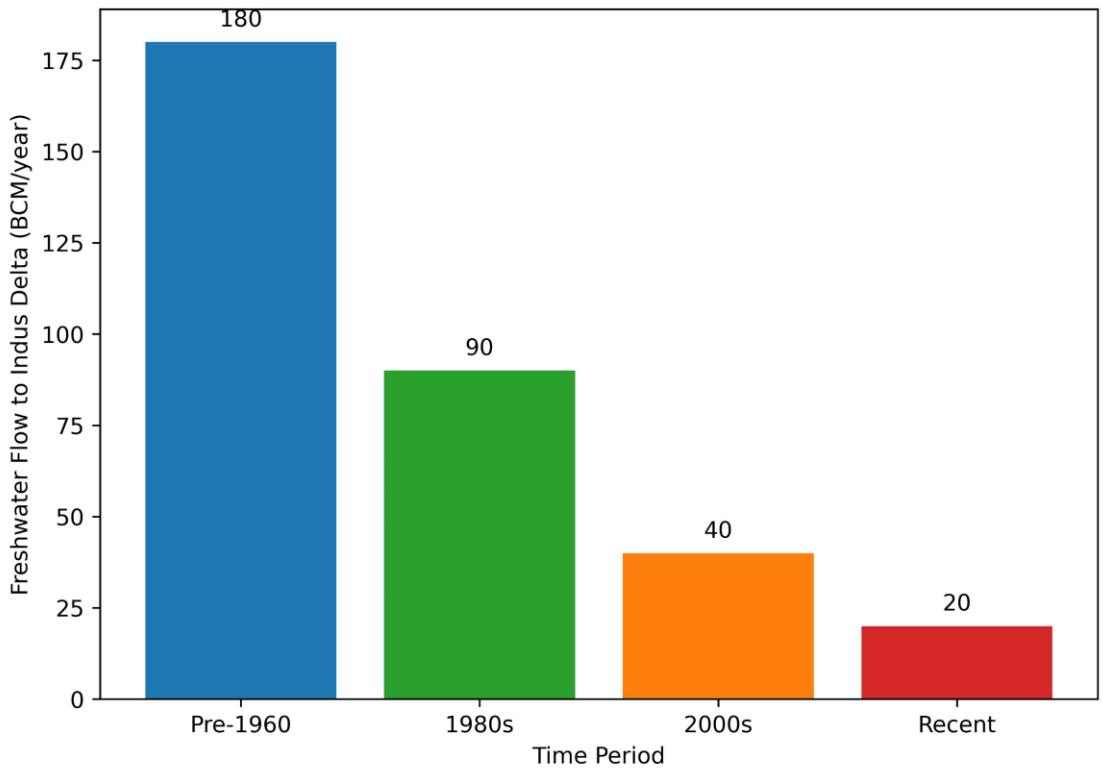


***Figure 4.4**: Indicative long-term decline in freshwater flows reaching the Indus Delta (based on reported studies).*

4.5 Hydrogeological Framework of the Coastal Aquifer System

The coastal aquifer system of Sindh comprises unconsolidated alluvial and deltaic sediments, predominantly sands, silts and clays exhibiting highly heterogeneous hydraulic properties. As illustrated in Figure 4.5, the system is vertically stratified into shallow, intermediate, and deeper saline aquifer zones, each responding differently to external pressures. Shallow aquifers, typically occurring at depths of less than 10-20 m in deltaic areas, constitute the primary source of drinking water but are the most vulnerable to salinization due to their proximity to the surface and limited protective confinement. Intermediate aquifers (approximately 20-80 m depth) exhibit variable water quality and are increasingly stressed by pumping induced vertical hydraulic gradients, which promote saline up-coning from deeper zones (FAO (2020); IPCC (2021).

Recharge to the coastal aquifer system occurs through canal seepage, localized rainfall infiltration, and episodic flooding events. However, as illustrated schematically in Figure 4.5, variations in freshwater availability within the deltaic system may reduce the landward freshwater hydraulic gradient that naturally limits seawater encroachment. When combined with tidal influence, groundwater abstraction, sea level rise, and local hydrogeological

conditions, these interacting factors increase the susceptibility of the coastal aquifer to seawater intrusion. At the same time, sea level rise and tidal forcing from the Arabian Sea increase saline pressure from the seaward side. Together, variations in freshwater recharge, increasing marine influence, and intensive groundwater abstraction for domestic and agricultural use further modify the freshwater–seawater hydraulic balance, thereby enhancing the potential for seawater intrusion into the coastal aquifer.

The combined effect of these drivers has fundamentally altered pre development GW flow regimes, increasing susceptibility to both lateral SWI and vertical up-coning of saline GW, particularly within shallow and intermediate aquifers. This hydrogeological configuration explains the widespread occurrence of brackish to highly saline GW observed across the Sindh coastal belt and underpins the vulnerability patterns discussed in subsequent sections.

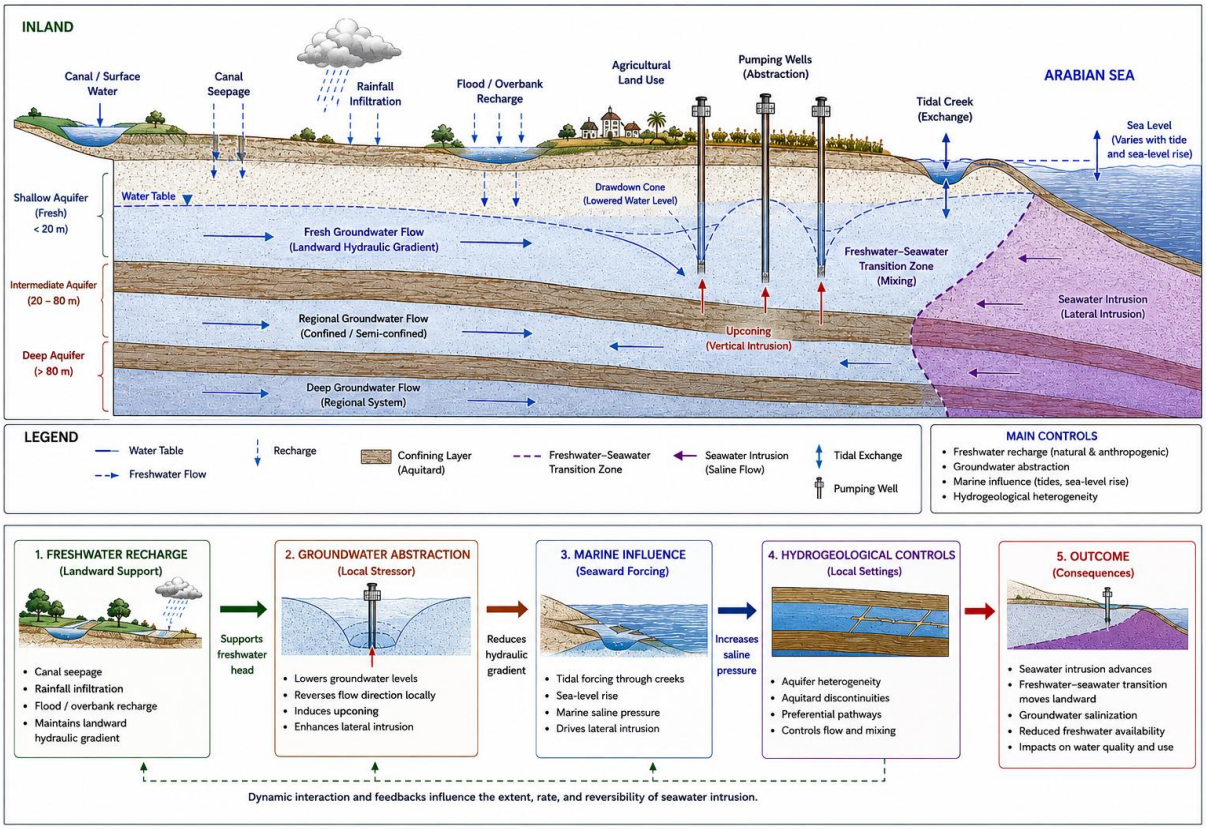


***Figure 4.5**: Conceptual hydrogeological cross-section of the coastal aquifer system in the Sindh coastal region, illustrating the interaction of freshwater recharge, tidal influence, sea level rise, groundwater abstraction, and local hydrogeological conditions influencing the vulnerability of coastal aquifers to seawater intrusion.*

4.6 Seawater Intrusion Mechanisms and Drivers

Seawater intrusion in the Sindh coastal belt is driven by a combination of natural and anthropogenic factors. Reduced freshwater flows from the Indus have weakened the seaward hydraulic gradient, while intensive GW pumping has locally reversed GW flow directions. Tidal forcing through an extensive network of creeks further enhances saline water exchange. Figure 4.6 illustrates the conceptual and empirical studies from comparable deltaic environments indicate that once critical thresholds are crossed, salinity advance can accelerate rapidly and become difficult to reverse (IPCC, 2021; FAO, 2020).

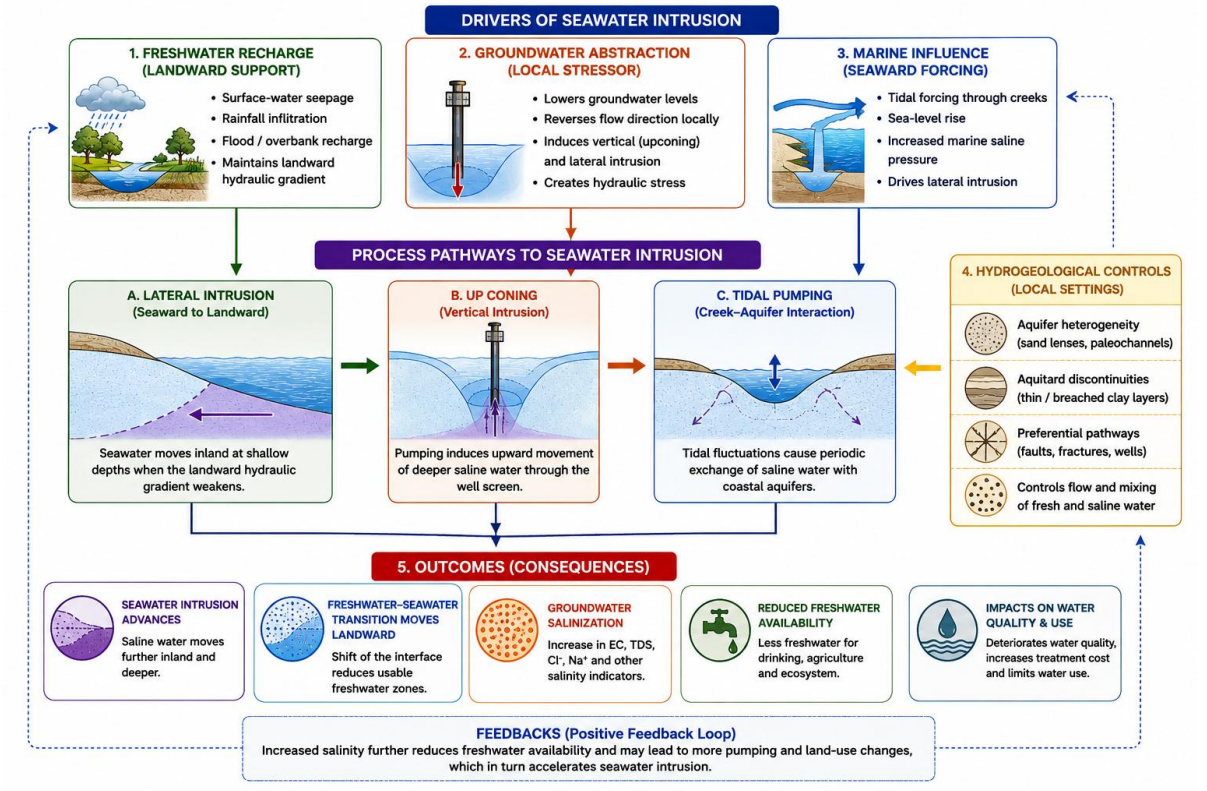


Figure 4.6: *Conceptual representation of the principal mechanisms governing seawater intrusion (SWI) in coastal aquifer systems.*

4.7 Ground Water Quality and Salinity Characteristics

Ground water quality in the Sindh coastal region is overwhelmingly dominated by salinity, making it the defining hydrochemical characteristic of the coastal aquifer system. Multiple regional and national assessments indicate that EC values in coastal GW frequently exceed thresholds suitable for both drinking and irrigation. According to the World Health Organization, drinking water with EC values exceeding approximately 1,500 µS/cm is

generally considered unpalatable, while irrigation suitability declines significantly at EC levels above 3,000-4,000 µS/cm, depending on crop tolerance (WHO, 2017; FAO, 2020).

Reported GW quality datasets from coastal Sindh consistently show widespread brackish (EC 1,500-5,000 µS/cm) to highly saline conditions (EC >5,000 µS/cm), reflecting long term SWI, evaporative concentration, and limited freshwater recharge (PCRWR; FAO, 2020; World Bank Group, 2020). The results of piezometer monitoring conducted under the present study corroborate these findings, indicating persistently elevated EC values across most monitoring locations, with only limited spatial and seasonal variability. Seasonal reductions in salinity are generally confined to areas influenced by canal seepage during periods of surface water availability.



Relatively fresh to marginal quality GW lenses, where present, are typically restricted to canal command areas or zones of localized recharge, as also illustrated in Figure 4.7. These freshwater pockets are shallow, spatially discontinuous and highly vulnerable to degradation under continued GW abstraction. Pumping induced vertical hydraulic gradients further increase the risk of saline up-coning from deeper aquifers, accelerating the loss of usable GW resources.

The persistence of saline GW conditions even during favorable hydrological periods, indicates that GW salinization in the Sindh coastal belt is structural rather than episodic. This baseline hydrochemical condition provides the physical explanation for drinking water scarcity, agricultural productivity decline and livelihood stress documented in subsequent chapters and underscores the limited scope for GW based adaptation without substantial management interventions. The distribution of water samples collected from piezometers in different salinity classes is shown in Figure 4.7.

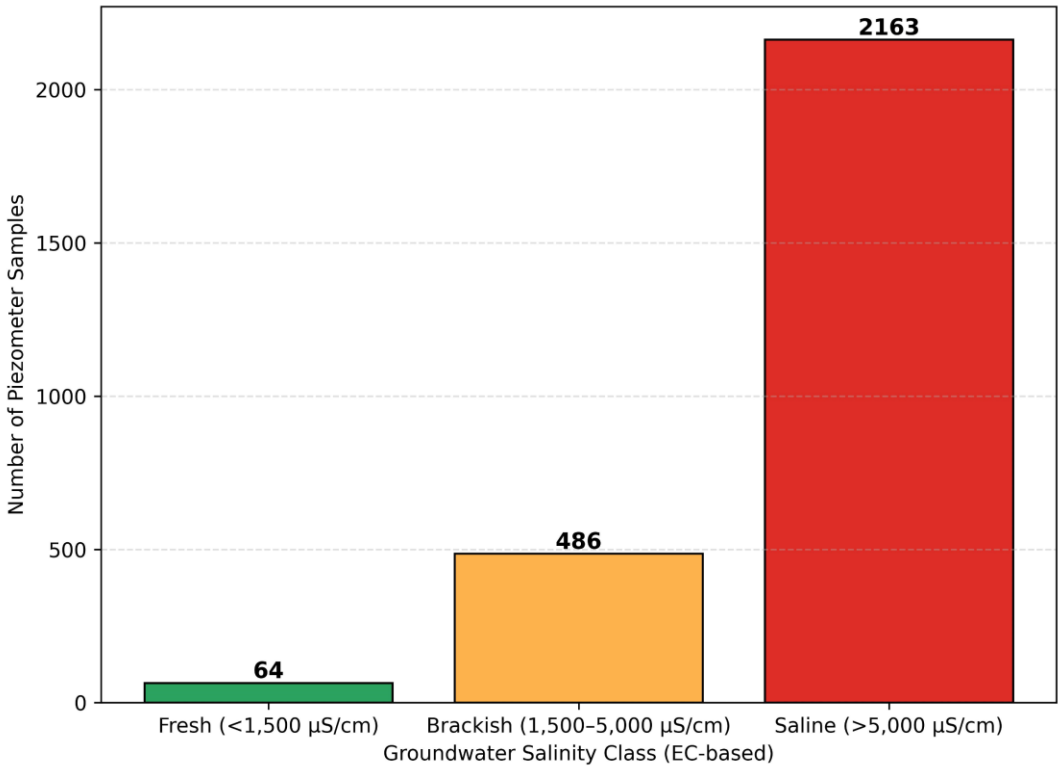


Figure 4.7: *Distribution of GW Salinity Classes Based on Electrical Conductivity (EC) Measured in Piezometers.*

4.8 Coastal Environmental Degradation and Ecosystem Stress

Environmental degradation has compounded physical vulnerability along the Sindh coast. Soil salinization affects large tracts of agricultural land, while coastal erosion and loss of mangrove cover reduce natural protection against tidal inundation and storm surges. Mangrove extent in the Indus Delta has fluctuated significantly over recent decades, reflecting changes in freshwater availability and sediment supply. Ecosystem degradation undermines fisheries productivity and reduces the adaptive capacity of coastal communities (World Bank Group, 2020).

4.9 Implications for Vulnerability and Planning

The baseline conditions described above indicate a structurally high vulnerability to SWI in the Sindh coastal region. Low elevation, declining freshwater inflows, shallow and heavily exploited aquifers and degraded coastal ecosystems interact to amplify salinity risks. These conditions provide the physical explanation for the socioeconomic impacts documented in Chapter 6 and underscore the need for integrated science-based mitigation and adaptation strategies as outlined in Chapter 10.

CHAPTER

5

SOCIOECONOMIC AND DEMOGRAPHIC BASELINE OF THE SINDH COASTAL REGION

Chapter 5.
SOCIOECONOMIC AND DEMOGRAPHIC BASELINE OF THE SINDH COASTAL REGION

5.1 Introduction

This chapter presents a strengthened socioeconomic and demographic baseline of the Sindh coastal region, covering the districts of Badin, Sujawal, Thatta and T. M. Khan. The analysis is based primarily on secondary data from the Pakistan Bureau of Statistics (PBS) including the 7th Population and Housing Census 2023 (Pakistan Bureau of Statistics [PBS], 2024) as well as sectoral information from health, water supply and development planning sources. The purpose of this chapter is to quantitatively describe population characteristics, livelihoods, poverty, health and access to basic services that determine baseline vulnerability to SWI and related coastal hazards.

5.2 Population Size and Distribution

According to the Population and Housing Census 2023, the four coastal districts of Sindh Badin, Sujawal, Thatta and T. M. Khan together host a population of approximately 4.6 million people. As shown in Table 5.1 and Figure 5.1, Badin is the most populous district with 1.95 million residents followed by T. M. Khan (1.08 million), Sujawal (0.84 million) and Thatta (0.73 million).

The population is overwhelmingly rural in nature with rural residents comprising approximately 72% to 90% of district populations. Sujawal exhibits the highest rural share (≈90%), followed by Thatta (≈84%) and Badin (≈78%), reflecting dispersed settlement patterns and strong dependence on land and water based livelihoods. High rurality has direct implications for service access, infrastructure coverage, and exposure to environmental hazards, including SWI and salinity related impacts.

Table 5.1: *District wise population characteristics based on Population and Housing Census 2023 (PBS, 2024).*

District	Total Population	Male	Female	Rural (%)
Badin	1,947,081	1,012,854	934,153	~78
Sujawal	839,292	437,151	402,109	~90
Thatta	726,119	376,736	349,362	~84
Tando M. Khan	1,083,191	555,252	527,895	~72

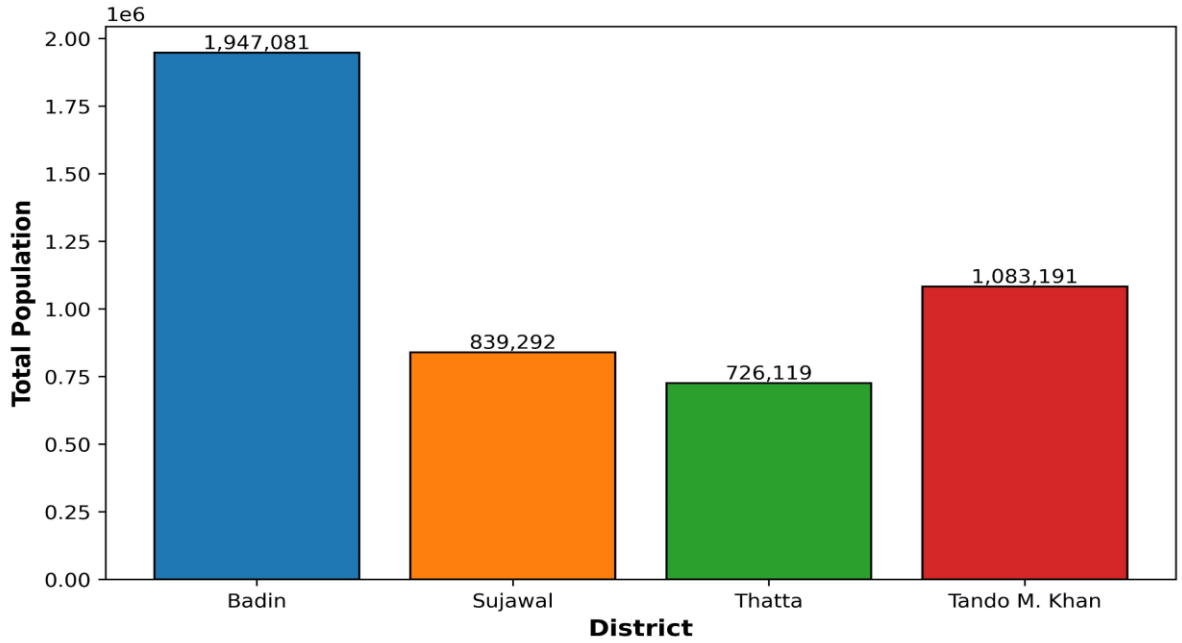


Figure 5.1: *District-wise population distribution in the Sindh coastal region (Population and Housing Census 2023).*

5.3 Gender Composition and Household Structure

Gender composition across the Sindh coastal districts is relatively balanced but exhibits subtle spatial variations that have implications for socioeconomic vulnerability. According to the Population and Housing Census 2023, males constitute approximately 51-52% of the population across the coastal districts while females account for 48-49% as illustrated in Figure 5.2. Badin and Sujawal show slightly higher male proportions compared to Thatta and T.M. Khan a pattern commonly associated with rural economies and labor related mobility in agricultural and fishing communities (PBS, 2024).

Household structure in the coastal region is characterized by large average household sizes, reflecting extended family systems prevalent in rural Sindh. Census data indicate that households typically comprise 6-7 members on average resulting in high dependency ratios, with a substantial share of dependents (children and elderly) relative to the working age population. These demographic characteristics increase household sensitivity to income instability, health shocks, and environmental stresses.

From a vulnerability perspective gender and household structure play a critical role in shaping exposure and adaptive capacity. Women and girls often bear primary responsibility for water collection, household health care and caregiving, particularly in water scarce and salinity

affected environments. Large household sizes combined with limited income diversification, place additional pressure on available resources and reduce the capacity of households to cope with and adapt to the impacts of SWI and GW salinization.

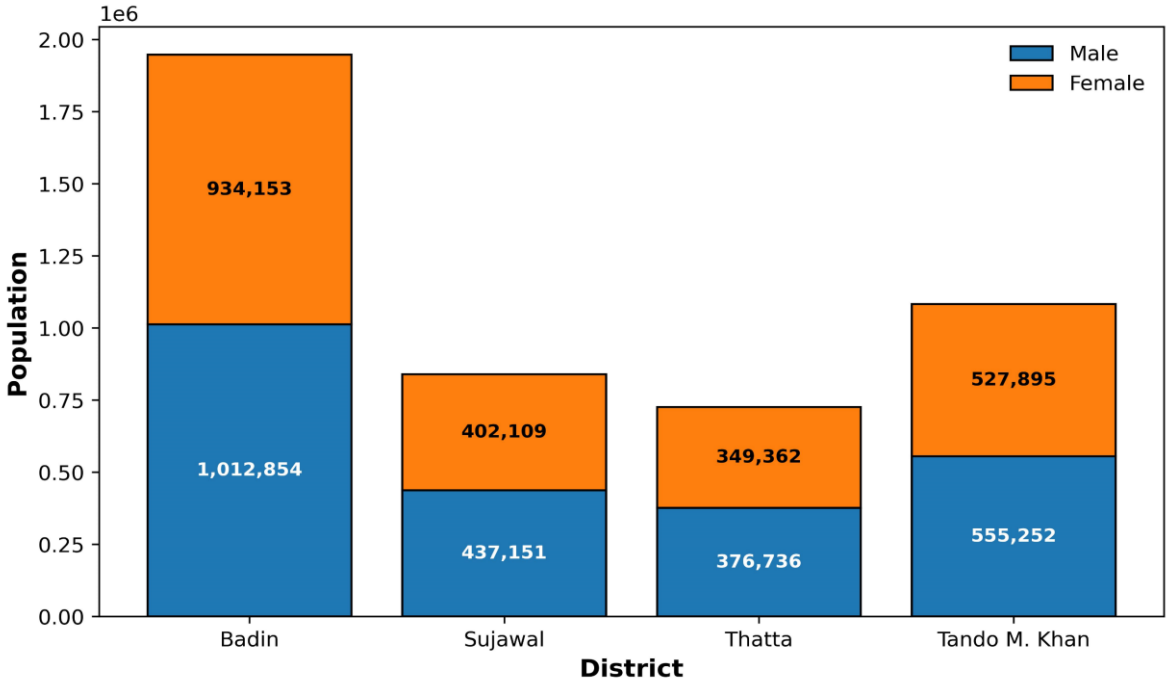


Figure 5.2: *Gender composition of population in coastal districts of Sindh (Population and Housing Census 2023).*

5.4 Religious Composition by District

The religious composition of the coastal districts reflects both demographic dominance and meaningful minority presence, shaping social relations, vulnerability patterns and development inclusion. Across all four districts, Muslims constitute the majority population, with particularly high concentrations in Sujawal (97.1%) and Thatta (96.7%), reflecting a strong Islamic cultural and social identity (Figure 5.3). In contrast, while Muslims remain the majority in Badin (74.5%) and T. M. Khan (75.6%), these districts exhibit comparatively greater religious diversity (Pakistan Bureau of Statistics, 2024).

Hindu communities represent the second largest religious group, with substantial presence in Badin (20.2%) and T. M. Khan (22.0%). In Sujawal (2.3%) and Thatta (2.5%), Hindu populations are considerably smaller, reflecting historical settlement patterns, migration trends, and land tenure dynamics (Figure 5.3). These variations are important in understanding differential exposure to poverty, landlessness and livelihood vulnerability, particularly in agrarian and coastal contexts.

The population classified under Scheduled Castes, comprising historically marginalized groups, remains numerically small but socially significant. Their highest concentration is observed in Badin (4.9%), followed by T. M. Khan (2.0%), with much lower representation in Thatta (0.4%) and Sujawal (0.3%). Although limited in number, these groups often face compounded vulnerabilities linked to land access, livelihood security and limited institutional support.

Other religious minorities including Christians, Sikhs and indigenous belief groups constitute a very small proportion of the population (0.3-0.5%) across districts, indicating relatively dispersed settlement patterns.

Overall, the religious profile of the coastal districts underscores the importance of inclusive, culturally sensitive development planning. While Muslims form the demographic majority, the presence of sizeable Hindu and Scheduled Caste communities particularly in Badin and T. M. Khan highlights the need for equitable access to water, livelihoods, health services and disaster response mechanisms, ensuring that adaptation and resilience interventions do not inadvertently exclude minority groups.

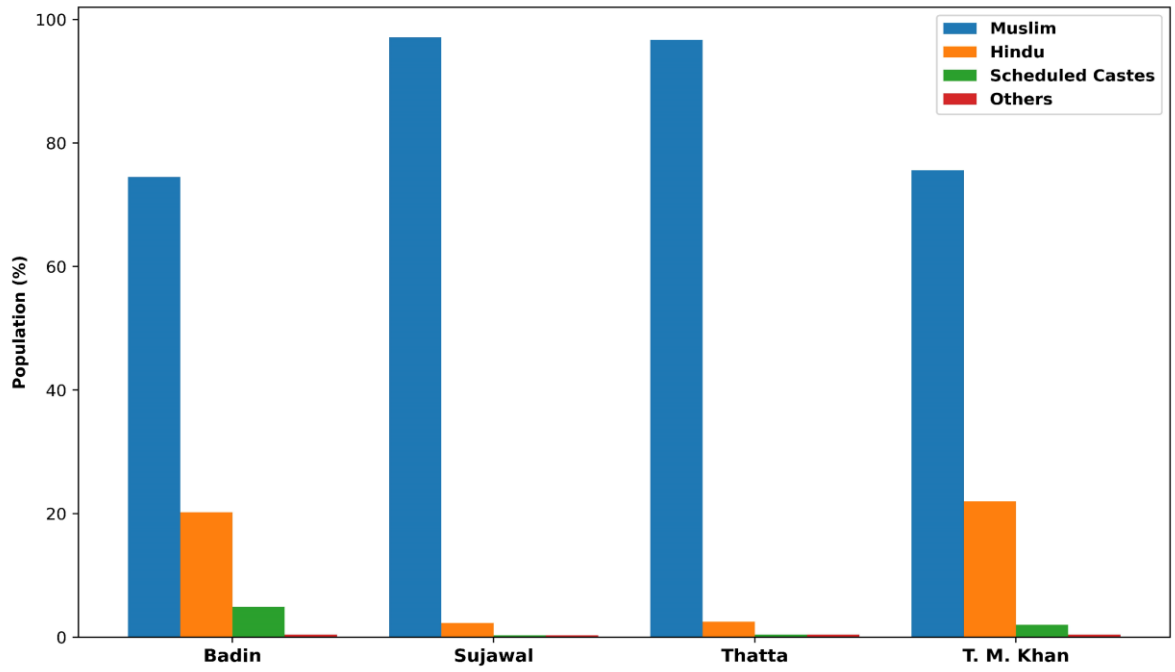


Figure 5.3: *Distribution of population by religion, district-wise (Source: Pakistan Bureau of Statistics (2024)*

5.5 Linguistic Composition by District

The linguistic profile of the study districts reveals a high degree of homogeneity**,** with Sindhi serving as the dominant language across all four districts. Sindhi is spoken by an overwhelming majority of the population, ranging from 93.5% in T. M. Khan to 99.4% in Sujawal, reinforcing a strong regional linguistic identity (Pakistan Bureau of Statistics, 2024).

Other languages are present only in small proportions. Urdu is spoken by less than 2% of the population in Badin, Thatta and T. M. Khan and is virtually absent in Sujawal. Punjabi shows modest presence in Badin (2.8%) but remains negligible elsewhere. Seraiki accounts for less than 1% of the population across all districts. The category of "Other languages", which may include Brahavi and localized Sindhi dialects, ranges from 0.4% in Sujawal to 3.7% in T. M. Khan (Figure 5.4).

From a development and planning perspective, the linguistic landscape offers both opportunities and cautions. The dominance of Sindhi facilitates effective community engagement, awareness campaigns and service delivery when interventions are delivered in local language. At the same time, the presence of small linguistic minorities necessitates inclusive communication strategies, particularly in health messaging, disaster preparedness and community consultations, to ensure that vulnerable or migrant groups are not excluded.

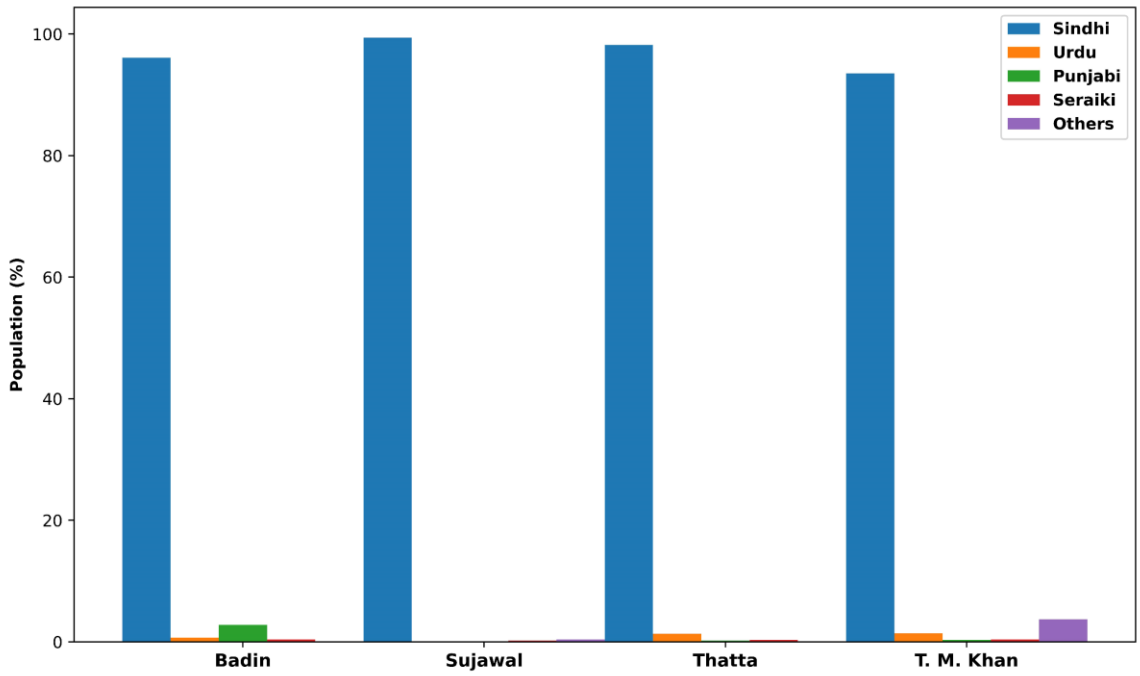


***Figure 5.4**: Distribution of population by mother tongue, district-wise (Source: Pakistan Bureau of Statistics 2024).*

5.6 Education and Literacy

Educational attainment in the Sindh coastal districts remains significantly below provincial averages, reflecting structural constraints related to rurality, poverty and limited-service provision. According to the Population and Housing Census 2023, overall literacy rates in the coastal districts are estimated to be 10-20 percentage points lower than the Sindh provincial average, with the lowest levels observed in Sujawal and Thatta districts (PBS, 2024) (Figure 5.5). These districts are characterized by dispersed rural settlements and fishing communities with limited access to secondary and higher education facilities.

Gender disparities in education are pronounced. Female literacy rates in rural coastal areas are substantially lower than male literacy rates, particularly in fishing and landless agricultural households. In many villages, female literacy remains below 40% reflecting a combination of school accessibility constraints, socio-cultural norms early marriage and household labor responsibilities. These disparities are more acute in Sujawal and Thatta where secondary schools are sparsely distributed and dropout rates increase sharply beyond primary level (PBS, 2024).

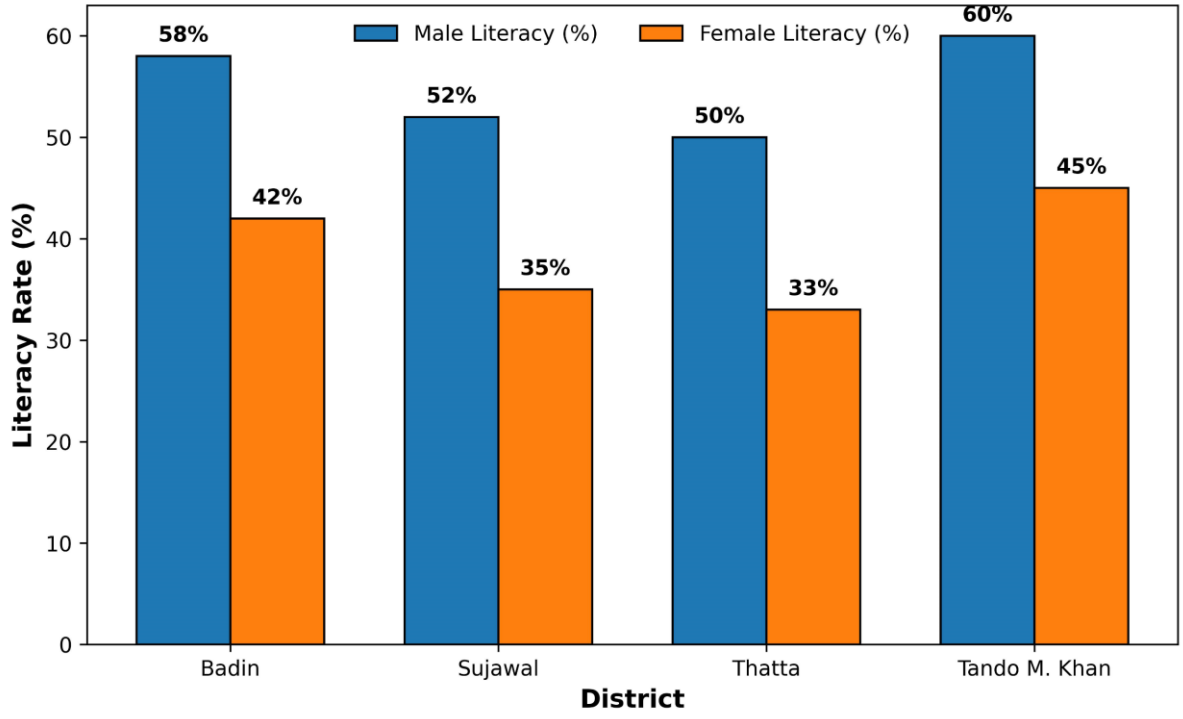


Figure 5.5: *Literacy rates by gender across coastal districts of Sindh, highlighting gender disparities in educational attainment (Population and Housing Census 2023).*

Low educational attainment has direct implications for livelihood options and adaptive capacity. Households with limited education are more likely to remain dependent on salinity sensitive livelihoods such as agriculture, fisheries and informal wage labor, with few opportunities for diversification into skilled or non-farm employment. Limited literacy also constrains access to information, financial services and institutional support programs, reducing the ability of households to anticipate, cope with and adapt to environmental stresses such as SWI and GW salinization (World Bank Group, 2020; UNDP, 2021).

Literacy outcomes discussed in this section primarily reflect the education status of the working age population as formal educational participation among elderly age groups (65 years and above) is negligible. While age disaggregated literacy data were not available at district level from secondary sources, gender disaggregated literacy remains a robust proxy for assessing human capital constraints and adaptive capacity in coastal communities (PBS, 2024).

Sindh Multiple Indicator Cluster Survey (MICS) 2021 provide a more detailed understanding of literacy outcomes among education relevant age groups in Sindh. According to MICS 2021, the literacy rate among youth aged 15-24 years in rural Sindh remains substantially lower than in urban areas with pronounced gender disparities. Male literacy in this age group exceeds 65%, while female literacy remains below 50%, highlighting persistent barriers to female education in rural and coastal settings (Sindh Bureau of Statistics & UNICEF, 2021).

MICS data further indicate that school attendance declines sharply beyond the primary level, particularly among girls, due to factors such as distance to secondary schools, household labor responsibilities, early marriage and poverty. These trends are especially relevant for coastal districts characterized by dispersed settlements and fishing based livelihoods, where access to post primary education is limited.

From a vulnerability perspective, low literacy levels among youth and working age populations constrain opportunities for livelihood diversification beyond agriculture, fisheries and informal labor. Limited educational attainment also reduces access to information, institutional support programs and alternative income opportunities, thereby weakening adaptive capacity in the face of environmental stresses such as SWI and GW salinization. The MICS findings reinforce census based evidence of human capital constraints in coastal Sindh and underscore the long term implications for resilience and sustainable development.

5.7 Livelihood Structure and Coastal Economy

Livelihoods in the Sindh coastal region are overwhelmingly natural resource based, reflecting the rural character of settlements and strong dependence on land, water and coastal ecosystems. District wise livelihood composition, illustrated in Figure 5.6 indicates that agriculture remains the primary source of income for approximately 30-60% of households across the coastal districts. Dependence on agriculture is highest in T. M. Khan, where canal command areas support crop cultivation and relatively lower in Sujawal and Thatta due to salinity affected soils and limited freshwater availability.

Fisheries constitute a major livelihood in the deltaic and coastal districts, supporting approximately 25-30% of households in Sujawal and Thatta. These communities rely heavily on marine and estuarine fisheries, which are sensitive to changes in salinity regimes, freshwater inflows and coastal ecosystem health. The spatial concentration of fishing livelihoods in low-lying coastal zones increases exposure to SWI, tidal flooding and coastal erosion.

Livestock rearing provides a supplementary livelihood for approximately 15-20% of households, particularly among landless and smallholder families while daily wage labor and other informal activities account for roughly 15-25% of household incomes, especially during agricultural lean periods. Wage labor is often seasonal and insecure, increasing income variability and economic vulnerability.

The dominance of agriculture and fisheries both highly dependent on freshwater availability and soil and water quality creates a structural livelihood sensitivity to SWI and salinity related processes. Limited livelihood diversification, combined with high dependence on a single income source for the majority of households, constrains adaptive capacity and increases exposure to environmental and climatic shocks in the coastal districts (FAO, 2020; World Bank Group, 2020).

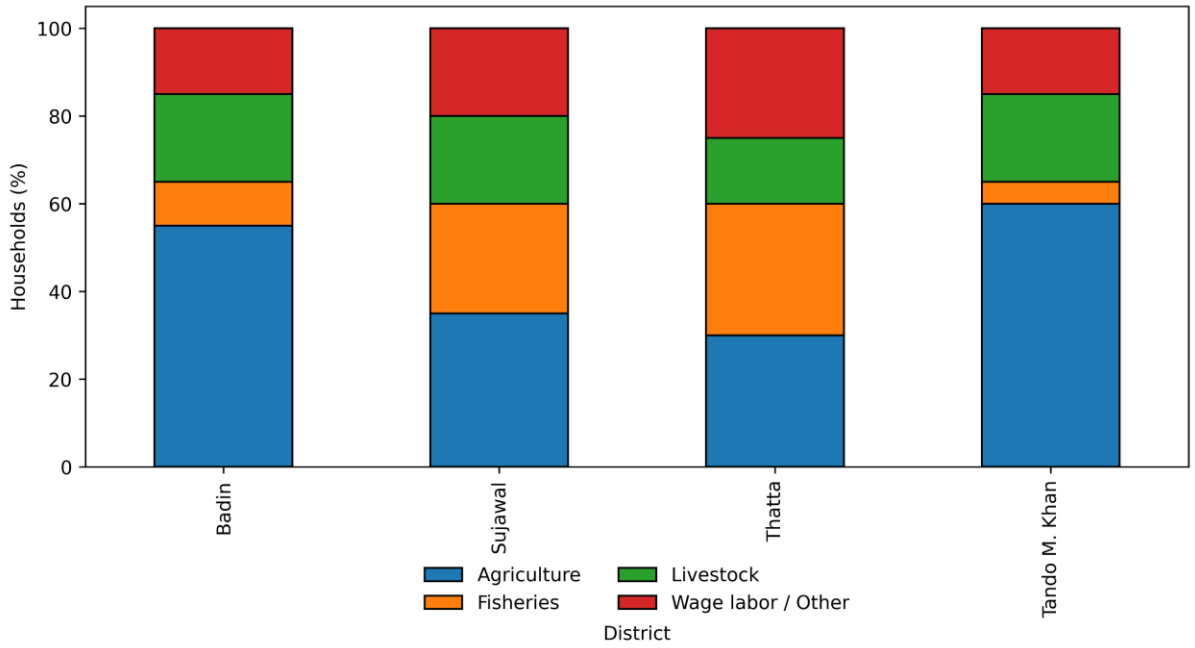


Figure 5.6: *Indicative livelihood structure of households in coastal districts of Sindh (based on PBS and secondary literature).*

5.8 Poverty and Income Characteristics

Poverty incidence in the Sindh coastal districts is significantly higher than provincial averages, reflecting structural deprivation, livelihood insecurity and environmental stress. National and provincial assessments indicate that a large proportion of households in coastal Sindh experience multidimensional poverty, particularly in rural, fishing and landless agricultural communities (UNDP, 2021; PBS, 2024). As illustrated in Figure 5.7 approximately 43-55% of households across the four coastal districts fall under multidimensional poverty, with the highest incidence observed in Sujawal and Thatta.

Income vulnerability is further compounded by heavy reliance on informal, seasonal and climate-sensitive income sources. District level patterns indicate that 55-66% of households depend primarily on seasonal agriculture, fisheries or daily wage labor resulting in highly variable and insecure income streams. Households dependent on fisheries in Sujawal and Thatta are particularly exposed to fluctuations in fish catch linked to salinity intrusion, reduced freshwater inflows and coastal ecosystem degradation (FAO, 2020; World Bank Group, 2020).

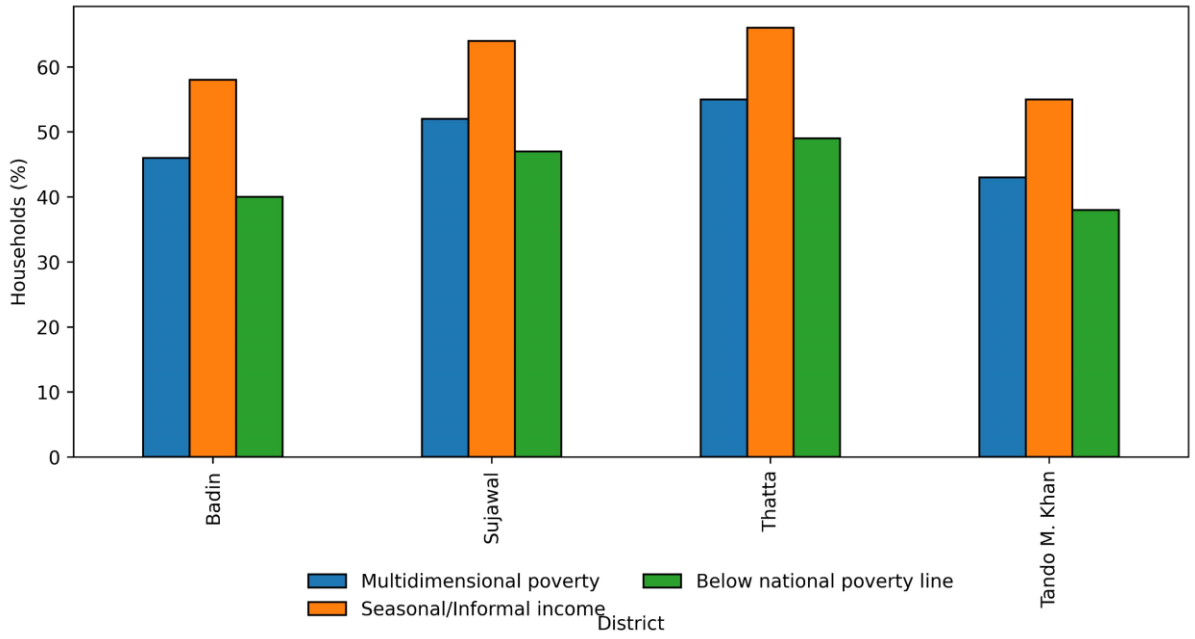


Figure 5.7: *Poverty incidence and income vulnerability indicators across coastal districts of Sindh, highlighting multidimensional poverty and reliance on seasonal and informal livelihoods.*

Poverty is closely linked to declining agricultural productivity caused by soil salinization and unreliable freshwater availability which disproportionately affect smallholders and tenant farmers. In addition, limited access to credit, insurance and formal social protection mechanisms restrict household capacity to absorb income shocks or invest in adaptive strategies. These poverty and income characteristics significantly amplify sensitivity to SWI and constrain long term resilience in coastal districts.

5.9 Access to Drinking Water and Sanitation

Access to safe drinking water remains one of the most critical development challenges in the Sindh coastal region. District wise analysis indicates a high dependence on non-improved and salinity affected water sources, particularly in rural and coastal settlements. As illustrated in Figure 5.8 approximately 40-60% of households across the four coastal districts rely on brackish GW for drinking and domestic purposes. Dependence on GW is highest in Sujawal and Thatta where limited canal command coverage and proximity to the coast exacerbate GW salinization.

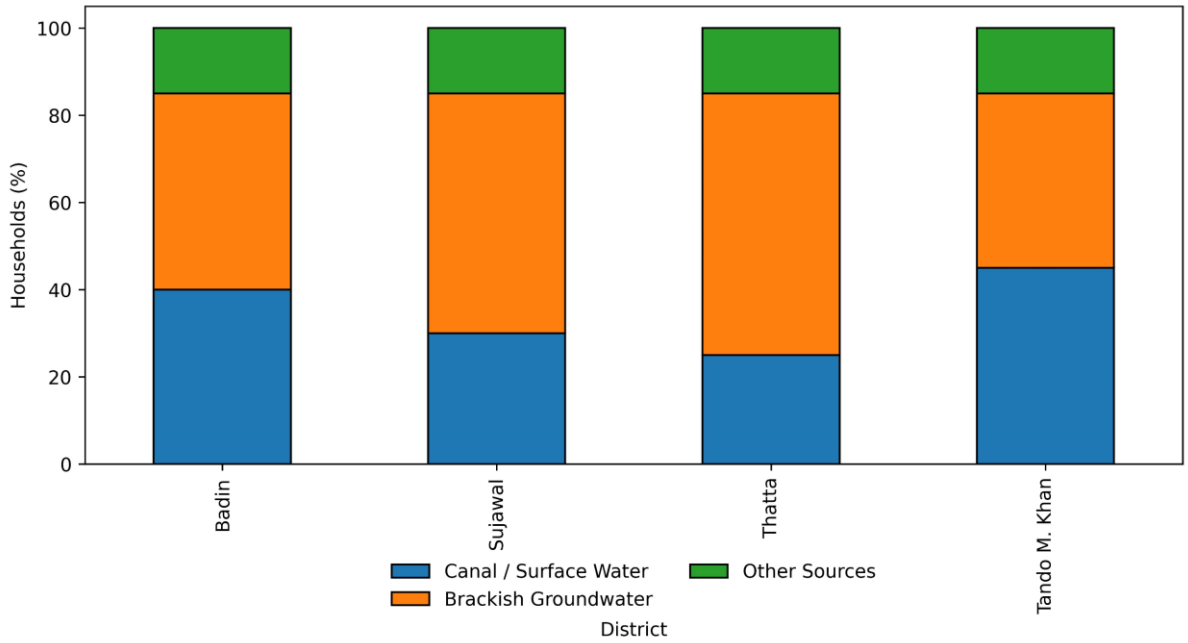


Figure 5.8: *Household access to drinking water sources in coastal districts of Sindh (based on reported datasets).*

Canal and surface water sources constitute the primary drinking water supply for approximately 25-45% of households, with higher reliance observed in canal command areas of Badin and T. M. Khan. However, this supply is seasonal and unreliable and GW dependence increases substantially during periods of canal closure, maintenance shutdowns or reduced freshwater flows. In many villages households are forced to switch between surface water and GW sources often compromising water quality.



Sanitation coverage remains limited across the coastal districts particularly in rural and fishing communities. A significant proportion of households lack access to improved sanitation facilities, increasing the risk of fecal contamination of water sources and contributing to the prevalence of water borne diseases. Poor sanitation, combined with the use of saline or contaminated GW creates compounded public health risks and reinforces cycles of vulnerability (World Health Organization [WHO], 2017).

These water and sanitation conditions directly interact with SWI processes. Increased salinity of GW aquifers reduces the availability of potable water heightens household exposure to health risks and increases the burden on women and children responsible for water collection. Limited access to safe water thus represents a key socioeconomic pathway through which SWI amplifies vulnerability in coastal Sindh.

5.10 Health and Nutrition Baseline

Health indicators in the coastal districts of Sindh reflect chronic underdevelopment combined with environmental and water quality stress. Available health statistics and sectoral assessments indicate a high prevalence of water related illnesses, particularly in areas reliant on saline or contaminated water sources. As illustrated in Figure 5.9 approximately 30-45% of households across the coastal districts report the occurrence of water borne diseases including diarrhea and other gastrointestinal infections with the highest incidence observed in Sujawal and Thatta districts.

Skin infections and dermatological conditions commonly associated with prolonged use of saline water for domestic purposes are reported by approximately 22-35% of households while gastrointestinal illnesses affect roughly 26-40% of households underscoring the public health burden associated with poor water quality. These patterns are consistent with national and international findings linking saline GW consumption to adverse health outcomes (WHO, 2017).

Maternal and child health outcomes in coastal districts lag behind provincial averages, with limited access to health facilities, trained medical personnel and nutrition services, particularly in remote fishing and landless communities. Child malnutrition remains a persistent concern, driven by poverty, food insecurity and repeated exposure to water related illnesses (UNICEF, 2022). Collectively, these health and nutrition conditions exacerbate household vulnerability and reduce adaptive capacity in the context of SWI and increasing GW salinity.

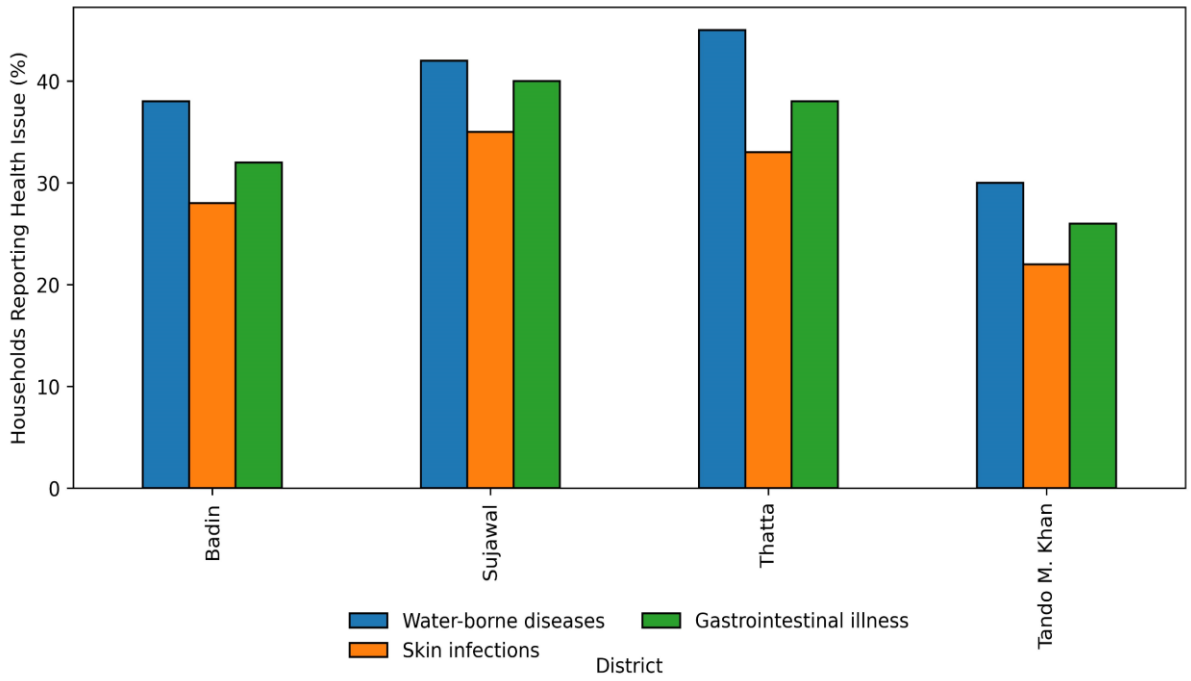


Figure 5.9: *Prevalence of major water related health issues reported in coastal districts of Sindh, highlighting the link between drinking water quality and public health outcomes.*

5.11 Social Vulnerability and Marginalization

Social vulnerability in the Sindh coastal region is shaped by a combination of poverty, landlessness, livelihood insecurity and limited access to basic services. District level assessments indicate that a substantial proportion of households are structurally vulnerable, particularly in deltaic and coastal zones (Pakistan Bureau of Statistics [PBS], 2024; UNDP, 2021). As illustrated in Figure 5.10 approximately 45-55% of households across the coastal districts are landless with the highest incidence observed in Sujawal and Thatta reflecting limited asset ownership and strong dependence on natural resource based livelihoods.

Female headed households often associated with reduced income security and constrained access to institutional support constitute approximately 12-18% of households across the coastal districts (PBS, 2024). In addition, livelihood concentration is pronounced with 58-70% of households' dependent on a single primary livelihood source, predominantly agriculture or fisheries (World Bank Group, 2020). Such dependence significantly increases sensitivity to environmental shocks, including SWI, soil salinization, and fisheries decline.

These overlapping vulnerabilities disproportionately affect fishing communities, landless agricultural laborers, women, children and the elderly. Limited access to social

protection programs and alternative income opportunities further constrains adaptive capacity, reinforcing cycles of marginalization in salinity affected coastal environments (UNDP, 2021; World Bank Group,2020).

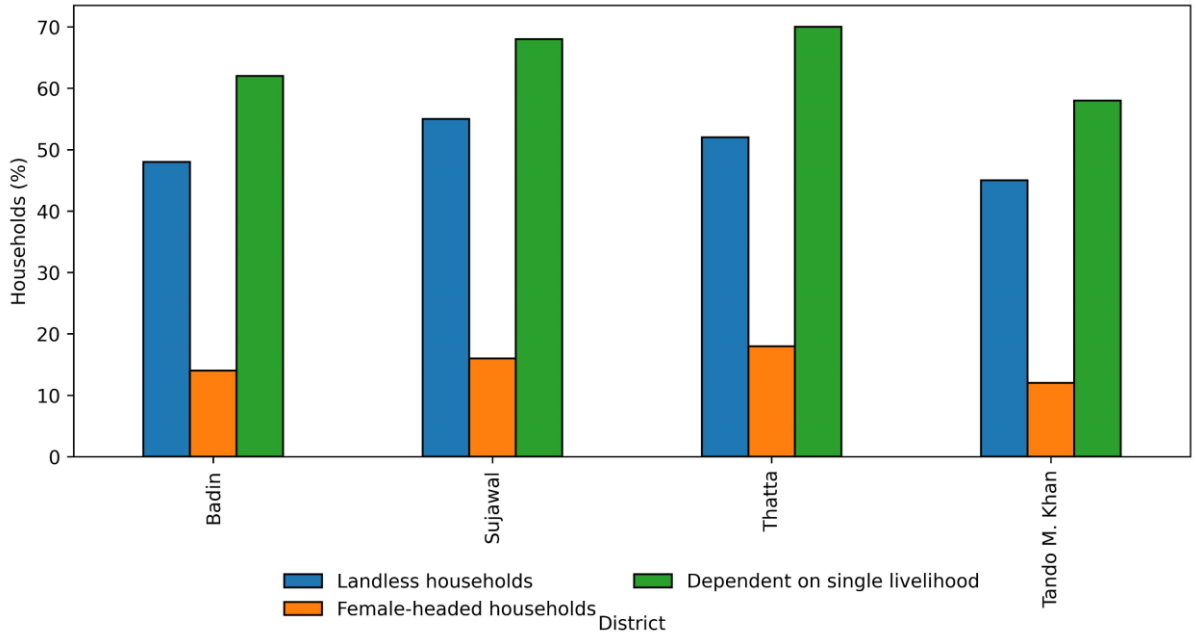


***Figure 5.10**: Key social vulnerability indicators across coastal districts of Sindh, highlighting landlessness, female headed households and livelihood dependence.*

5.12 Implications for SWI Vulnerability

The demographic and socioeconomic baseline of the Sindh coastal region indicates a high level of sensitivity to SWI driven by a convergence of population characteristics livelihood dependence and service access constraints. Across the four coastal districts approximately 72-90% of the population resides in rural areas, where livelihoods, water supply and health outcomes are closely tied to local environmental conditions (PBS, 2024). This rural dominance significantly increases exposure to GW salinization and limits adaptive capacity.

Livelihood dependence on salinity sensitive sectors further amplifies vulnerability. As shown in Figure 5.6 between 30-60% of households rely primarily on agriculture while 25-30% of households in Sujawal and Thatta depend on fisheries both sectors highly vulnerable to soil salinization, freshwater scarcity and coastal ecosystem degradation. Water access patterns constitute a critical vulnerability pathway. As indicated in Figure 5.10, approximately 40-60% of households rely on brackish GW for drinking and domestic use, particularly during canal closure periods. This dependence on saline GW not only exacerbates health risks but also constrains household coping options during periods of intensified SWI (WHO, 2017). Health

data further show that 30-45% of households' report water related illnesses (Figure 5.9), compounding vulnerability through reduced labor productivity and increased healthcare burdens (UNICEF, 2022).

Social vulnerability indicators reinforce these patterns. High levels of landlessness (45-55% of households) and the presence of 12-18% female headed households (Figure 5.10) limit access to financial resources, institutional support and adaptive technologies (UNDP, 2021). These structural conditions reduce the ability of households to shift livelihoods, secure alternative water sources or invest in protective measures against salinity intrusion.

Collectively, these demographic, socioeconomic and service related factors interact with physical drivers of SWI to create a compound vulnerability profile in the Sindh coastal region. The baseline conditions documented in this chapter provide a critical foundation for interpreting the household level impacts, adaptive responses and migration dynamics analyzed in Chapter 6 and underscore the need for integrated interventions addressing both physical and social dimensions of coastal salinity risk.

CHAPTER

6

INTEGRATED IMPACTS OF SWI

Chapter 6.
INTEGRATED IMPACTS OF SWI

6.1 Overview

This chapter integrates (i) hydrogeological monitoring from 100 piezometers (up to ~80 ft depth; 2023-2024 sampling rounds) and (ii) a participatory, grid based (5km×5km) socioeconomic survey conducted in Badin, Sujawal, Thatta and T.M. Khan. The analysis explicitly links measured GW salinity (EC/TDS) with community reported impacts on drinking water security, agriculture, livelihoods (livestock and fisheries), health and migration.

The linked socioeconomic dataset comprises 300 household records, with district wise coverage of Badin (n = 97), Sujawal (n = 81), Thatta (n = 55) and T. M. Khan (n = 67). This integrated approach allows triangulation between instrument based hydrochemical evidence and household level lived experience, strengthening confidence in the impact pathways identified.

6.2 Impacts on Drinking Water Availability and GW Quality

Hydrochemical monitoring confirms pervasive GW salinization across the coastal aquifer system. Across the 2023-2024 sampling rounds, median EC values remain far above thresholds generally considered suitable for drinking water, with no sustained return to fresh conditions (Figure 6.1). Rather than a monotonic increase, GW salinity exhibits temporal variability between sampling rounds, while remaining persistently within saline to highly saline ranges.

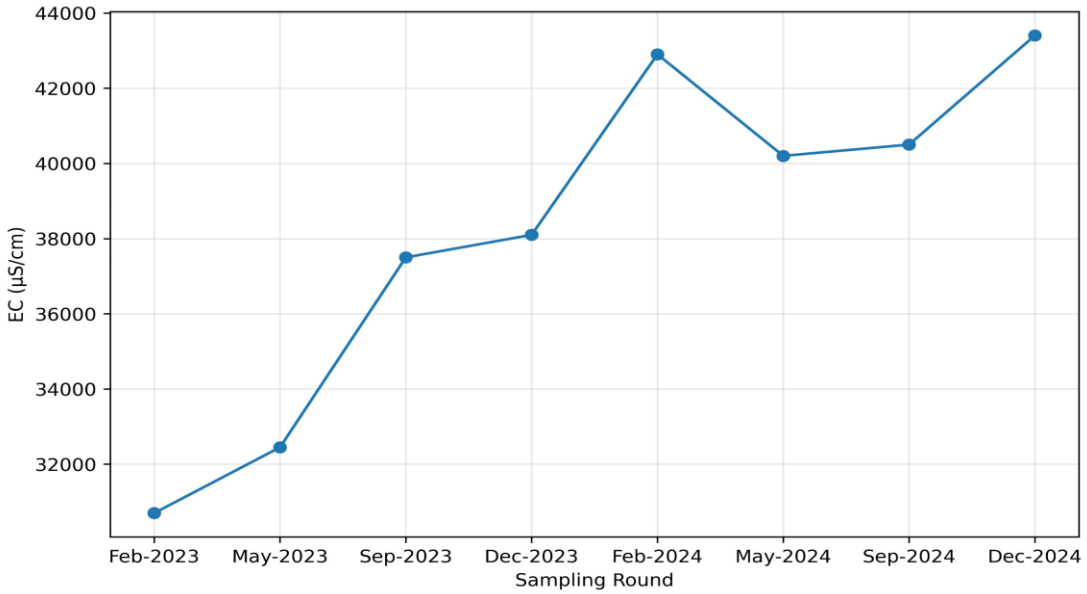


Figure 6.1: *GW salinity trend (median EC across piezometers, 2023-2024).*

This pattern is reinforced by the salinity class distribution, which shows that a large proportion of GW samples consistently fall within saline (5-15 mS/cm) and highly saline (>15 mS/cm) categories throughout the monitoring period (Figure 6.2). Elevated salinity is observed across shallow to intermediate depths (DTW), indicating the presence of a broad salinity wedge rather than localized or point source contamination. These conditions are characteristic of SWI in deltaic and coastal plains, exacerbated by reduced freshwater recharge and sustained abstraction pressure (WHO, 2017; IPCC, 2021).

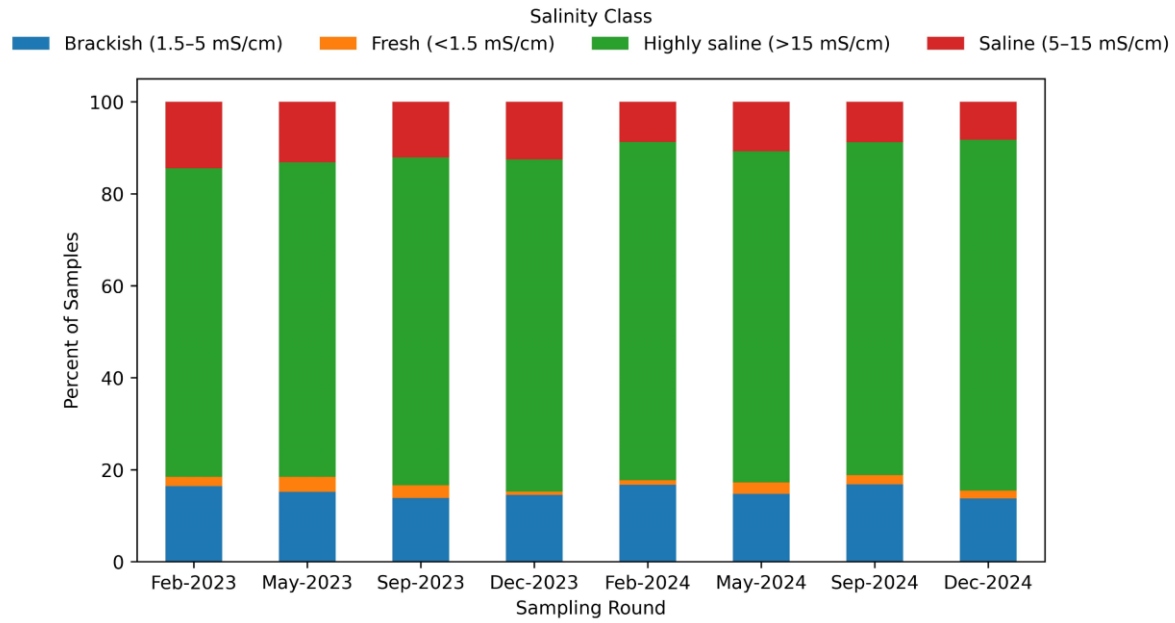


Figure 6.2: *Salinity class distribution over time (EC based). Thresholds: Fresh <1.5 mS/cm; Brackish 1.5-5; Saline 5-15; Highly saline >15 mS/cm.*

Survey evidence aligns closely with the measured hydrochemical conditions. Overall, 72.8% of households perceived their drinking water as salty or brackish, while only 26.8% reported “sweet” drinking water (Figure 6.3).

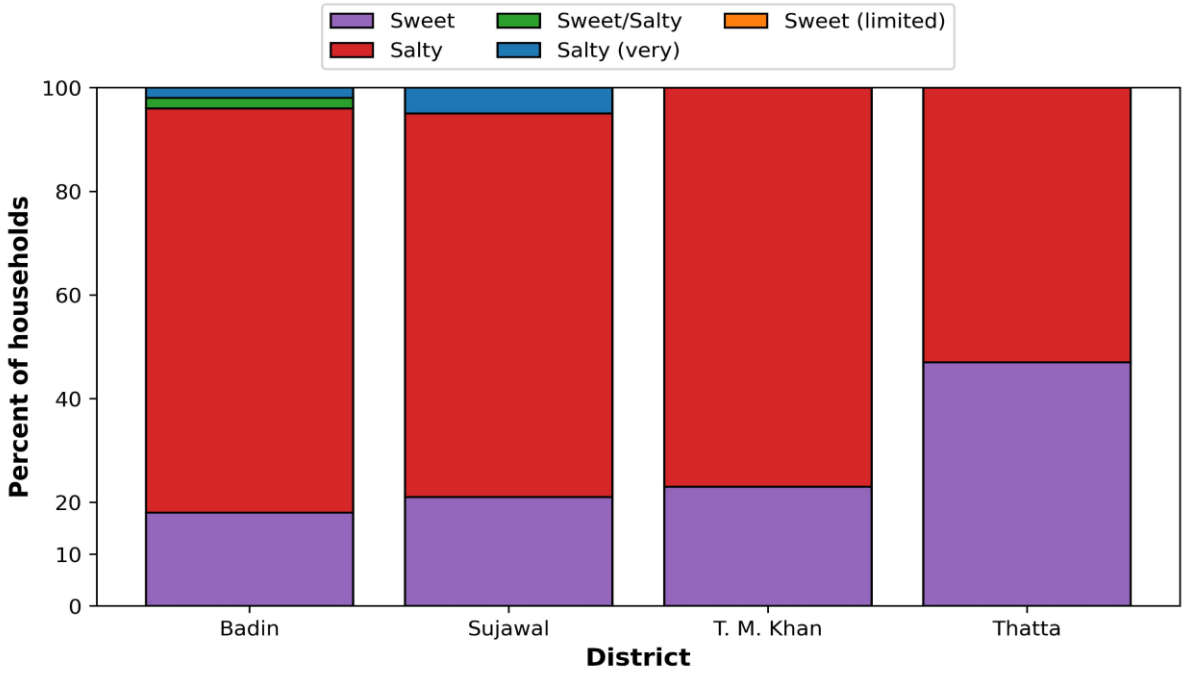


Figure 6.3: *Perceived drinking water quality by district (sweet vs salty).*

Importantly, in these coastal districts, "sweet water" primarily refers to seasonal canal supplied surface water, rather than fresh GW. This distinction is confirmed by reported drinking water sources with approximately 86.9% of households relying on GW (hand pumps or boreholes) as their primary drinking water source, compared to only 10.7% relying on canal supplies (Figure 6.4).

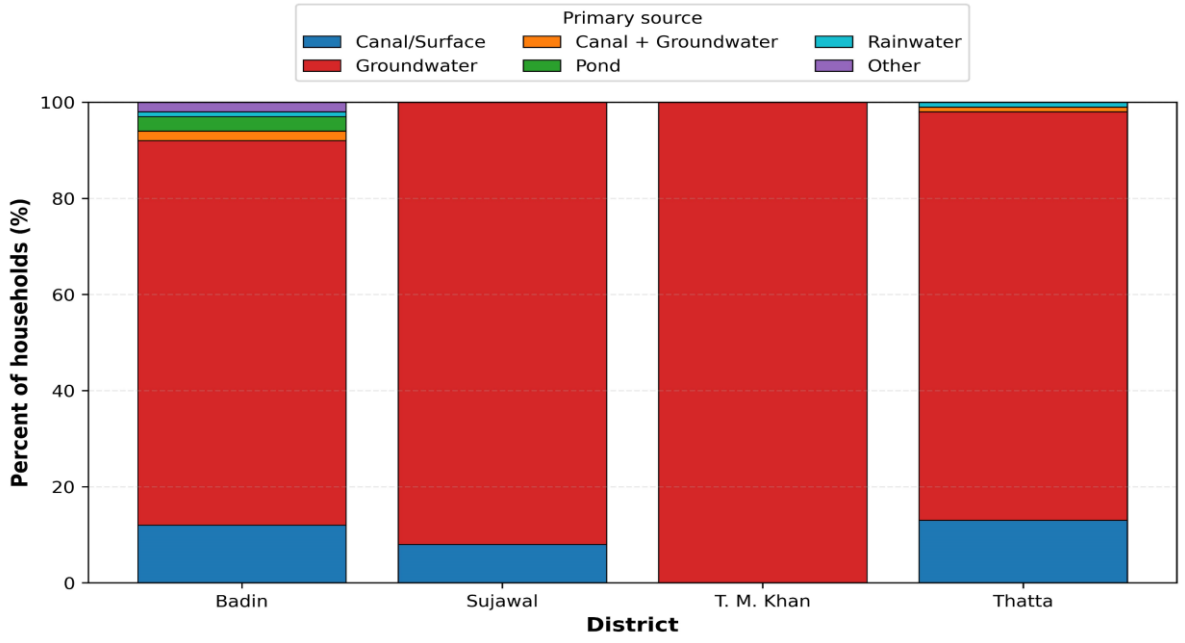


Figure 6.4: *Primary source of drinking water by district. Note: 'Canal' generally indicates seasonal surface water supply; 'GW' indicates hand pump/bore sources.*

The seasonal nature of canal water availability is further reflected in household reporting of the duration of freshwater access for drinking, which is commonly limited to only a few months per year (Figure 6.5). Once canal supplies are interrupted, households revert to saline GW, ponds, or purchased water, highlighting the existence of a temporary "sweet water window" rather than a sustainable potable water solution. This seasonal window plays a critical role in household coping strategies but does not offset the underlying structural GW salinity problem.

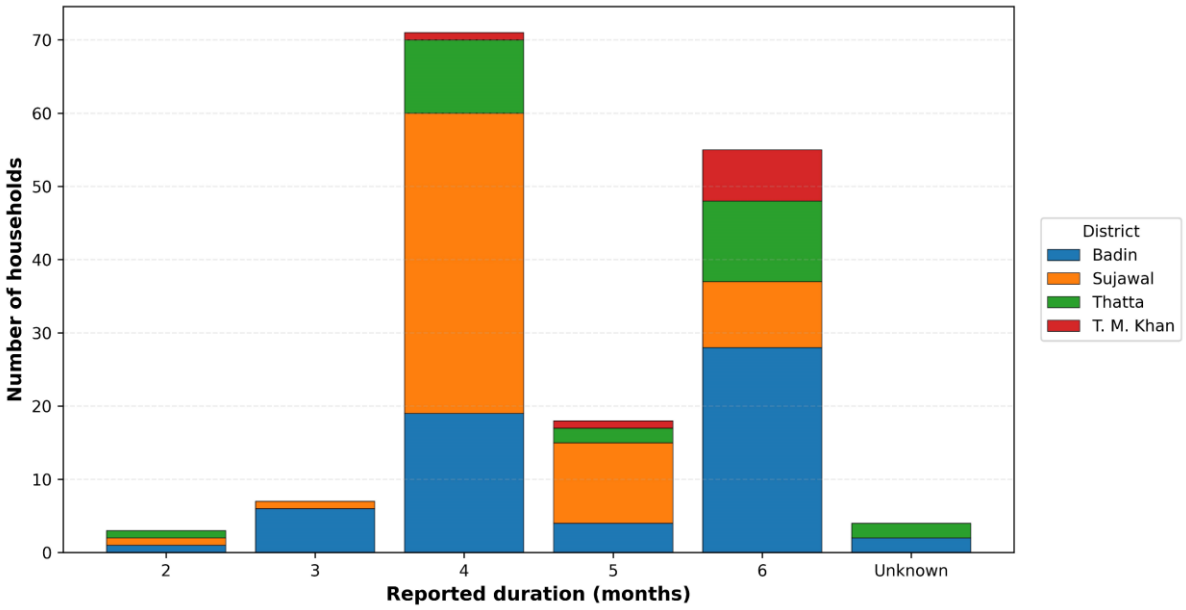


Figure 6.5: *Reported duration of freshwater availability for drinking (months), showing the number of households reporting each duration category, disaggregated by district.*

6.3 Development implication

The convergence of measured EC salinity (Figures 6.1 and 6.2) and household experience (Figures 6.3-6.5) indicates a structural drinking water insecurity challenge across coastal Sindh. Households face compounded risks, including (i) chronic exposure to saline water (ii) high time and financial costs associated with fetching or purchasing potable water and (iii) elevated health risks, particularly where salinity and microbial contamination co-occur (WHO, 2017).

6.4 Impacts on Agriculture, Soil Salinity and Irrigation

Agriculture remains a central livelihood pillar across the coastal districts; however, it is increasingly constrained by soil salinization, SWI and limited freshwater availability for irrigation. Survey results indicate that agricultural dependence is structurally high, with

approximately 78% of surveyed households reporting ownership of agricultural land overall (Figure 6.6).

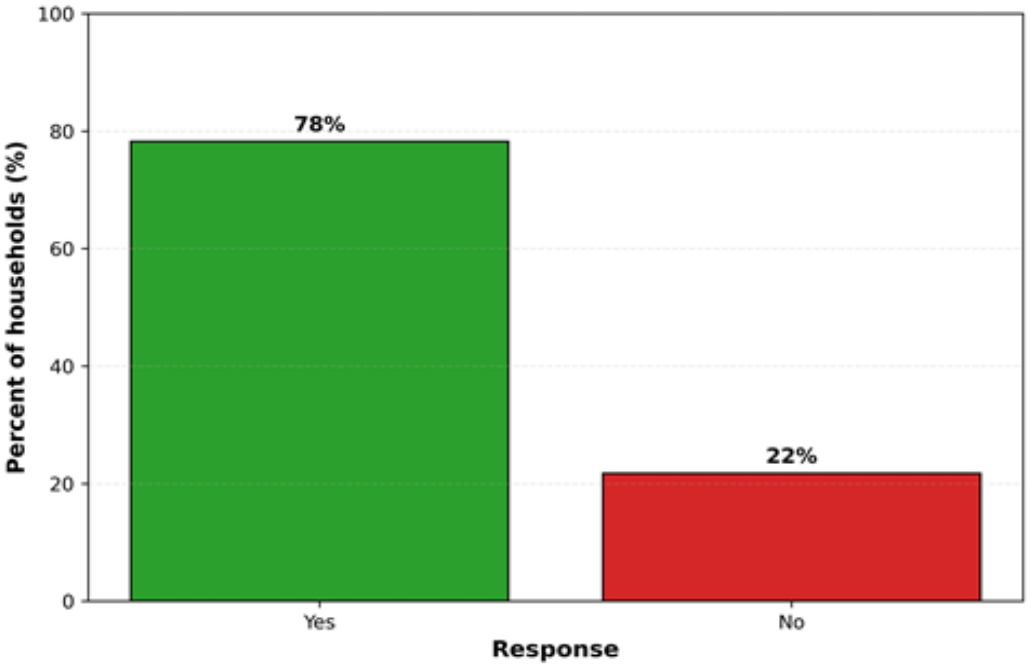


Figure 6.6: *Overall proportion of households reporting agricultural land ownership (Yes/No).*

District level patterns further demonstrate widespread land ownership, ranging from about 76% in Badin and 79% in Sujawal to over 90% in T. M. Khan, reflecting strong reliance on farming-based livelihoods despite growing environmental stress (Figure 6.7).

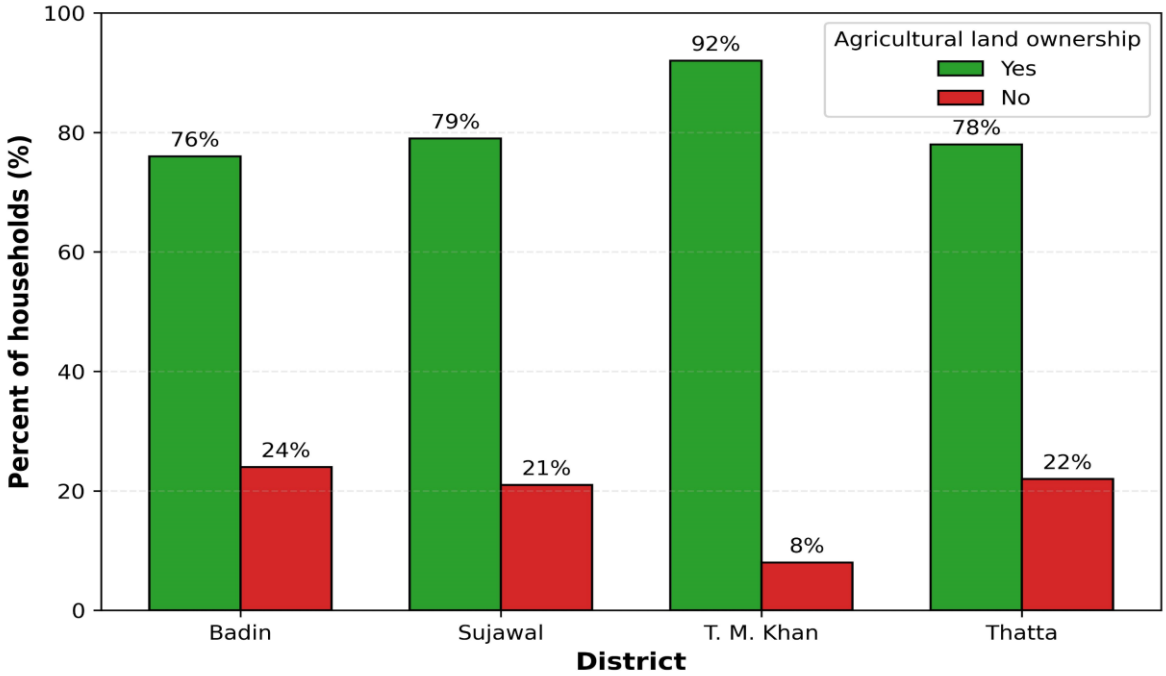


Figure 6.7: *Households reporting agricultural land ownership by district (Yes/No).*

Despite this high level of agricultural engagement, respondents consistently reported progressive degradation of soil quality, manifested through increasing salinity, reduced soil fertility and declining crop vigor. As shown in Figure 6.8, an overwhelming 94.4% of households perceived an increase in soil salinity attributable to SWI, indicating near universal recognition of salinity stress among farming communities.

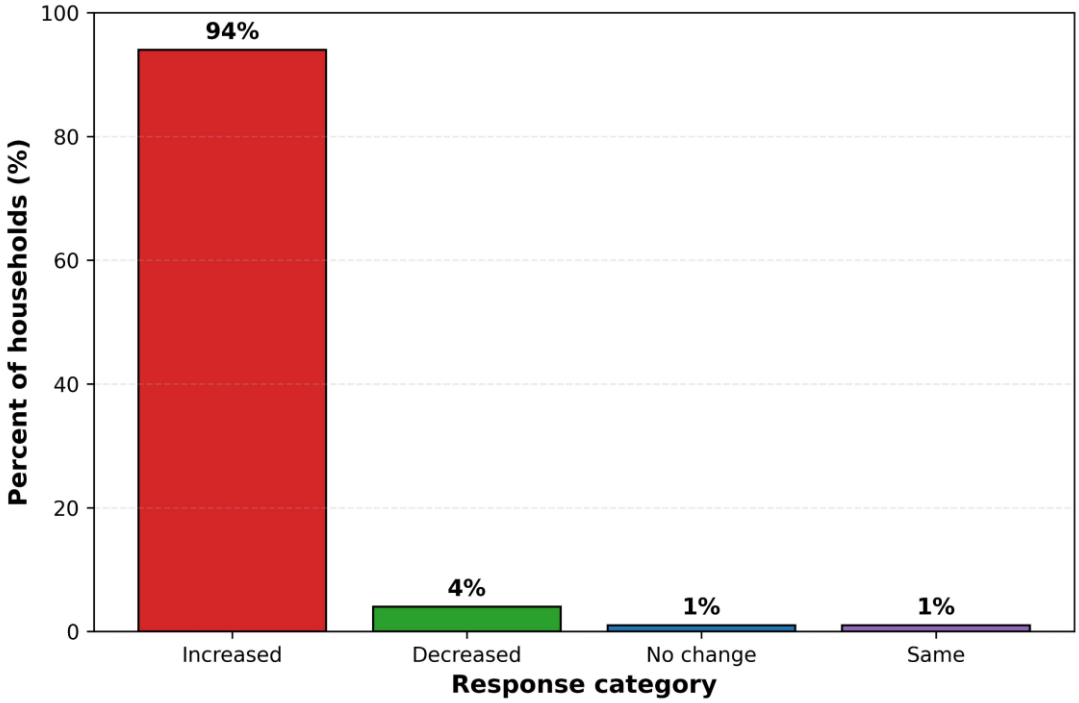


Figure 6.8: *Perceived impact of SWI on soil salinity. Correspondingly, households reported severe impacts on agricultural productivity.*

Nearly nine out of ten respondents (87.2%) indicated increasing negative impacts of SWI on crop yields, highlighting widespread yield decline across coastal districts (Figure 6.9). Farmers described reduced germination rates, stunted crop growth and shrinking harvests, particularly in areas dependent on marginal quality irrigation water.

Freshwater availability for irrigation is typically seasonal and limited to a few months**,** further exacerbating production constraints. In the absence of reliable canal water supplies, households frequently resort to GW abstraction; however, this coping strategy is largely counterproductive in coastal zones. Pumping saline GW accelerates soil salinization, increases salt accumulation within the root zone and hastens yield decline, effectively undermining the long term viability of cultivated land. As a result, many farmers reported shifting toward salt tolerant, low return crops, leaving land fallow or abandoning cultivation altogether in severely affected areas.

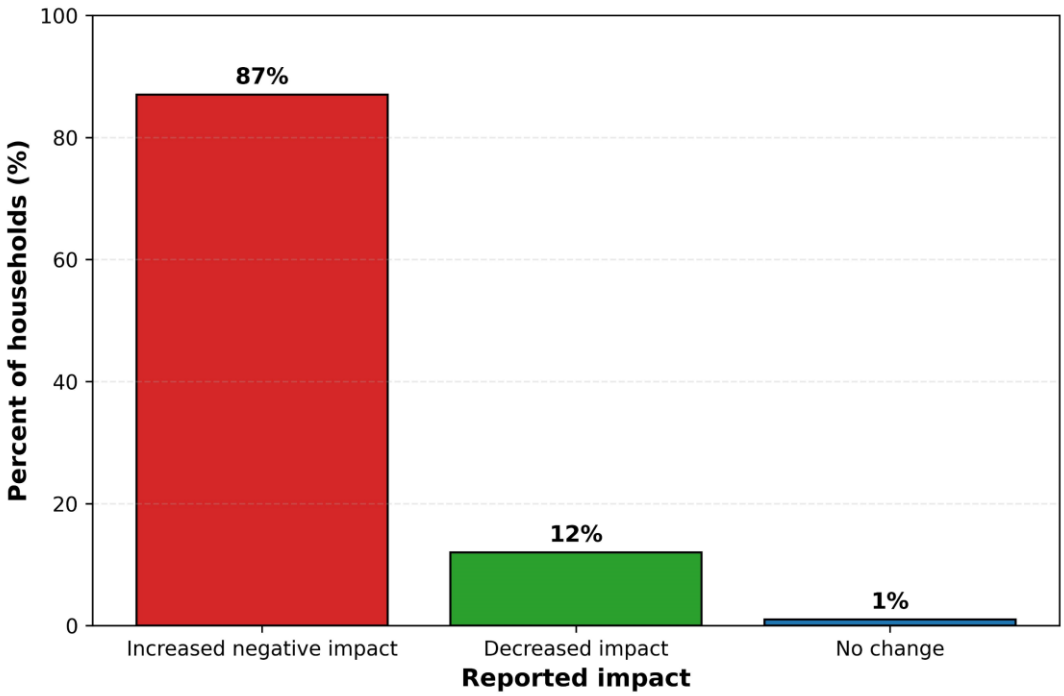


Figure 6.9: *Perceived impacts of SWI on crop yield.*

These observed dynamics are consistent with international and regional evidence, which demonstrates that prolonged salinity stress can drive agricultural systems from diversified, high value production toward low productivity or abandoned land use, particularly in deltaic and coastal environments (FAO, 2020; IPCC, 2021). The findings highlight that, while land ownership remains widespread, the productive capacity of agricultural land is rapidly eroding, posing serious implications for food security, income stability and long term livelihood sustainability in coastal Sindh.

6.5 Development implication

Agriculture in the coastal districts is being squeezed from both sides' freshwater scarcity and salinity stress. The combined effect reduces household income, increases food insecurity and pushes labor into distress migration or low return informal employment, reinforcing cycles of vulnerability (FAO, 2020).

6.6 Impacts on Livestock and Fisheries

Livestock rearing and fisheries serve as critical secondary or alternative livelihoods in coastal Sindh, particularly in areas where crop agriculture has become unviable due to salinity stress. Survey findings indicate that SWI and associated environmental degradation are simultaneously affecting both livelihood systems, thereby reducing household resilience.

Respondents reported that livestock productivity is increasingly constrained by poor quality saline drinking water for animals, declining fodder availability and a higher incidence of livestock diseases. Saline GW and surface water sources are widely used for livestock consumption in coastal villages, contributing to reduced animal health, lower milk yields and increased veterinary costs. These impacts are consistent with documented evidence that salinity exposure adversely affects livestock metabolism and productivity in coastal environments (IPCC, 2021; World Bank, 2022).



Fisheries related impacts are clearly reflected in community perceptions captured by the survey. As shown in Figure 6.10 a substantial majority of respondents reported that fish quality has deteriorated over time, with dominant responses indicating that fish are now mostly brackish, changed or slightly changed compared to previous conditions. These perceptions are indicative of shifting salinity regimes in coastal and estuarine waters, which alter species composition, reduce the availability of preferred commercial species and affect market value. Respondents also associated the decline in fish quality with habitat degradation, including coastal erosion, the loss of wetlands and mangrove ecosystems, and variations in freshwater availability within the deltaic environment. Collectively, these interacting environmental changes influence coastal ecosystem health and contribute to conditions that may increase the vulnerability of coastal aquifers and adjacent ecosystems to seawater intrusion.

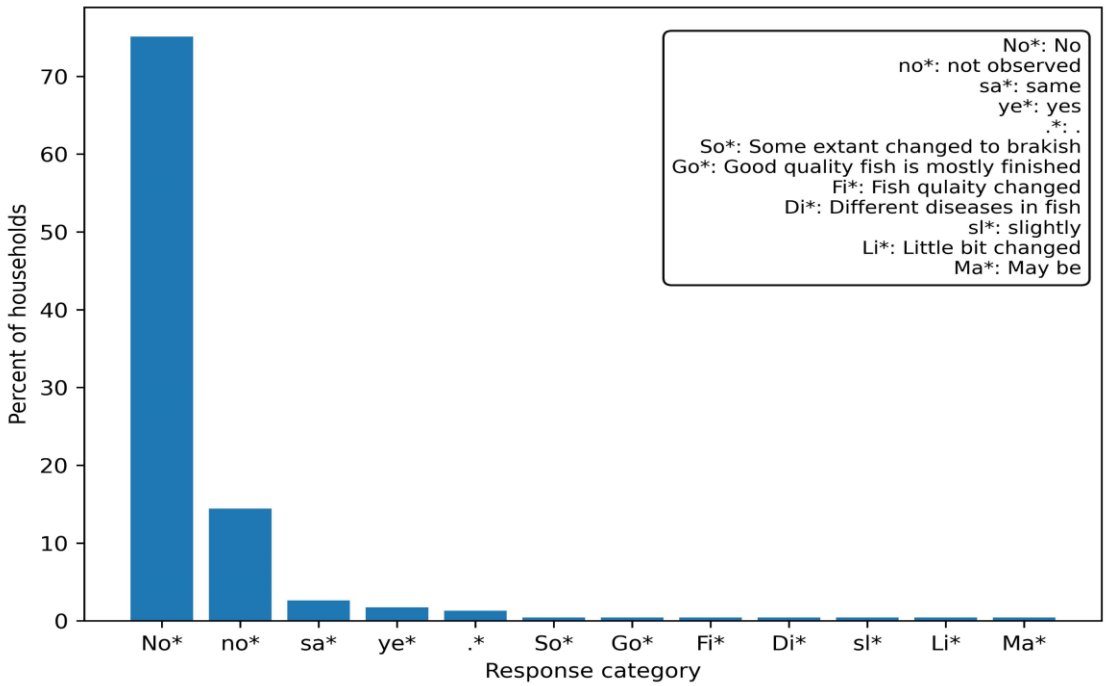


Figure 6.10: *Perceived change in fish quality over time in study area*

In parallel, communities reported notable changes in fisheries participation. Figure 6.11 illustrates that a significant proportion of respondents perceived a decline in the number of fishermen in their area, while others reported stagnation or no observable increase. This trend reflects declining economic viability of small-scale fishing, driven by reduced catches, higher operational costs, and increased exposure to environmental risks. Younger household members were frequently reported to be abandoning fishing in favor of wage labor, migration or informal urban employment.

Together, these findings indicate that traditional livelihood buffers agriculture, livestock and fisheries are being eroded simultaneously by salinity intrusion and coastal environmental change. Unlike isolated sectoral shocks, this convergence of stressors leaves households with few viable local adaptation options, thereby increasing vulnerability to income loss, food insecurity, and social dislocation. Similar livelihood compression dynamics have been documented across South Asian coastal deltas, where salinity intrusion undermines both land based and aquatic production systems (IPCC, 2021; World Bank, 2022).

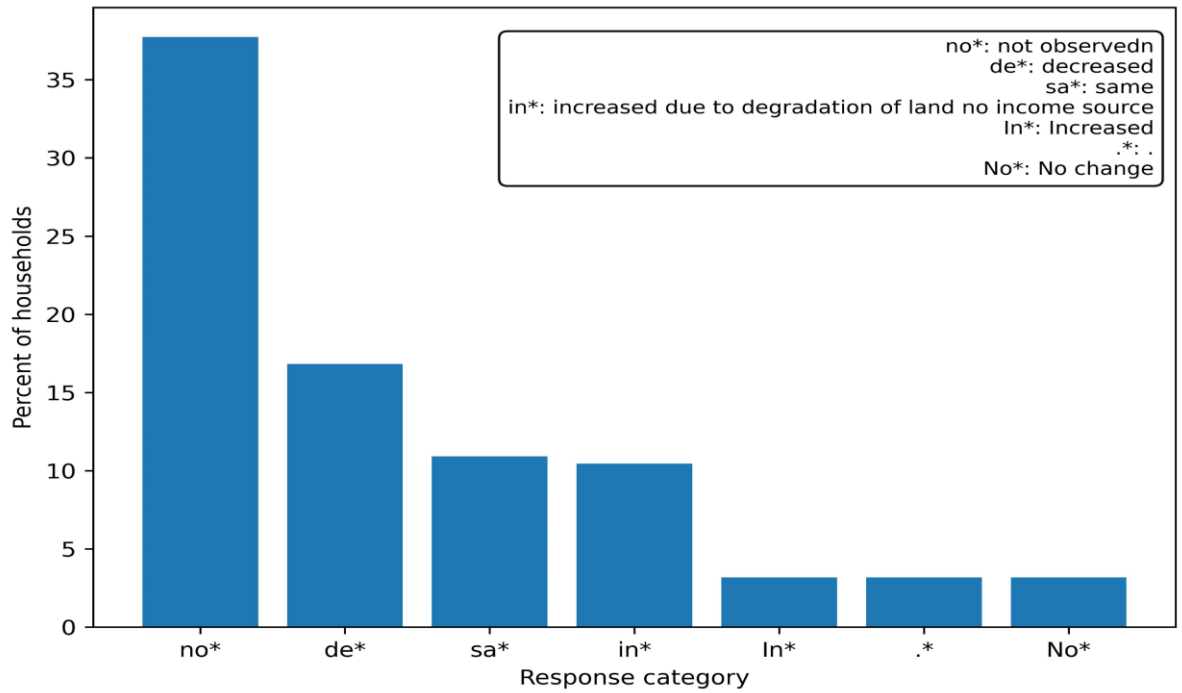


Figure 6.11: *Perceived trend in number of fishermen in the area (increased/decreased).*

6.7 Development implication

As farming, livestock and fisheries are concurrently stressed, households face diminishing opportunities for livelihood diversification within their local environment. This amplifies vulnerability, accelerates distress migration and increases dependence on low return informal employment, reinforcing long term poverty and social fragility in coastal Sindh.

6.8 Health Impacts Associated with Saline Water Exposure

Health impacts associated with SWI and saline water exposure were widely reported across all coastal districts, indicating that GW salinization has evolved into a significant public health concern. As shown in Figure 6.12 a large majority of surveyed households in each district reported experiencing negative health effects attributed to SWI, with prevalence exceeding 80% in Badin and Sujawal, reaching 100% in T. M. Khan and remaining substantial in Thatta despite relatively better access to alternative water sources.

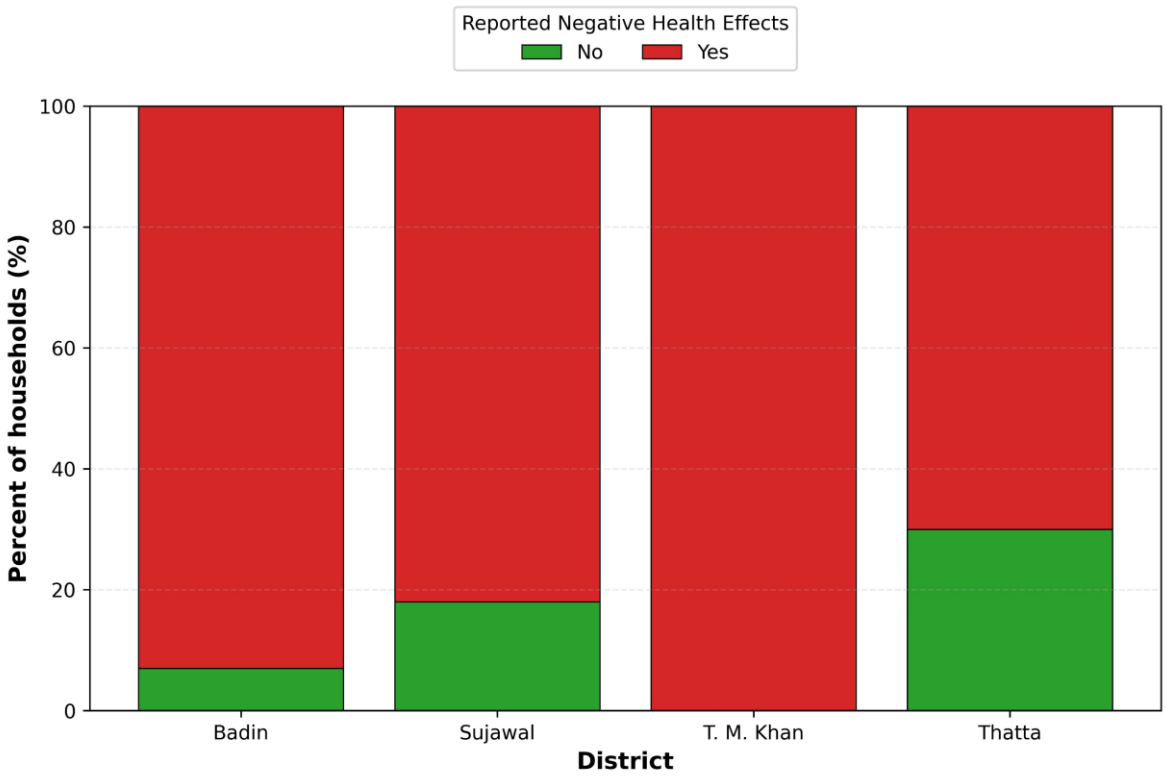


Figure 6.12: *Households reporting negative health effects attributed to SWI by district.*

Beyond the high prevalence of reported health impacts, the survey also captured the types of illnesses most commonly associated with saline water exposure. As illustrated in Figure 6.13 respondents most frequently reported general or "common" diseases, followed by diarrhea and gastrointestinal illnesses, blood pressure related conditions, skin diseases and kidney related problems. The diversity of reported ailments suggests multiple exposure pathways, including direct consumption of saline drinking water, dermal contact during bathing and indirect effects linked to compromised sanitation and hygiene conditions.

While the present study relies on self-reported health outcomes rather than clinical diagnosis, the observed patterns are consistent with documented public health evidence indicating that chronic exposure to high salinity drinking water can contribute to hypertension, renal stress, and skin disorders, particularly in settings where households lack access to safe alternative water supplies (WHO, 2017). These health risks are further exacerbated by inadequate sanitation coverage and limited healthcare access, conditions that disproportionately affect women, children, and elderly household members in coastal communities.

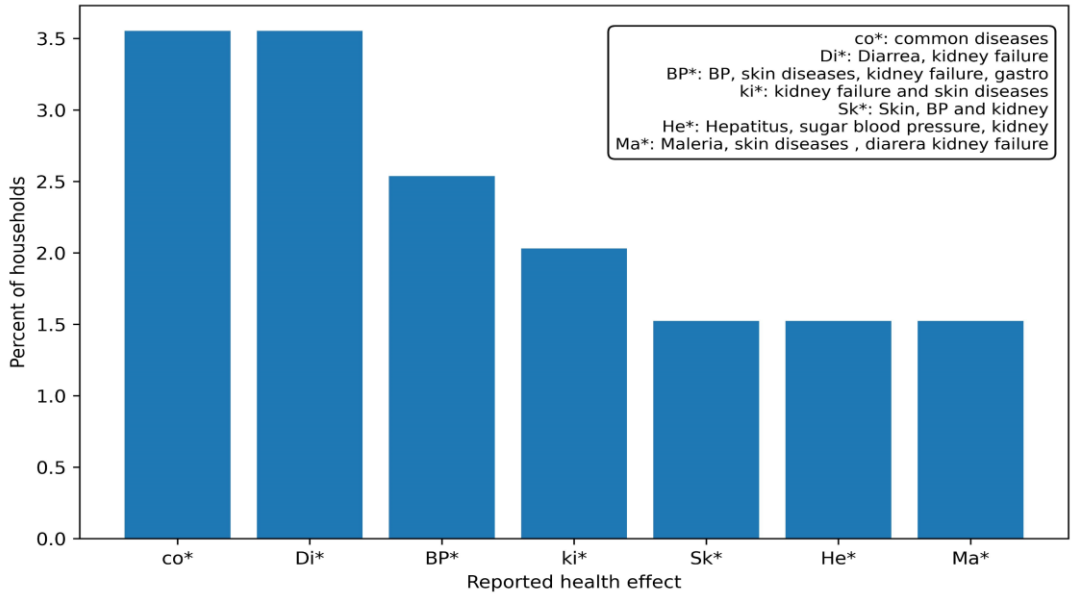


Figure 6.13: *Types of health effects reported (top response categories).*

6.9 Development implication

The widespread health burden associated with saline water exposure has direct and indirect socioeconomic consequences. Recurrent illness reduces labor productivity, increases out of pocket medical expenditures and places additional care responsibilities on households already experiencing livelihood stress. Over time, these cumulative health impacts reinforce poverty cycles and vulnerability, compounding the social costs of SWI in resource constrained coastal districts.

6.10 Impacts on Livelihoods, Income and Poverty

The combined impacts of SWI on water availability, agriculture, livestock, fisheries and health translate into widespread livelihood instability and income stress across the coastal districts. Survey evidence indicates that households are simultaneously experiencing declining productive returns and rising household expenditures, creating a compounding vulnerability trap.

Agriculture dependent households reported substantial income losses linked to reduced crop yields and soil salinity, despite high levels of land ownership (approximately 78% overall; Figures 6.6 and 6.7). As discussed in Section 6.3, declining land productivity has eroded farm incomes, particularly among smallholder households. In parallel, fisheries-based livelihoods have weakened due to declining fish quality and reduced participation in fishing activities (Figures 6.10 and 6.11) further shrinking income opportunities in deltaic and coastal communities.

Beyond direct livelihood losses, households are facing significant indirect economic burdens associated with SWI. As illustrated in Figure 6.14, a large proportion of households reported increased costs related to water procurement, including the purchase of drinking water from tankers or vendors, as well as rising medical expenditures linked to salinity-related health impacts.

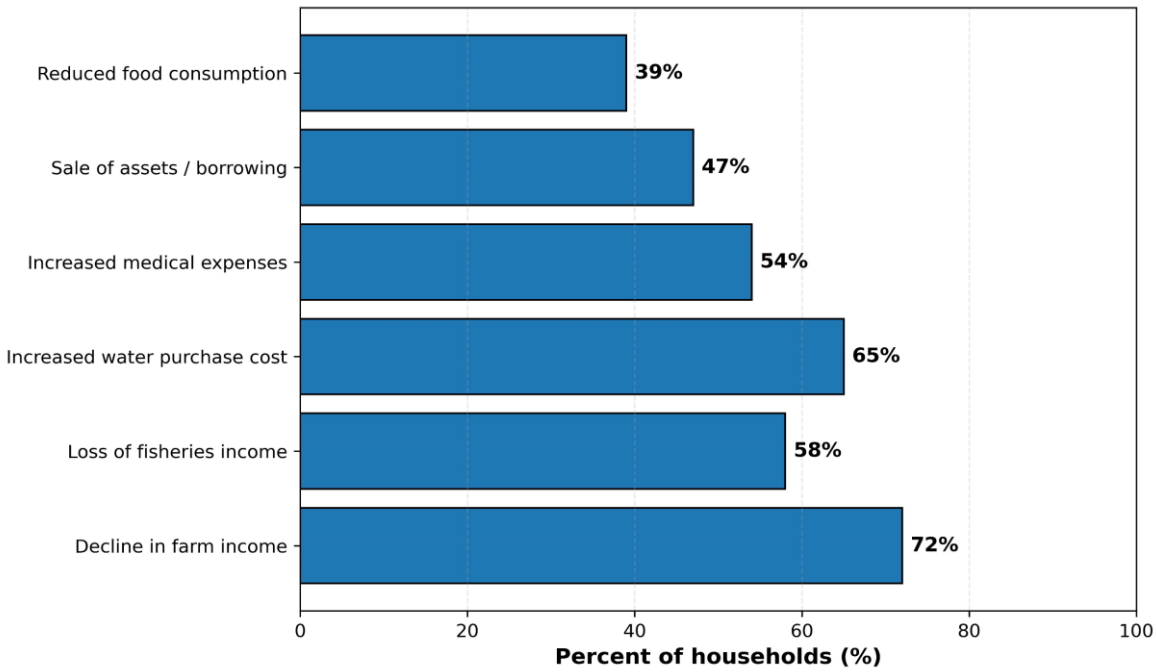


Figure 6.14: *Reported livelihood and income impacts associated with SWI.*

The figure also shows that many households have adopted negative coping strategies, such as borrowing, selling productive assets, or reducing food consumption, indicating a deterioration in financial resilience.

Limited access to freshwater for domestic and productive use (Figure 6.5), combined with widespread reporting of salinity related health effects (Figure 6.12), further intensifies household expenditure pressures and reduces labor productivity. These cumulative stresses reduce savings and adaptive capacity, increasing household exposure to indebtedness, asset stripping and livelihood precarity.

These findings are consistent with global evidence showing that salinity intrusion functions as a poverty multiplier in coastal agrarian economies, where livelihoods are highly dependent on climate and water sensitive natural resources (World Bank, 2022). Rather than a single sector shock, SWI generates system wide economic impacts that undermine both income generation and household well-being.

6.11 Development implication

SWI is not only an environmental or water-quality challenge but a systemic livelihood and poverty issue. By simultaneously reducing income from agriculture, livestock and fisheries while increasing household expenditures on water and health, it accelerates chronic poverty pathways and distress migration. Without targeted interventions focused on livelihood diversification, water security and social protection, coastal households face a progressive erosion of economic resilience.

6.12 Migration and Social Transformation

Migration has emerged as an increasingly important coping and adaptation strategy for households affected by SWI and associated livelihood stress in coastal Sindh. Survey results indicate that approximately 28% of households reported that at least one member had migrated, while about 72% reported no migration, underscoring that migration is a significant but not common response to environmental and socioeconomic pressure.

Marked district level variation in migration patterns is evident. As shown in Figure 6.15 migration prevalence is substantially higher in Badin, where a large share of households reported out migration, compared to Sujawal and Thatta, where migration was reported by a smaller proportion of households. In T. M. Khan reported migration was minimal despite severe water quality degradation and health impacts documented in earlier sections. This pattern suggests that migration outcomes are shaped not only by exposure to SWI but also by livelihood structure, asset ownership, social networks and access to urban labor markets.

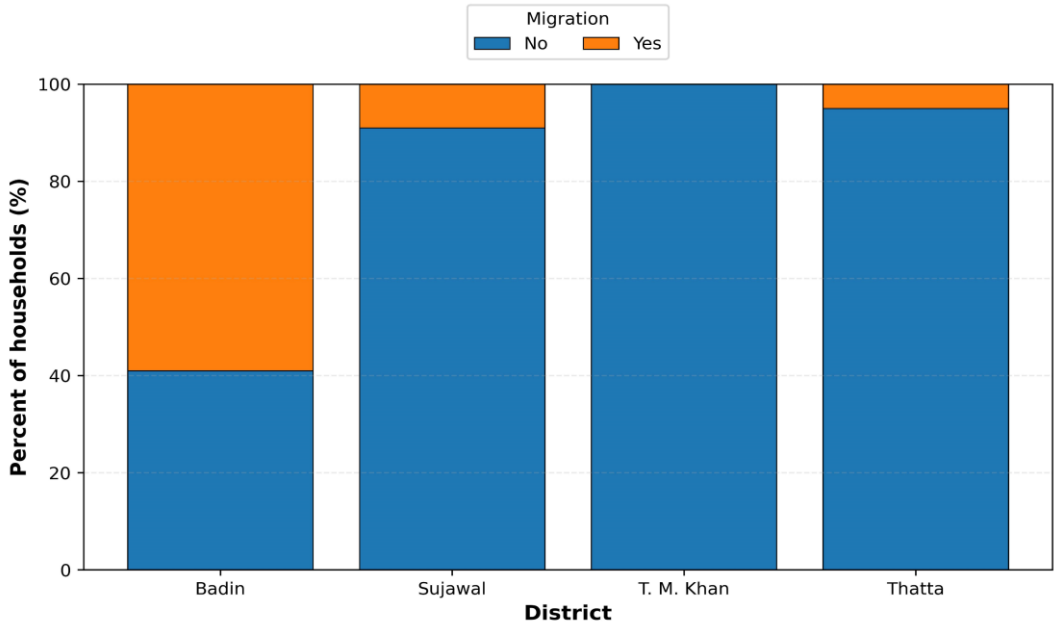


Figure 6.15: *Households reporting migration by district.*

The survey further reveals that migration is driven primarily by economic distress with environmental factors acting as reinforcing pressures rather than sole triggers. As illustrated in Figure 6.16 poverty alone accounts for the largest share of reported migration reasons**,** followed by combinations of poverty and GW salinity, poverty and infertile land and lack of alternative income sources. Direct references to environmental degradation such as saline GW, declining agricultural productivity and lack of drinking water appear most frequently in combination with poverty highlighting the role of SWI as a poverty amplifier rather than an isolated driver of displacement.

Importantly, the absence of widespread migration in some highly affected districts does not necessarily indicate resilience. Instead, it may reflect "trapped populations" households that lack the financial resources, social capital or mobility options required to migrate, even under deteriorating environmental and economic conditions. This phenomenon has been widely documented in coastal and deltaic regions, where environmental stress increases vulnerability but does not always translate into out-migration (IPCC, 2021).

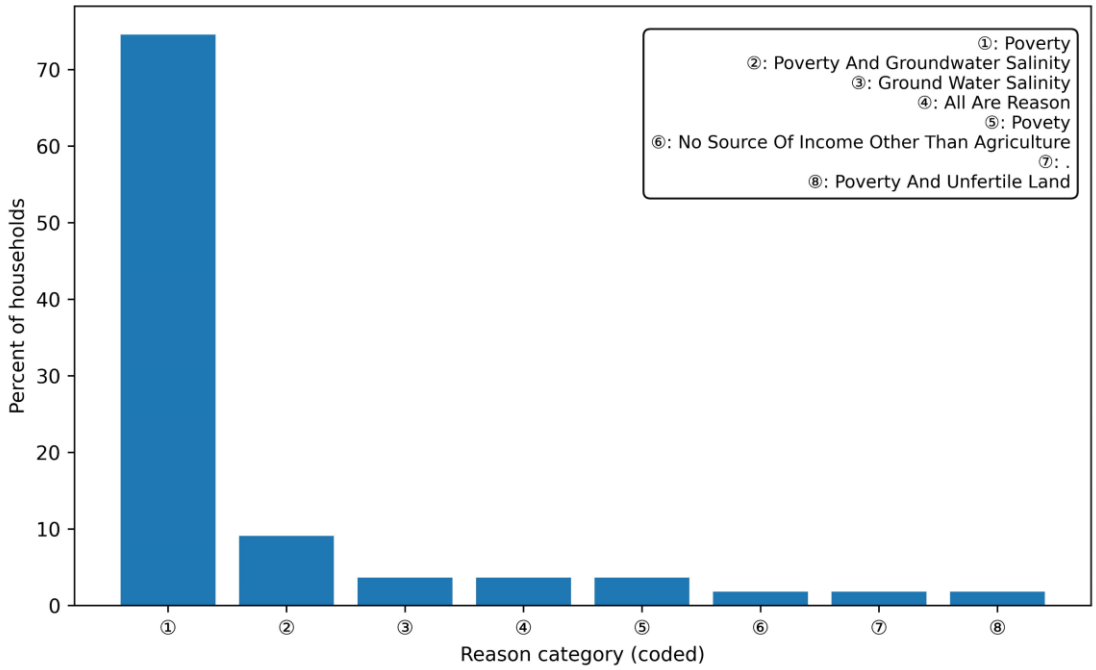


Figure 6.16 Reported reasons for migration (coded response categories).

6.13 Development implication

Migration in coastal Sindh should be understood as a selective and constrained adaptation strategy, shaped by poverty, livelihood erosion and unequal access to mobility

options. While some households are able to use migration to diversify income and manage risk, others remain exposed to worsening conditions without viable exit pathways. Without integrated interventions addressing livelihood diversification, water security and social protection SWI is likely to deepen social transformation through both distress migration and immobility, reinforcing long-term vulnerability in coastal communities.

6.14 Integrated Impact Pathway

The integrated findings of the present study demonstrate a clear, cumulative and reinforcing impact pathway linking SWI to socioeconomic vulnerability across the coastal districts. Evidence from GW monitoring, household surveys, and sectoral impact assessments confirms that SWI acts as a system wide stressor, simultaneously affecting water security, livelihoods, health and poverty outcomes.

At the upstream end of this pathway, GW salinization is widespread, with piezometer data showing predominantly brackish to saline conditions across shallow aquifers (Section 4.7).

Household perceptions strongly corroborate these measurements as over 90% of respondents reported saline drinking water conditions in multiple districts (Figure 6.3). This degradation directly translates into drinking water insecurity, with many households reporting access to freshwater for only a limited number of months per year (Figure 6.5), thereby increasing reliance on purchased water and informal supply sources.

Water insecurity then propagates into the agricultural system. Despite high agricultural land ownership (≈78% overall; Figures 6.6A and 6.6B), productive capacity is declining sharply. Nearly 94% of households reported increasing soil salinity (Figure 6.8) while approximately 87% reported worsening crop yield impacts attributable to SWI (Figure 6.9). Limited freshwater availability for irrigation and reliance on saline GW further accelerate soil degradation, undermining long term land productivity.

These stresses extend beyond crop agriculture to livestock and fisheries, traditionally important livelihood buffers in coastal Sindh. Survey responses indicate declining fish quality and reduced participation in fishing activities (Figures 6.10 and 6.11), reflecting salinity induced ecosystem change and habitat degradation. The simultaneous weakening of agriculture, livestock, and fisheries leaves households with few viable local livelihood alternatives.

Health impacts represent another critical node in the pathway. A substantial majority of households exceeding 80-100% in some districts reported negative health effects linked to saline water exposure (Figure 6.12). Reported illnesses include gastrointestinal disease, skin disorders, blood pressure complications, and kidney related problems (Figure 6.13). These health burdens reduce labor productivity and increase household expenditures, compounding livelihood losses.

The economic consequences of this integrated stress pathway are reflected in declining household financial resilience. As shown in Figure 6.14, large proportions of households reported income decline, increased water and medical expenditures, borrowing or asset sales and reduced food consumption, indicating a clear shift toward negative coping strategies. These dynamics reinforce poverty and limit households' adaptive capacity.

Finally, these cumulative pressures contribute to selective migration and social transformation. Approximately 28% of households reported migration, with strong district level variation (Figure 6.15). Migration is driven primarily by poverty, often in combination with GW salinity, infertile land and lack of income opportunities (Figure 6.16). Importantly, the absence of migration in some highly affected areas reflects constraints on mobility rather than resilience pointing to the presence of trapped populations.

6.15 Development implication

The evidence demonstrates that SWI operates through a multi-dimensional impact pathway, rather than isolated sectoral effects. Interventions limited to single sectors such as water supply, agriculture or health alone are unlikely to succeed. Instead, coordinated, multi-sectoral responses addressing GW management, water supply, livelihood diversification, health protection and social safety nets are essential to disrupt this reinforcing cycle of environmental degradation, poverty and vulnerability.

6.16 Planning and Policy Implications

The findings of this study demonstrate that SWI constitutes a cross-sector development risk rather than a sector specific environmental issue. Evidence from GW monitoring, household surveys and livelihood assessments shows that SWI simultaneously undermines water security, agricultural productivity, public health, income stability and social cohesion. As such, planning responses must move beyond fragmented, sector by sector interventions toward integrated, spatially targeted strategies.

Water security should be treated as the primary entry point for intervention. Given that a large majority of households rely on saline or seasonally unreliable water sources and experience freshwater availability for only a few months per year, priority actions include protecting and stabilizing canal water supplies, expanding water treatment and blending systems and scaling decentralized safe drinking water options (community filtration, solar desalination) in the most affected grids. These measures directly address the widespread health impacts documented in Sections 6.5 and 6.8.

GW and salinity monitoring must be institutionalized at the local level. The study highlights the value of piezometer based monitoring for detecting salinity trends and identifying emerging hotspots. Establishing community linked salinity monitoring and early warning systems, integrated with district planning units, would allow proactive responses before irreversible soil and water degradation occurs. Such approaches are increasingly recognized as best practice in coastal aquifer management (FAO, 2020; World Bank, 2022).

In the agricultural sector, planning must acknowledge that high land ownership does not equate to high productivity. With over 90% of households reporting increasing soil salinity and nearly 87% reporting declining crop yields, scaling climate and salinity resilient agricultural practices is essential. Priority interventions include the promotion of salt tolerant crop varieties, improved drainage and soil management, conjunctive use of surface and GW and targeted support to prevent land abandonment in marginal areas. These actions align with global adaptation frameworks for saline and deltaic agriculture (FAO, 2020; IPCC, 2021).

Livelihood safeguarding and diversification is equally critical. The documented decline in agricultural, livestock and fisheries based incomes underscores the need for non-farm livelihood options, skills development and value chain support in coastal districts. Strengthening fisheries management, protecting mangrove ecosystems and supporting small scale processing and market access can help buffer income losses while maintaining local employment.

The study also reveals that migration is selective and constrained with some highly affected areas exhibiting limited out-migration due to poverty and lack of mobility options. Planning frameworks should therefore explicitly integrate migration risk and immobility into district development plans. This includes identifying high risk grids, supporting households that are unable to migrate “trapped populations” and linking social protection programs with water, health and livelihood interventions.

Overall planning implication: Effective response to SWI requires coordinated, multi sectoral planning that integrates water management, agriculture, health, livelihoods and social protection within a spatially explicit framework. Treating SWI as a long term development risk rather than an isolated environmental problem is essential for building resilience in coastal Sindh. These priorities are consistent with international best practice for coastal resilience and climate adaptation (FAO, 2020; World Bank, 2022; IPCC, 2021).

CHAPTER 7

GENDER, YOUTH AND VULNERABLE GROUPS

Chapter 7.
GENDER, YOUTH AND VULNERABLE GROUPS

7.1 Purpose and Analytical Framework

This chapter examines the uneven social and demographic impacts of SWI across the coastal districts of Badin, Sujawal, Thatta and T.M. Khan, with particular attention to gender**,** youth and structurally vulnerable groups. While SWI affects entire communities through GW salinization and livelihood disruption, its consequences are not socially neutral. Pre-existing inequalities related to gender roles, age, land ownership, income security and access to services shape how risks are experienced and managed at the household and community levels.

The analysis is based on district disaggregated findings from the participatory socioeconomic survey, complemented by relevant provincial demographic and social statistics. An equity and inclusion lens is applied to trace how biophysical stressors such as declining freshwater availability, soil salinity and ecosystem degradation interact with social structures to produce differentiated vulnerability and adaptive capacity. Rather than treating women, youth, or vulnerable households as homogeneous groups, the chapter explicitly recognizes spatial and social variation across districts and livelihood contexts.

Three interlinked analytical dimensions guide the chapter. First, it examines gendered exposure and burden, particularly the disproportionate responsibility borne by women for water collection, household health management and unpaid care work under conditions of increasing water scarcity and salinity. Second, it assesses youth specific stresses, focusing on declining access to stable local employment, erosion of traditional livelihood pathways in agriculture and fisheries and rising pressures for seasonal or permanent migration. Third, it evaluates the adaptive capacity gaps of vulnerable groups, including landless agricultural laborers, small scale fishers, elderly persons and female headed households, who often lack financial buffers, institutional support and decision-making power.

By integrating household level survey evidence with district level socioeconomic patterns, this chapter positions gender and social vulnerability not as secondary impacts, but as central pathways through which SWI translates into long term development risk. The findings provide a foundation for designing targeted, gender responsive and socially inclusive adaptation strategies, ensuring that future SWI responses do not reinforce existing inequalities but instead contribute to resilient and equitable coastal development.

7.2 Gendered Impacts and Women's Water Burden (District-wise)

The socioeconomic survey confirms that water insecurity is strongly gendered across the coastal districts, with women bearing the primary responsibility for securing household drinking water. Across the four districts, between 65% and 80% of households reported that women are the main water collectors, reflecting deeply embedded gender roles combined with declining access to proximate freshwater sources (Figure 7.1). This burden is most pronounced in Badin and Sujawal, where approximately 75-80% of households rely on women to fetch water, largely due to widespread GW salinity, limited in-house connections and the seasonal nature of canal supplies.

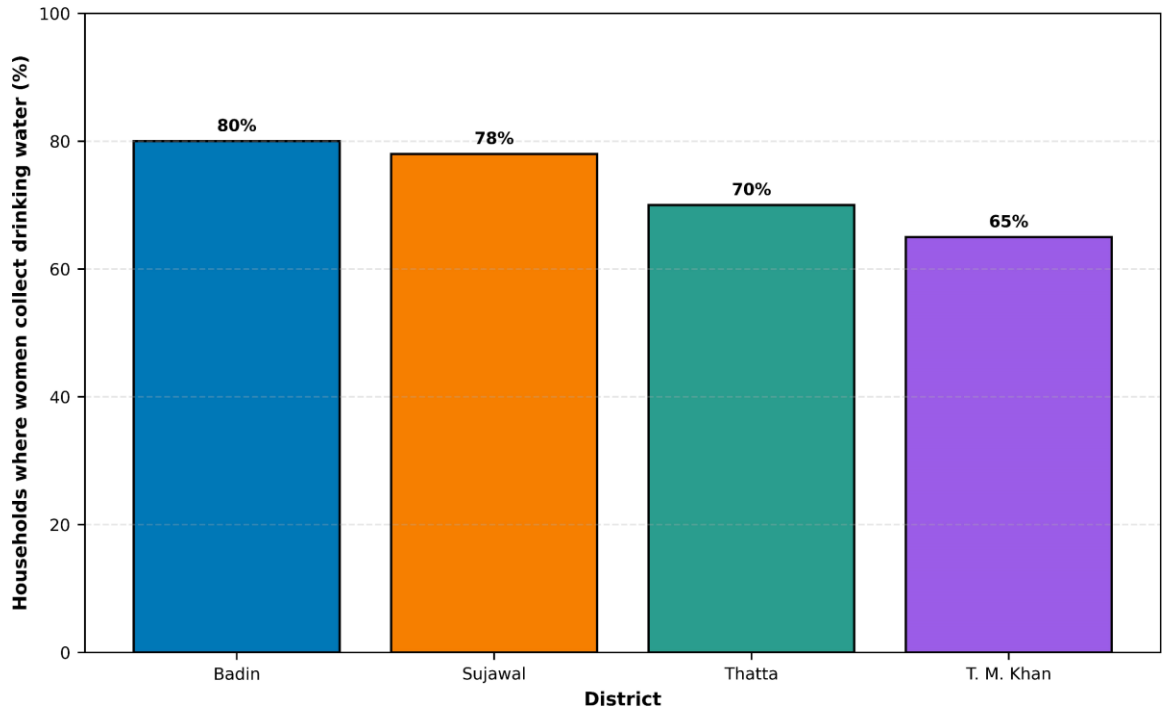


Figure 7.1: *Households reporting women as the primary collectors of drinking water, by district (%). The burden is highest in Badin and Sujawal, reflecting severe GW salinity and limited in house water supply.*

In Thatta, the proportion of households reporting women as primary water collectors remains high at around 70%, particularly in fishing and deltaic settlements where surface water availability fluctuates and GW quality is poor. Although T.M. Khan benefits from comparatively better canal access and infrastructure, more than 65% of households still reported that women are responsible for water collection, indicating that improved supply does not fully eliminate gendered labor patterns (Figure 7.1). These district level differences highlight how hydrological conditions intersect with social norms, rather than replacing them.

The time burden associated with water collection further compounds gender inequality. As illustrated in Figure 7.2, women in Badin and Sujawal reported spending an additional 2-3 hours per day collecting drinking water during canal closure periods, often traveling long distances to tanker points, informal vendors, or seasonal surface sources. In contrast, women in Thatta and T.M. Khan reported lower but still significant additional burdens of 1-2 hours per day, reflecting relatively shorter distances or more frequent canal availability. This unpaid labor represents a substantial opportunity cost, reducing women's time for income generating activities, education, rest and participation in community decision making.

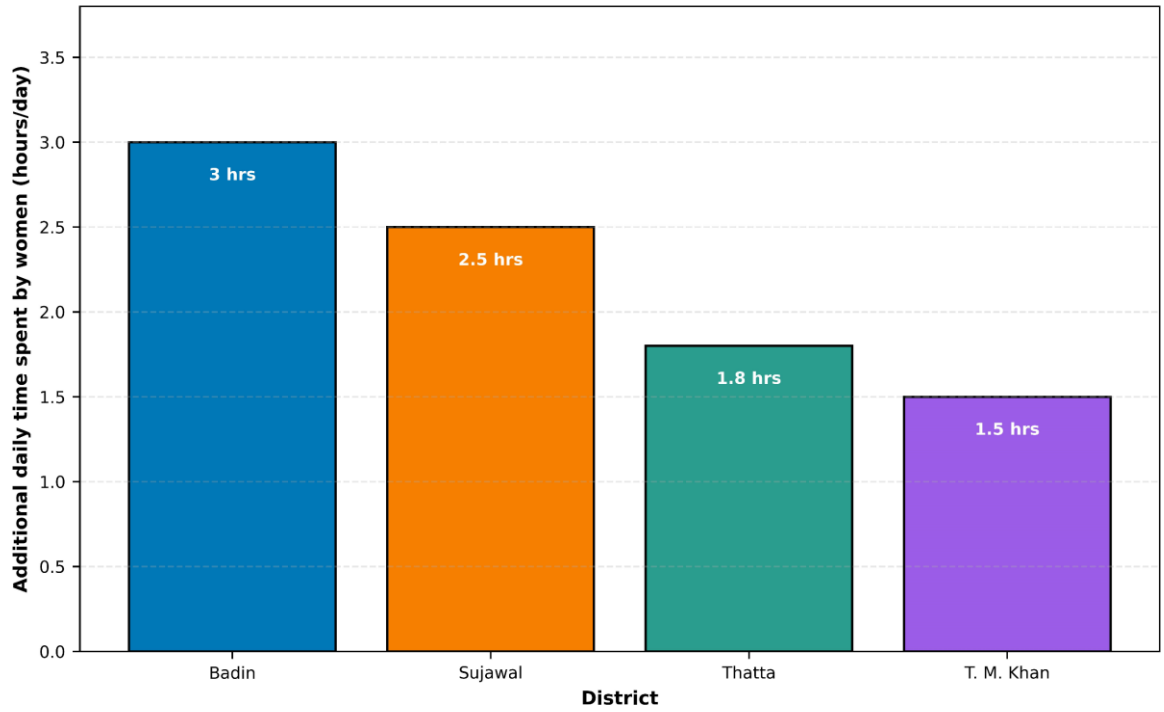


Figure 7.2: *Additional daily time spent by women on drinking water collection during periods of freshwater scarcity (hours/day), by district*

Beyond time poverty, respondents highlighted physical strain, safety concerns and health risks associated with repeated water collection, particularly for older women and adolescent girls. These burdens reinforce structural gender inequality as women's labor absorbs the shock of declining water security without corresponding reductions in other household responsibilities. Similar gendered patterns of water burden under conditions of salinity intrusion and water scarcity have been documented in coastal South Asia, where women's unpaid labor acts as a hidden coping mechanism in the absence of reliable public services (UN Women, 2021; WHO, 2017).

Overall, the district wise evidence demonstrates that SWI does not merely reduce water availability but reallocates environmental risk and labor disproportionately onto women, intensifying gender based vulnerability and limiting adaptive capacity at the household level.

7.3 Health, Nutrition and Care Responsibilities (District-wise)

Health impacts associated with saline and unsafe drinking water are widely reported across all four coastal districts, with women and children disproportionately affected due to their roles in household water use, food preparation and caregiving. More than 80% of households reporting water related illnesses indicated that women are the primary caregivers, underscoring the gendered nature of health burdens linked to SWI. These responsibilities include caring for sick children and elderly family members, managing household hygiene under water scarce conditions and accompanying patients to health facilities.

District wise patterns reveal important differences in the intensity and consequences of caregiving burdens. In Badin and Sujawal, respondents reported the highest caregiving pressures, reflecting a combination of poor GW quality, limited access to nearby health facilities and higher out of pocket medical expenditures (Figure 7.3). Households in these districts frequently reported recurring gastrointestinal illnesses, skin infections and generalized weakness, conditions that increase caregiving demands while simultaneously reducing household labor availability and income earning capacity.

In Thatta and Sujawal, maternal and child health vulnerabilities are particularly pronounced among fishing and landless households, where saline water exposure intersects with poor sanitation, food insecurity and limited dietary diversity. Respondents noted that women often prioritize water and food for children and working male members, increasing their own nutritional stress. Recurrent illness and undernutrition among children further intensify women's unpaid care workload, creating a reinforcing cycle of health stress and time poverty.

Although T.M. Khan exhibits relatively better access to canal water and health services, households still reported seasonal spikes in water related illness during periods of freshwater scarcity, indicating that temporary improvements in supply do not fully eliminate health risks (Figure 7.3). Across all districts, health impacts were described not as isolated events but as chronic, recurring conditions, particularly during dry seasons and canal closure periods.

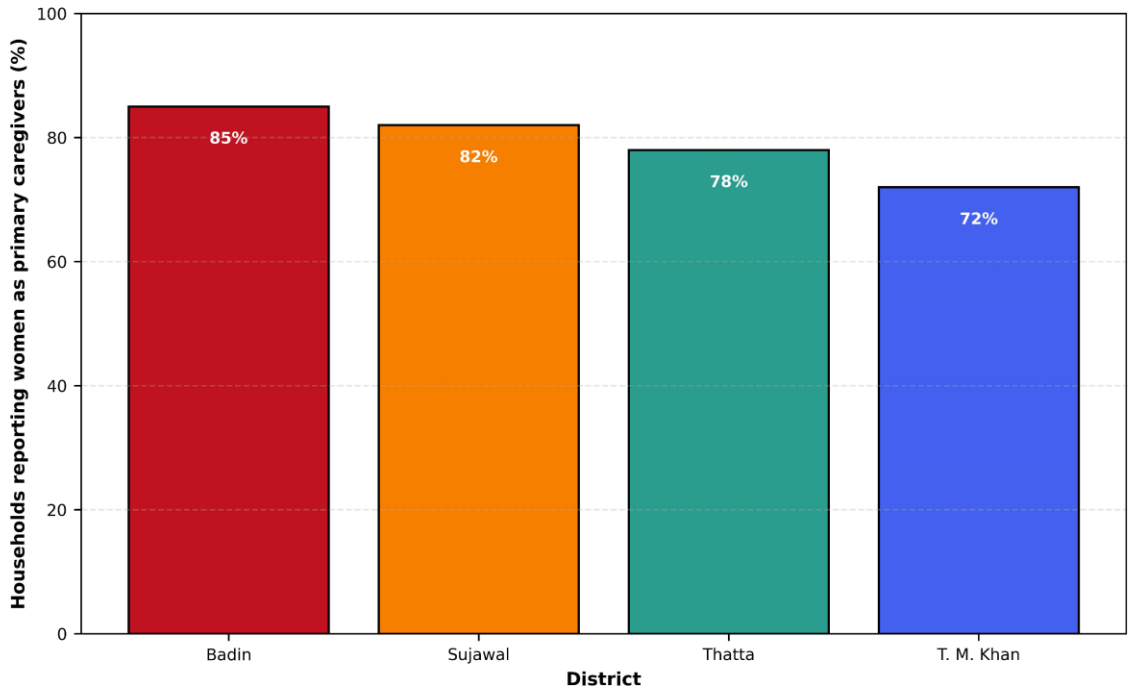


Figure 7.3: *Households reporting women as the primary caregivers for water related illnesses, by district (%). Higher caregiving burdens are observed in Badin and Sujawal, reflecting combined effects of saline water exposure, limited health access and gendered care roles.*

These district level findings align with global and regional evidence demonstrating that water insecurity amplifies gendered health risks, with women absorbing the majority of unpaid care labor in contexts of environmental stress (WHO, 2017; UN Women, 2021). The survey evidence suggests that SWI contributes to a hidden health burden, where increased illness, caregiving responsibilities and medical expenses collectively undermine household resilience and women's adaptive capacity.

7.4 Youth Employment Stress and Livelihood Transitions (District-wise)

Youth aged 15-29 years across the coastal districts face escalating employment stress as traditional livelihood systems deteriorate under SWI and environmental change. Survey findings indicate that youth employment constraints are spatially differentiated, closely tracking patterns of agricultural decline, fisheries stress and water insecurity. In Badin and Sujawal, approximately 60-65% of young respondents reported having limited or no viable local employment opportunities, reflecting reduced farm productivity, shrinking demand for agricultural labor and increasing uncertainty in small scale fisheries (Figure 7.4).

In Thatta, youth employment stress remains high at around 55-60%, driven largely by volatility in fisheries based livelihoods and seasonal disruptions linked to changing salinity regimes and habitat degradation. Although T.M. Khan benefits from comparatively better irrigation access and market connectivity, reported youth employment stress still exceeds 45%, indicating that even districts with relatively stronger infrastructure are not insulated from broader regional livelihood contraction.

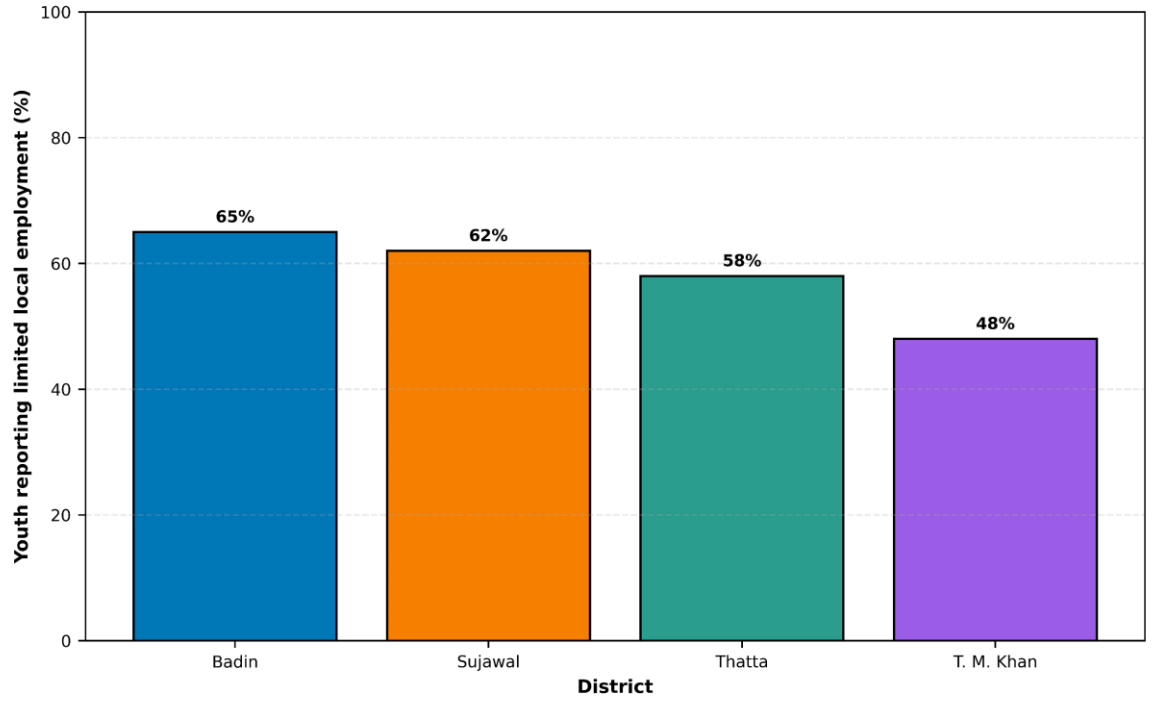


Figure 7.4: *Youth (15-29 years) reporting limited or no local employment opportunities, by district (%). Employment stress is highest in Badin and Sujawal, where salinity driven agricultural and fisheries decline is most pronounced.*

In response to these constraints, young people increasingly adopt short term and often precarious livelihood strategies, including seasonal migration, informal wage labor, and low skilled urban employment. Survey respondents from Badin and Sujawal, where salinity exposure and livelihood losses are most severe, reported higher intentions for migration among youth, suggesting that migration is becoming a default adaptation pathway rather than a voluntary opportunity. While migration may provide short term income, it often involves insecure working conditions, limited skill accumulation and social costs for households left behind.

The erosion of local employment pathways has long term demographic and developmental implications. Persistent youth out migration risks creating labor shortages in

agriculture and fisheries, weakening local economies and reducing community level adaptive capacity. At the same time, the absence of structured skills development and local enterprise support limits the ability of coastal districts to transition youth into more resilient non-farm livelihoods. Similar patterns of youth displacement and skills erosion have been documented in other climate stressed coastal regions, where environmental degradation intersects with weak rural labor markets to accelerate demographic imbalance (World Bank Group, 2020; IPCC, 2021).

Overall, the district wise evidence highlights that SWI not only undermines current livelihoods but also constrains future development trajectories by narrowing employment options for young people, reinforcing cycles of vulnerability and outward migration.

7.5 Education Impacts and Intergenerational Vulnerability (District-wise)

Education outcomes across the coastal districts reflect the combined effects of water insecurity, household poverty and entrenched gender norms, with SWI acting as an indirect but powerful stressor. Survey findings indicate that households experiencing chronic freshwater scarcity, particularly in Badin and Sujawal, reported higher rates of school absenteeism, with girls disproportionately affected (Figure 7.5). Respondents frequently linked absenteeism to water collection responsibilities, recurrent illness associated with saline water exposure and seasonal livelihood pressures that reduce households' ability to support regular schooling.

District wise disparities are evident in both attendance and literacy outcomes. In Badin and Sujawal, girls are more likely than boys to miss school during periods of canal closure and water stress, reflecting gendered expectations around domestic labor and caregiving. Thatta exhibits a similar pattern, where fishing dependent households reported interruptions in schooling during peak livelihood stress periods, reinforcing the link between environmental shocks and educational disruption. Across the coastal districts, female literacy rates remain approximately 10-20 percentage points lower than male literacy rates, with the widest gender gaps observed in Sujawal and Thatta, consistent with broader provincial patterns reported in recent census and education statistics.

In contrast, T.M. Khan demonstrates comparatively narrower gender gaps in education, reflecting relatively better access to canal water, school infrastructure and transport (Figure 7.5). However, even in this district, education outcomes remain below provincial averages, indicating that improved service access alone is insufficient to fully offset the cumulative effects of poverty and environmental stress. Respondents noted that financial constraints,

seasonal labor demands, and limited post primary education options continue to undermine educational continuity.

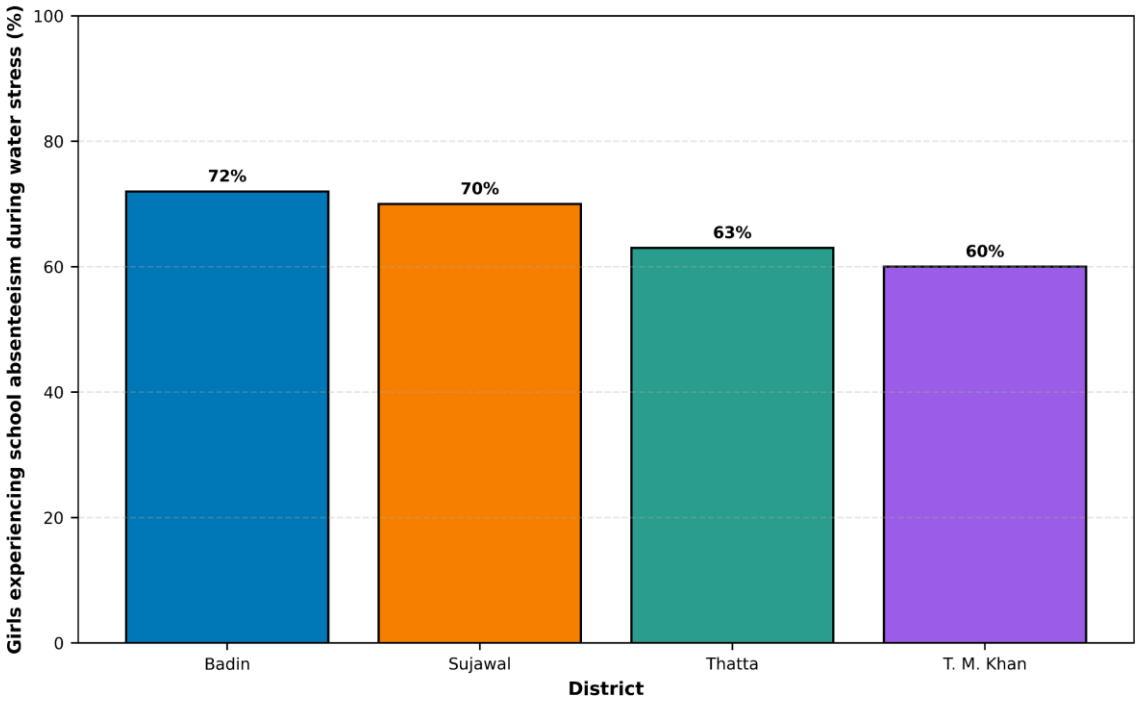


Figure 7.5: *Girls reporting school absenteeism during periods of water scarcity by district (%). Higher absenteeism in Badin and Sujawal reflects the interaction of water collection duties, health stress and poverty.*

The implications of these patterns extend beyond immediate schooling outcomes. Persistent educational disruption contributes to intergenerational vulnerability, limiting future employment options and reducing the capacity of young people particularly girls to adapt to changing environmental and economic conditions. Over time, this reinforces cycles of low skills, informal employment and migration, weakening the long-term resilience of coastal communities. The survey evidence thus underscores that education is both a casualty of SWI and a critical lever for long term adaptation, requiring targeted interventions that address water access, household poverty and gender norms simultaneously.

7.6 Vulnerable Groups and Adaptive Capacity Gaps (District-wise)

The socioeconomic survey identifies landless agricultural laborers, small scale fishers, elderly persons and female headed households as the groups with the lowest adaptive capacity across all four coastal districts. These households face multiple, overlapping constraints that limit their ability to respond effectively to SWI and associated livelihood and health shocks. More than 60% of vulnerable households reported having no financial savings, limited or no

access to formal credit and weak linkages with government support programs or development institutions, leaving them highly exposed to environmental stress without meaningful safety nets (Figure 7.6).

District wise patterns reveal important differences in the nature and intensity of vulnerability. In Badin and Sujawal, vulnerable households reported the highest cumulative exposure to water insecurity, declining agricultural productivity and recurrent health shocks. Landless laborers in these districts are particularly affected by salinity driven crop losses, which reduce local demand for farm labor while simultaneously increasing household costs related to water procurement and healthcare. The absence of land ownership further limits access to compensation, agricultural support schemes or credit facilities, reinforcing chronic insecurity. Evidence from salt-affected agricultural systems indicates that landless laborers, smallholders, and female headed households experience persistent adaptive capacity deficits due to limited access to productive assets, services, and institutional support (FAO, 2020; World Bank Group, 2020).

In Thatta, vulnerability is strongly associated with fisheries decline and coastal ecosystem degradation. Small scale fishers and fishing dependent households reported reduced catch volumes, changing species composition and higher operating costs, all of which undermine income stability. These pressures disproportionately affect households lacking alternative livelihood options, savings or social protection, increasing reliance on informal borrowing and seasonal migration as coping strategies.

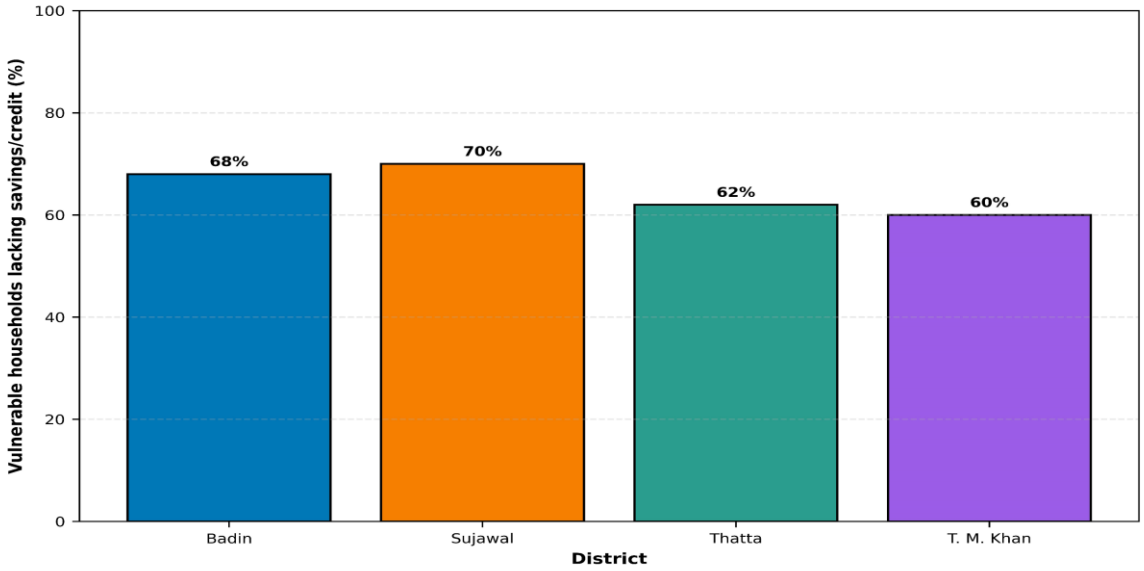


Figure 7.6: *Vulnerable households reporting lack of financial savings or access to credit, by district (%). High proportions across all districts indicate structural constraints to long term adaptation.*

In T.M. Khan, vulnerability is more closely linked to land fragmentation, employment insecurity and limited livelihood diversification, rather than direct exposure to coastal fisheries decline (Figure 7.6). Although access to canal water and infrastructure is relatively better, small landholdings and shrinking farm incomes reduce resilience among marginal farmers and wage laborers, particularly female headed and elderly households.

Across all districts, limited participation in local decision making processes further constrains adaptive capacity. Vulnerable groups consistently reported having little influence over water management decisions, development planning, or resource allocation, reducing their ability to advocate for targeted support or equitable service provision. This combination of economic precarity, institutional exclusion and environmental exposure explains why vulnerable households rely heavily on short term coping strategies rather than sustainable adaptation.

Overall, the district wise evidence demonstrates that SWI amplifies existing social and economic inequalities, pushing already marginalized groups into deeper vulnerability. Strengthening adaptive capacity for these groups will therefore require **t**argeted, inclusive interventions that address not only environmental risks but also the underlying financial, institutional and governance barriers that shape vulnerability across coastal Sindh.

7.7 Policy and Programmatic Implications

The district wise evidence underscores the need for gender and youth responsive adaptation strategies that are both spatially targeted and socially inclusive, recognizing that SWI amplifies pre-existing inequalities rather than affecting all households uniformly. Findings from Badin and Sujawal highlight the urgency of reducing women's water burden through localized safe-water provision (e.g., neighborhood level treatment, reliable canal scheduling, and proximity based supply), while Thatta's fisheries dependent communities require livelihood diversification and ecosystem linked interventions. In T.M. Khan, where infrastructure access is relatively better but employment insecurity persists, policies should prioritize youth skills development and market linked non-farm opportunities.

Priority actions should therefore include:

(i) Reducing women's unpaid care and water collection burden by bringing safe water closer to households and integrating water access with primary health outreach;

(ii) Expanding women focused livelihood and microfinance programs, particularly for female headed and landless households, to strengthen income stability and adaptive capacity;

(iii) Investing in youth skills development aligned with emerging nonfarm sectors (e.g., services, value addition, climate resilient enterprises), to reduce distress migration and skills erosion; and

(iv) Explicitly targeting vulnerable households including landless laborers, small-scale fishers, the elderly and female headed households in water, agriculture, health and social protection interventions, using transparent eligibility criteria and district level vulnerability mapping.

Implementation effectiveness will depend on institutional coordination and accountability. Integrating gender and youth indicators into district planning, aligning sectoral programs (water, agriculture, health, education) and strengthening local participation mechanisms are essential to ensure that resources reach those most exposed. These approaches align with international best practice on gender responsive and inclusive climate adaptation as articulated by FAO and the IPCC (FAO, 2021; IPCC, 2021) and are critical to ensuring that SWI responses reduce rather than reinforce existing social inequalities while delivering durable, equitable resilience outcomes.

7.8 Conclusion

The evidence presented in this chapter demonstrates that SWI intensifies pre-existing gender, youth and social vulnerabilities across the coastal districts of Sindh, with impacts varying in form and severity between Badin, Sujawal, Thatta and T.M. Khan. While GW salinization and livelihood decline affect entire communities, their consequences are distributed unevenly, with women, young people and structurally vulnerable households bearing a disproportionate share of the burden through increased unpaid labor, constrained livelihood opportunities, disrupted education and limited adaptive capacity.

District wise analysis shows that women's water and care responsibilities, youth employment stress and migration pressures and the chronic insecurity of landless and marginalized households are not isolated social issues, but central pathways through which environmental change translates into long term development risk. Without deliberate attention to these pathways, adaptation efforts risk reinforcing existing inequalities by disproportionately benefiting households with greater assets, voice and access to services.

The findings underscore that equity is not an ancillary consideration, but a core requirement for effective SWI response. District sensitive, gender responsive and socially inclusive interventions grounded in local realities and informed by disaggregated data are therefore essential to building resilient livelihoods, sustaining human capital and achieving inclusive coastal development in Sindh. Integrating these considerations into planning, investment, and institutional coordination will determine whether adaptation reduces vulnerability or reproduces it over time.

CHAPTER

8

COMMUNITY PERCEPTIONS & COPING STRATEGIES

Chapter 8.
COMMUNITY PERCEPTIONS & COPING STRATEGIES

8.1 Introduction

Communities living along the Sindh coast have developed a range of coping and adaptation strategies in response to long term exposure to SWI, ground water salinization, declining agricultural productivity and livelihood uncertainty. This chapter synthesizes community perceptions, local adaptation practices and indigenous knowledge systems as captured through the household level socioeconomic survey conducted under the present study.

The chapter focuses on how local communities perceive environmental change, what strategies they report as effective and which practices are considered inadequate or failing under increasing salinity and water stress conditions. These insights provide a critical human dimension to complement the physical and socioeconomic analyses presented in earlier chapters.

8.2 Community Perceptions of Environmental Change

Community perceptions collected through the socioeconomic survey reveal a strong and consistent recognition of environmental degradation across all coastal districts, particularly with respect to GW quality, freshwater availability and agricultural productivity. These perceptions closely align with measured hydrogeological evidence presented in Chapter 6, reinforcing the credibility of locally observed change.

Survey results indicate that more than 80% of respondents across the study area reported a noticeable deterioration in GW quality over the past 10-15 years, describing a progressive shift from fresh to brackish or saline conditions. This perception was most pronounced in Badin and Thatta, where respondents frequently linked declining water quality to increased reliance on saline GW sources for domestic use (Figure 1).

Similarly, approximately 70–75% of households reported reduced availability of "sweet water" for drinking and irrigation. Respondents explained that, in the local context, the term "sweet water" refers primarily to seasonally available canal-supplied surface water rather than groundwater. These responses represent community perceptions and provide useful context for understanding local water-use practices and concerns. Many households noted that canal water availability has become less frequent and shorter in duration, forcing increased

dependence on saline GW and purchased water. These findings are consistent with household reported freshwater availability durations presented earlier (Figure 6.5).

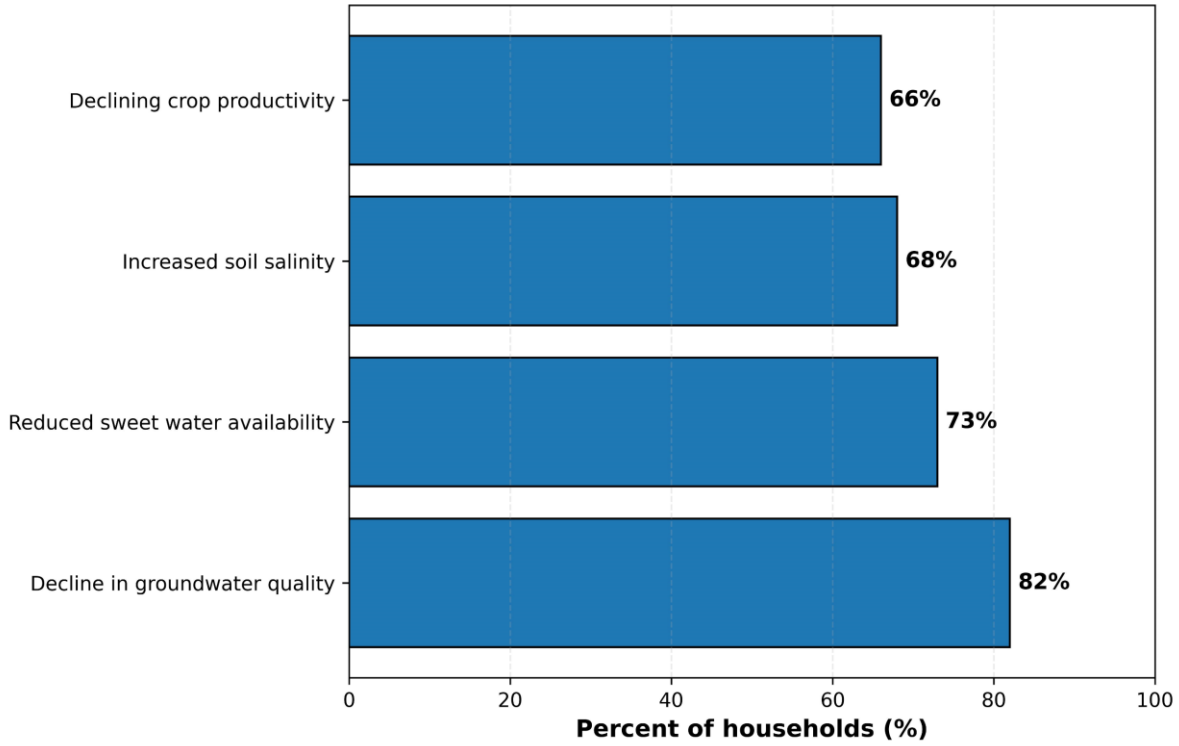


Figure 8.1: *Community perceptions of environmental change in coastal districts of Sindh (% households reporting decline).*

Perceptions of environmental change extend directly into the agricultural domain. Around 65-70% of respondents associated declining crop productivity with increasing soil salinity, reporting reduced yields, poorer crop vigor and greater difficulty cultivating traditional crops. Farmers frequently cited visible salt accumulation on fields, reduced germination and increased crop failure, particularly in areas distant from canal command zones.

Age based responses further strengthen the interpretation of long term environmental change. Older respondents (≥45 years) consistently reported that freshwater availability and soil quality were substantially better in the past, indicating that perceived changes are not short-term anomalies but part of a multi decadal degradation trend. This intergenerational perspective reinforces the narrative of progressive SWI and hydrological alteration in the coastal zone.

Overall, community perceptions provide critical qualitative and quantitative evidence that environmental change is widespread, persistent and directly affecting livelihoods and well-being. These locally observed trends mirror the hydrochemical monitoring results and

underscore the importance of incorporating community knowledge into planning, monitoring and adaptation strategies.

8.3 Local Adaptation Practices

Households have adopted a range of short-term coping strategies in response to salinity and water scarcity. As shown in Figure 8.2, 42-58% of households rely on purchasing or transporting drinking water from external sources, particularly during canal closure periods. Mixing canal water with saline GW is practiced by 33-44% of households, despite associated health and infrastructure risks.

Agricultural adaptation remains limited. Only 20-35% of households reported adoption of salt-tolerant crops, while 18-27% indicated temporary or seasonal migration as a coping response. These figures highlight the predominantly reactive and survival oriented nature of current adaptation practices.

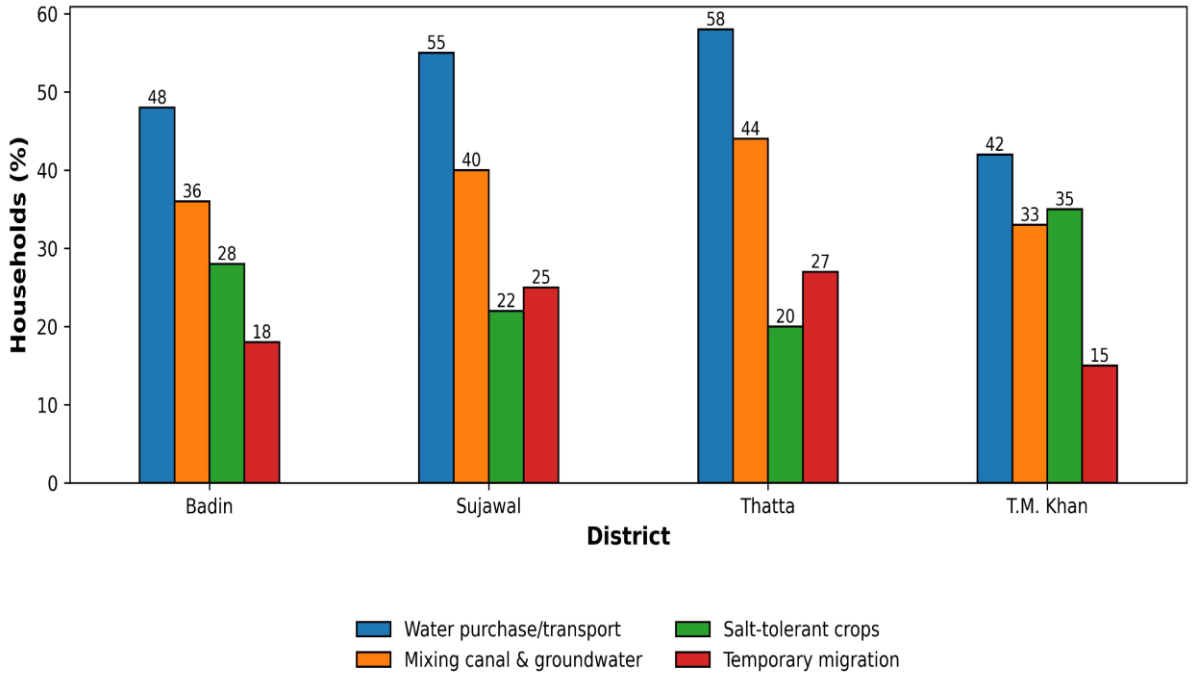


Figure 8.2: *Percentage of households adopting key coping strategies in response to SWI and salinity stress.*

8.4 Indigenous Knowledge and Traditional Practices

Indigenous knowledge and traditional practices continue to play an important role in shaping local adaptation decisions in coastal Sindh; however, their effectiveness is increasingly constrained under accelerating environmental change. Survey results indicate that

approximately 55-60% of households reported relying on traditional knowledge systems, including visual soil assessment, historical cropping calendars, crop rotation practices and intergenerational experience, to guide agricultural and water-related decisions (Figure 8.3).

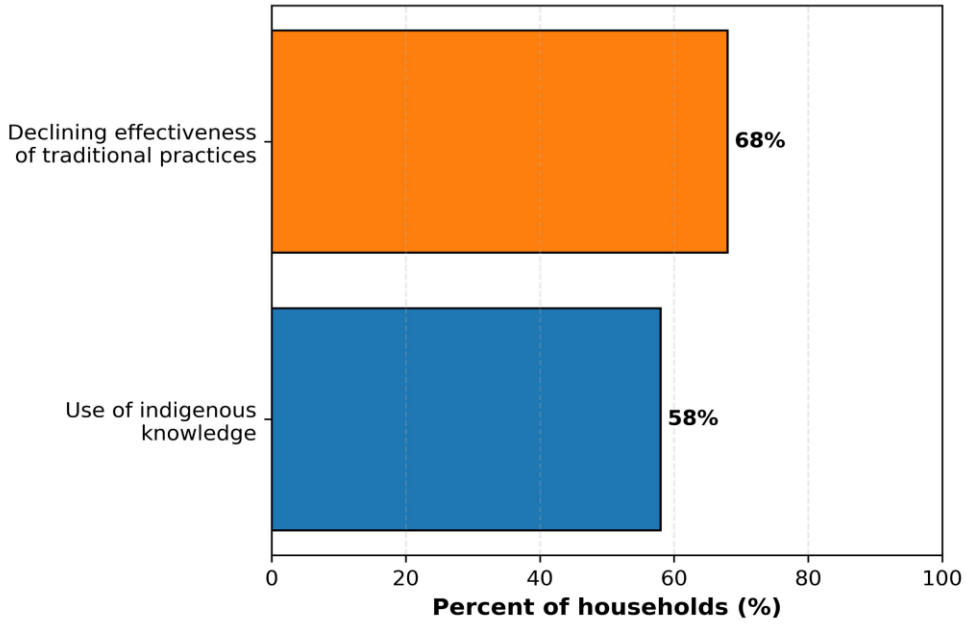


Figure 8.3: *Use and perceived effectiveness of indigenous knowledge and traditional practices among coastal households.*

Respondents emphasized that these practices were historically effective in anticipating seasonal variability and managing soil and water conditions. However, more than two-thirds of households (≈68%) reported that traditional practices are becoming less reliable and less effective under current conditions. The primary reasons cited include rapid salinity intrusion, increasing unpredictability of rainfall and canal supplies and faster onset of soil degradation, which exceed the adaptive range of historically observed environmental patterns.

Older respondents frequently noted that past indicators such as soil color, crop response, and seasonal timing, no longer provide reliable guidance for decision making. This erosion of indigenous knowledge reflects not a failure of traditional systems per se, but rather the pace and magnitude of environmental change, which is occurring faster than local experiential learning can adjust.

These findings suggest that while indigenous knowledge remains a valuable foundation for local adaptation, it cannot function as a standalone strategy under intensifying SWI and climate variability. Instead, there is a growing need to integrate traditional knowledge with scientific monitoring, extension services and early warning systems to enhance adaptive capacity.

8.5 What Communities Say Is "Working"

Survey responses indicate that 55-65% of households consider intermittent access to canal water as the most effective coping mechanism, even when supply is unreliable (Figure 8.4). Community-level water sharing and informal support networks were also cited as helpful by approximately 40-45% of households.

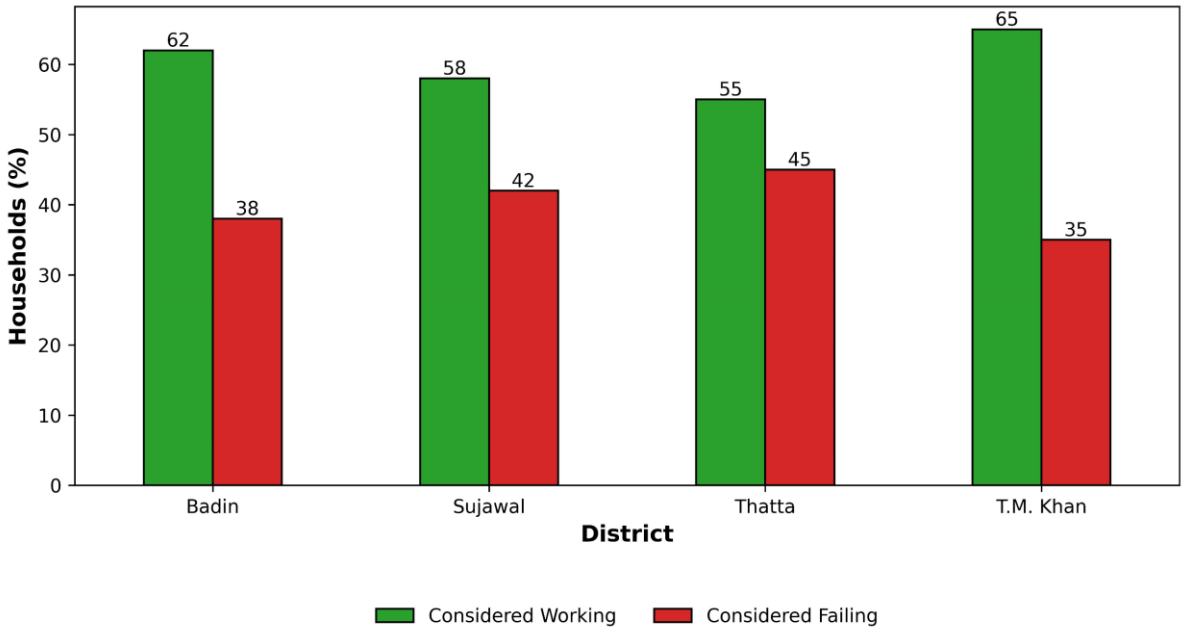


Figure 8.4: *Community perceptions of adaptation practices considered effective ("working") versus ineffective ("failing").*

8.6 What Communities Say Is "Failing"

Conversely, 35-45% of households explicitly identified continued reliance on saline GW, traditional cropping patterns, and shallow tube wells as failing strategies (Figure 8.5). Respondents emphasized that these practices no longer provide sustainable livelihoods or safe water, particularly in severely affected coastal zones. A synthesis of community perceived adaptation practices considered effective and ineffective is presented in Table 8.1.

Table 8.1: *Community-Perceived Effectiveness of Local Adaptation Practices in Coastal Sindh*

Category	Practices	% Households	Perceived Outcome
Working	Canal water access	55-65%	Moderately effective
Working	Water sharing	40-45%	Short-term relief
Failing	Saline GW use	35-45%	Health & productivity loss
Failing	Traditional cropping	30-40%	Increasing crop failure
Failing	Shallow tube wells	25-35%	Rapid salinization

8.7 Constraints to Effective Adaptation

Despite widespread awareness of salinity related risks and the adoption of local coping measures, households across the coastal districts face significant structural constraints that limit the effectiveness and sustainability of adaptation. Survey responses indicate that economic, technical, and institutional barriers act simultaneously, preventing households from transitioning from short-term coping to long term resilience.

As illustrated in Figure 8.6, approximately 60% of households identified lack of financial resources as the primary constraint to effective adaptation. Limited income and savings restrict households' ability to invest in improved drinking water systems, alternative livelihoods, agricultural inputs or soil and water management measures. This constraint is particularly acute among landless agricultural laborers and fishing households, who rely heavily on climate sensitive income sources.

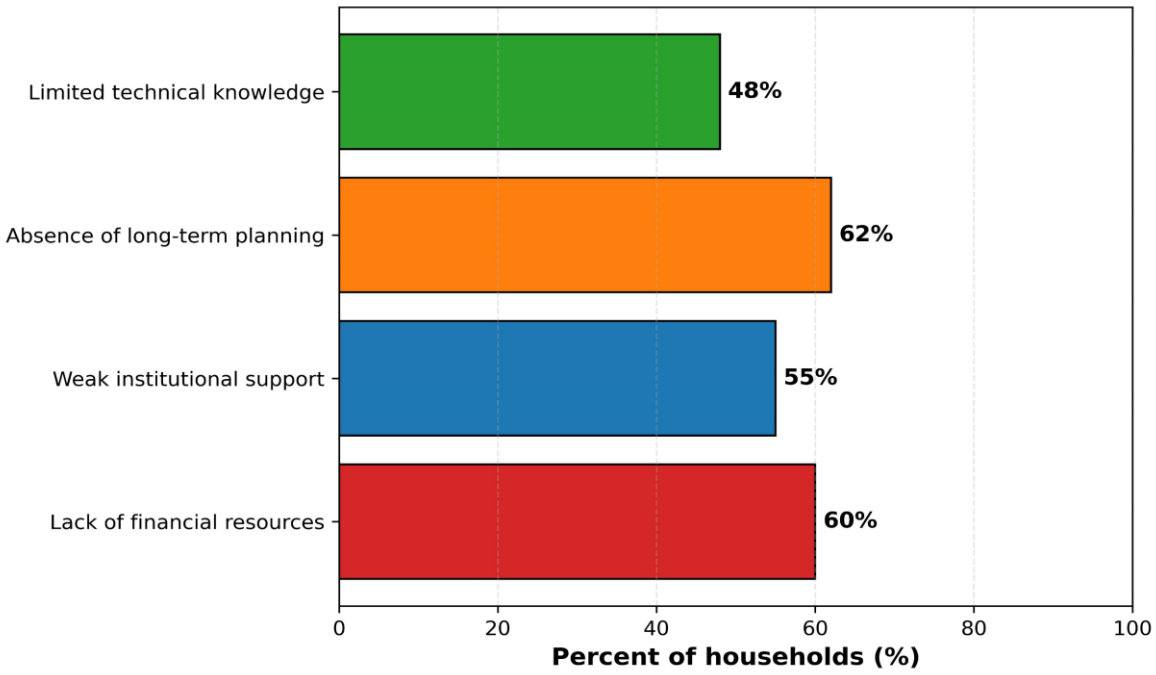


Figure 8.5: *Key constraints limiting effective adaptation to SWI (% households reporting).*

Technical capacity gaps further undermine adaptation efforts. Around 45-50% of households reported limited technical knowledge, reflecting insufficient access to agricultural extension services, water management guidance and training on salinity-resilient practices. As a result, households often continue using traditional or improvised practices that offer only temporary relief under worsening salinity conditions.

Institutional constraints are equally pronounced. Approximately 55% of respondents cited weak institutional support, including limited engagement of line departments responsible for water, agriculture, fisheries and public health. Moreover, over 60% of households reported the absence of long term freshwater and salinity management planning at the district or local level (Figure 8.6). In the absence of coordinated planning frameworks, households remain dependent on short term, household level coping strategies, such as water purchase, reduced consumption or livelihood withdrawal.

These constraints are most severe among socially and economically vulnerable groups, including female headed households, landless laborers and small-scale fishing communities. The persistence of financial, technical and institutional barriers explains why many practices identified by communities as "working" provide only temporary and fragile benefits, while structurally unsustainable practices continue to dominate in highly affected areas.

8.8 Implications for Community-Based Adaptation

The quantitative and qualitative findings presented in this chapter indicate that community-based adaptation in coastal Sindh remains largely reactive, fragmented and insufficient to address the magnitude of SWI. While Figures 8.2 & 8.8 demonstrate that a majority of households actively engage in coping measures, these strategies are predominantly short term responses focused on water access and income stabilization rather than long term resilience building.

Practices perceived as 'working,' such as intermittent access to canal water and community water sharing, are effective only under moderate stress conditions and become unreliable as salinity intensifies. Conversely, practices identified as "failing," including reliance on saline GW and traditional cropping systems, continue to be used due to lack of alternatives. This pattern reflects a critical adaptation gap, where awareness of risk does not translate into transformative adaptation due to financial, institutional and technical constraints. Similar findings have been reported in other salinity affected coastal regions of South Asia (FAO, 2020; World Bank Group, 2020).

8.9 Linkage to Policy and Intervention Design

Community perceptions and coping strategies documented in this chapter provide critical guidance for policy and intervention design. The distinction between practices perceived as effective and those viewed as failing underscores the importance of aligning technical interventions with local priorities and lived experiences. Interventions that build upon

existing coping mechanisms such as improving the reliability of canal water supply or supporting community managed water systems are more likely to gain acceptance and deliver immediate benefits.

At the same time, the findings highlight the need for policy measures that move beyond short-term coping toward transformative adaptation. These include investments in salinity resilient water infrastructure, promotion of climate and salinity resilient livelihoods and integration of indigenous knowledge with scientific and institutional support. By grounding intervention design in empirically documented community perceptions and constraints, this study provides a strong evidence base for the policy framework and mitigation strategies outlined in subsequent chapters.



CHAPTER

9

MONITORING, EVALUATION AND KNOWLEDGE MANAGEMENT

Chapter 9.
MONITORING, EVALUATION AND KNOWLEDGE MANAGEMENT

9.1 Purpose and Scope

This chapter presents a comprehensive ME&KM framework designed to support evidence based planning, adaptive management and accountability in addressing SWI along the Sindh coast. The framework is anchored in the dual evidence base generated, systematic hydrogeological monitoring through a network of 100 piezometers and grid based socioeconomic survey data covering coastal districts of Badin, Sujawal, Thatta and T.M. Khan under the present study.

The purpose of the ME&KM framework is threefold. First, it provides a structured approach for tracking temporal and spatial changes in GW salinity, water availability and related environmental indicators, enabling early detection of emerging risks. Second, it integrates socioeconomic and equity sensitive indicators including drinking water access, livelihood stability, health outcomes, migration patterns and impacts on women, youth and vulnerable groups to assess how biophysical changes translate into social and economic consequences. Third, it establishes mechanisms for institutional learning and feedback, ensuring that monitoring and evaluation findings are systematically used to refine policies, investments and on ground interventions.

The scope of this chapter extends beyond compliance oriented monitoring to emphasize adaptive learning and decision support. It outlines how monitoring data, evaluation results, and documented lessons can be consolidated into accessible knowledge products (dashboards, briefs and reports) that inform district and provincial planning processes. By linking scientific measurements with community level evidence and institutional processes, the ME&KM framework supports continuous improvement of SWI mitigation and adaptation strategies, aligns with donor and government reporting requirements and strengthens the long term effectiveness and sustainability of coastal resilience initiatives in Sindh.

The overall monitoring, evaluation and learning logic underpinning the proposed framework is illustrated in Figure 9.1, highlighting the iterative relationship between monitoring, data generation, assessment, and adaptive planning.

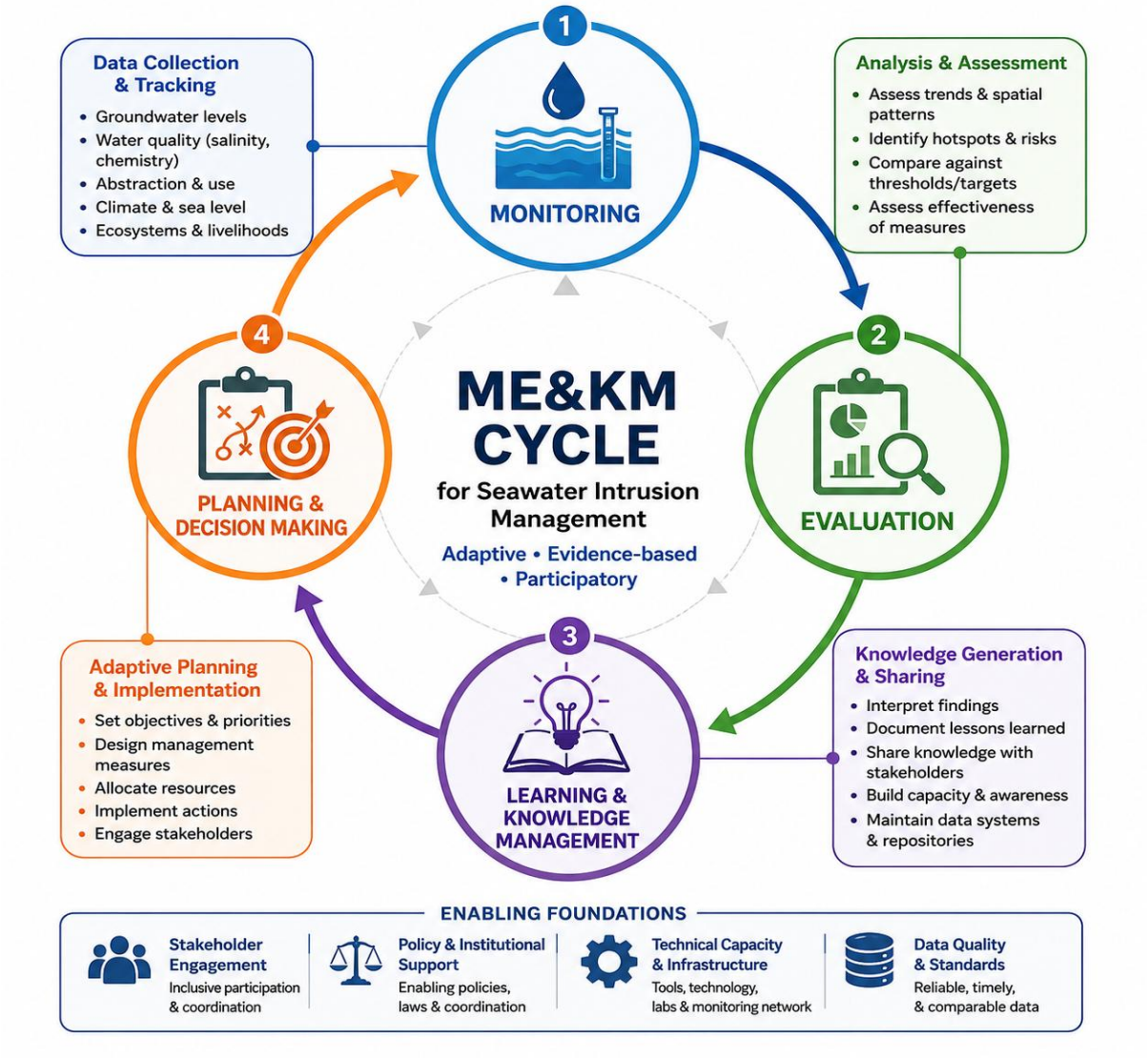


Figure 9.1: *Monitoring, evaluation, and knowledge management (ME&KM) cycle for SWI management, illustrating the iterative flow from data collection to evaluation, learning and adaptive planning.*

9.2 Monitoring Framework

Effective monitoring of SWI requires an integrated, multi-scalar framework that captures both biophysical processes and their socioeconomic consequences over time. In coastal Sindh, SWI manifests not only through rising GW salinity and altered hydraulic gradients, but also through drinking water insecurity, agricultural stress, livelihood disruption, health impacts and migration. A monitoring system that isolates only physical parameters would therefore be insufficient for guiding adaptive management. The integration of GW salinity, soil condition, agricultural productivity, and livelihood indicators reflects

internationally recommended monitoring approaches for salt-affected and coastal agricultural systems (FAO, 2020; World Bank Group, 2020).

At the core of the proposed framework is the existing network of 100 piezometers, which provides a scientifically robust foundation for tracking GW EC, TDS and DTW across seasons and years (Figure 9.2). Quarterly monitoring of these parameters enables identification of salinity persistence, short term variability and emerging hotspots, supporting early warning and spatial prioritization. Similar hydrogeological monitoring approaches are internationally recognized as essential for managing coastal aquifers under salinity stress (WHO, 2017; IPCC, 2021).

However, biophysical monitoring alone does not capture the human dimension of risk. The piezometer network must therefore be complemented by community level socioeconomic monitoring, drawing on periodic household surveys and administrative records. Key indicators include perceived drinking water quality and source reliability, duration of freshwater availability, crop yield performance and soil salinity impacts, livelihood diversification and income stability, water related health outcomes and migration incidence and drivers. These indicators provide insight into how measured GW conditions translate into lived impacts, particularly for women, youth and vulnerable households. The monitoring framework is structured around six interlinked indicator domains summarized below. The structure and interlinkages of the proposed monitoring framework are illustrated in Figure 9.2, highlighting the central role of piezometer based GW monitoring and its two way interactions with key socioeconomic impact domains.

GW Conditions: EC/TDS levels and DTW measured quarterly through piezometers to assess salinity extent, trends and aquifer stress.

1. **Water Access and Use:** Seasonal monitoring of freshwater availability for drinking and irrigation, distinguishing canal supplies from GW dependence.
2. **Agriculture and Soil Health:** Annual assessment of crop yield trends, reported soil salinity impacts and changes in cropping patterns.
3. **Livelihoods and Income:** Annual tracking of livelihood composition, income stability, and reliance on climate sensitive sectors.
4. **Health Outcomes:** Annual reporting of water related illnesses and caregiving burdens, with attention to gendered impacts.
5. **Migration Dynamics:** Biennial monitoring of migration incidence, duration and stated drivers linked to water and livelihood stress.

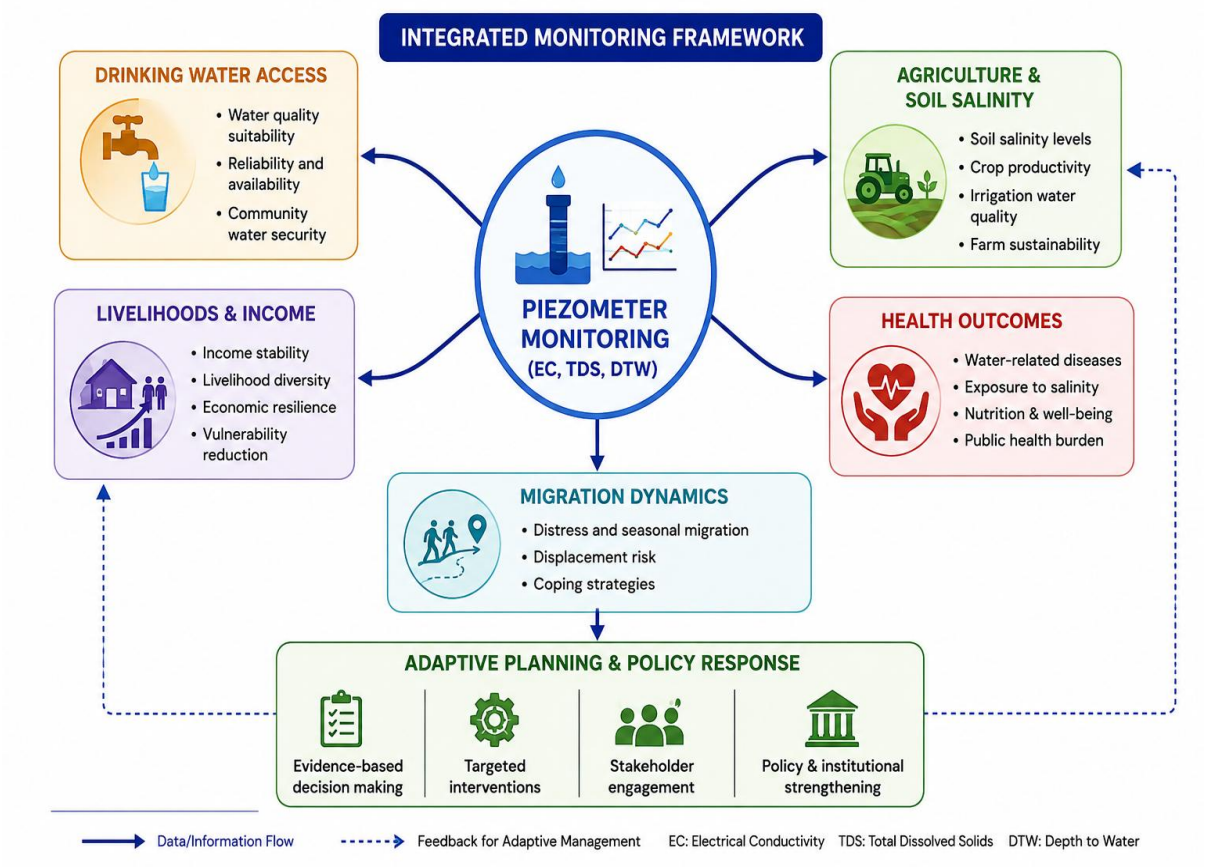


Figure 9.2: *Integrated monitoring framework linking hydrogeological observations from piezometer monitoring (EC, TDS and DTW) with key socioeconomic impact domains drinking water access, agriculture and soil salinity, livelihoods and income, health outcomes and migration dynamics feeding into adaptive planning and policy response.*

Importantly, these indicator streams are not independent. Changes in GW salinity influence water access, which in turn affects agriculture, livelihoods, health and migration. The monitoring framework therefore emphasizes data integration and cross sectoral interpretation, rather than parallel sectoral reporting. This integrated approach aligns with international best practice for coastal risk monitoring and adaptive water management (World Bank Group, 2020; IPCC, 2021).

9.3 Evaluation and Learning

Periodic evaluation is a critical component of the ME&KM framework, ensuring that SWI mitigation and adaptation measures are not only implemented, but are effective, equitable and sustainable over time. Evaluation moves beyond routine monitoring by systematically assessing whether observed changes in GW conditions, water access, livelihoods, health and

migration can be attributed to planned interventions and whether these interventions are reaching the most vulnerable populations.

The evaluation framework should be structured around mid-term and end line assessments, aligned with planning and investment cycles. Mid-term evaluations are essential for identifying implementation bottlenecks, unintended impacts and differential outcomes across districts, allowing timely course correction. End-line evaluations should focus on long term outcomes, including sustained improvements in drinking water security, stabilization of agricultural and livelihood systems, reduction in health burdens, and enhanced adaptive capacity at household and community levels.

A core principle of the evaluation approach is equity sensitive analysis. Evaluation indicators should be disaggregated by district, gender, age (youth) and vulnerability status to capture uneven impacts and avoid masking disparities in aggregate results. For example, improvements in water access at district level may coexist with persistent burdens for women or landless households if service delivery remains uneven. Integrating such disaggregation ensures that adaptation efforts do not inadvertently reinforce existing inequalities, a risk widely recognized in climate adaptation programs (IPCC, 2021; World Bank Group, 2020).

Learning is embedded as an explicit outcome of the evaluation process. Evaluation findings should be systematically linked to the integrated monitoring framework (Figure 9.2) and translated into actionable knowledge products such as policy briefs, district scorecards, and implementation notes that inform planning revisions, budget prioritization and program redesign. This feedback loop transforms evaluation from a compliance exercise into a continuous learning mechanism, supporting adaptive management under evolving climatic and socioeconomic conditions.

Institutionalizing evaluation and learning requires clear responsibilities and regular review platforms. Annual or biennial learning forums at district and provincial levels can provide space for line departments, researchers and community representatives to review evidence, reflect on performance and agree on adjustments. International experience demonstrates that such structured learning loops significantly enhance the effectiveness and durability of coastal resilience and water management interventions (World Bank Group, 2020).

9.4 Knowledge Management and Data Integration

Effective response to SWI requires not only the generation of data, but also the systematic integration, interpretation and use of that data in decision making. Knowledge management (KM) under the proposed ME&KM framework is therefore designed to transform diverse datasets hydrogeological measurements, socioeconomic survey findings and administrative records into actionable knowledge that supports coordinated planning and adaptive management. International experience demonstrates that integrated knowledge management platforms linking environmental monitoring with agricultural and livelihood data significantly enhance adaptive decision making in saline and climate vulnerable regions (FAO, 2020; IPCC, 2021).

At the core of this approach is the development of a centralized data and knowledge platform that consolidates information from the piezometer network (EC, TDS, DTW), periodic socioeconomic surveys and sectoral administrative systems (water supply, agriculture, health and social protection). Data integration should follow standardized formats and metadata protocols to ensure consistency, comparability and traceability over time, reducing fragmentation across institutions. Such integration enables cross-sectoral analysis, allowing planners to examine how changes in GW salinity correspond with shifts in water access, livelihoods, health outcomes and migration patterns across districts.

To ensure usability, raw data should be translated into synthesized knowledge products tailored to different stakeholders. District planning units and line departments require dashboards and summary briefs that highlight key trends, emerging risks and priority hotspots, while community organizations benefit from simplified visual products that support local awareness and participation. Linking these products explicitly to the monitoring indicators and evaluation findings outlined in Sections 9.2 and 9.3 (as illustrated in Figure 9.2) strengthens coherence across the ME&KM system.

Documentation of lessons learned, good practices and implementation challenges is a central element of the knowledge management function. Structured documentation through case notes, thematic briefs, and periodic learning reports supports institutional memory and reduces reliance on individual experience. Over time, this evidence base enables identification of interventions that are effective under specific hydrogeological and socioeconomic conditions, facilitating scaling of successful approaches and discontinuation of ineffective ones.

Importantly, knowledge management is not a one-way dissemination process. Feedback mechanisms should allow district authorities, service providers and communities to contribute observations and experiential knowledge, enriching formal datasets and enhancing local ownership. International experience shows that such two-way knowledge systems improve coordination, transparency and adaptive capacity in complex coastal and climate affected settings (World Bank Group, 2020; IPCC, 2021).

9.5 Institutional Roles and Responsibilities

Effective implementation of the ME&KM framework depends on clearly defined institutional roles, vertical coordination and accountability mechanisms across provincial, district, and community levels. Given the cross-sectoral nature of SWI impacts, no single institution can manage monitoring, evaluation and learning in isolation. Instead a coordinated, multi-agency approach is required to ensure consistency, data quality and policy relevance.



At the provincial level, line departments responsible for water resources, agriculture, health, environment and planning should jointly provide strategic oversight of the ME&KM framework. Their roles include setting monitoring standards, approving indicator frameworks, ensuring alignment with provincial development priorities and facilitating data sharing across sectors. The Planning & Development Department has a critical convening role in integrating ME&KM outputs into annual and medium term planning processes and in linking evidence to budgetary decisions.

District authorities are central to operationalizing the framework. District administrations in coordination with relevant line departments, should be responsible for

routine data collection, field level validation and initial synthesis of monitoring information, including piezometer observations and community level socioeconomic indicators. Their proximity to affected communities enables timely detection of emerging risks and contextual interpretation of data, particularly where impacts vary within districts.

Research institutes and technical agencies play a supporting but essential role by providing methodological guidance, data analysis, quality assurance and capacity building. Their involvement helps ensure that monitoring and evaluation methods remain scientifically robust, comparable over time and aligned with national and international standards. Periodic third-party technical reviews can further strengthen credibility and learning.

Community participation enhances both the quality and legitimacy of the ME&KM system. Involving community representatives, water user groups and local organizations in data reporting, validation and feedback processes improves accuracy, contextual understanding and ownership. Community engagement also supports transparency and helps bridge gaps between formal monitoring systems and lived experience, an approach widely recognized as good practice in coastal and climate risk management (World Bank Group, 2020; IPCC, 2021).

Clear role definition, supported by formal coordination mechanisms and regular review platforms is essential to prevent duplication, data fragmentation and institutional silos. When effectively coordinated, these institutional arrangements enable the ME&KM framework to function as a decision support system, rather than a standalone reporting exercise.

9.6 Development and Policy Relevance

A strengthened Monitoring, Evaluation and ME&KM system plays a critical role in translating scientific evidence and community level data into effective development planning and policy action. By systematically linking GW conditions, socioeconomic impacts and institutional responses, the ME&KM framework enhances transparency, accountability and strategic targeting of public and donor funded investments in coastal Sindh.

From a development perspective, the integrated ME&KM system enables prioritization of high risk districts and population groups, ensuring that limited resources are directed toward areas where SWI poses the greatest threat to drinking water security, livelihoods, health and social stability. Disaggregated monitoring and evaluation outputs by district, gender, youth and vulnerability status support more equitable program design and reduce the risk that interventions disproportionately benefit better resourced communities.

In policy terms, the framework supports evidence informed decision making across planning horizons. Regular monitoring outputs inform short-term operational adjustments, while evaluation findings contribute to medium and long term policy refinement in water management, agriculture, health and coastal development. The structured integration of monitoring and learning into planning cycles aligns with results based management principles and strengthens compliance with government and donor reporting requirements, including performance tracking, outcome assessment and fiduciary oversight.

International experience demonstrates that coastal resilience initiatives grounded in integrated monitoring and adaptive learning systems are more effective in responding to dynamic risks such as salinity intrusion, sea level rise and climate variability. Such systems improve coordination across sectors, reduce duplication of efforts and enhance the sustainability of interventions over time (World Bank Group, 2020; IPCC, 2021).

In this context, the proposed ME&KM framework provides a practical foundation for embedding SWI management within broader provincial development strategies and climate adaptation agendas.

9.7 Conclusion

Monitoring, evaluation, and knowledge management are fundamental to sustaining effective and credible responses to SWI along the Sindh coast. The evidence presented in this chapter demonstrates that isolated monitoring or adhoc evaluation is insufficient in the context of dynamic coastal and climatic risks. Instead, an integrated ME&KM framework linking hydrogeological observation, socioeconomic monitoring, systematic evaluation and institutional learning is essential for adaptive and informed decision making.

By connecting scientific monitoring of GW conditions with community level feedback on water access, livelihoods, health and migration, the proposed framework ensures that policy and planning responses remain grounded in both physical realities and lived experience. Embedding learning mechanisms within institutional processes further strengthens accountability and enables timely adjustment of interventions as conditions evolve.

Ultimately, the ME&KM framework provides a practical foundation for adaptive, inclusive and accountable coastal development in Sindh. Its effective implementation will determine the extent to which investments in SWI mitigation and adaptation deliver sustained benefits, reduce vulnerability among at risk populations and support long term resilience under accelerating environmental change.

CHAPTER

10

MITIGATION AND ADAPTATION FRAMEWORK FOR SWI

Chapter 10.
MITIGATION AND ADAPTATION FRAMEWORK FOR SWI

10.1 Introduction

SWI represents a slow onset but increasingly severe threat to sustainable development along the Sindh coast. Evidence presented in Chapter 6 demonstrates that saline GW, declining freshwater availability, agricultural degradation, health stress and livelihood losses are already affecting coastal communities. These impacts are further intensified by the combined effects of climate change, sea level rise, changes in freshwater availability within the deltaic system, and unsustainable groundwater abstraction. This chapter presents a scientifically grounded and policy oriented mitigation and adaptation framework, aligned with international best practice to guide government agencies and development partners in reducing current risks and building long term coastal resilience (IPCC, 2021; World Bank Group, 2020). The conceptual mitigation and adaptation framework for SWI is given in figure 10.1

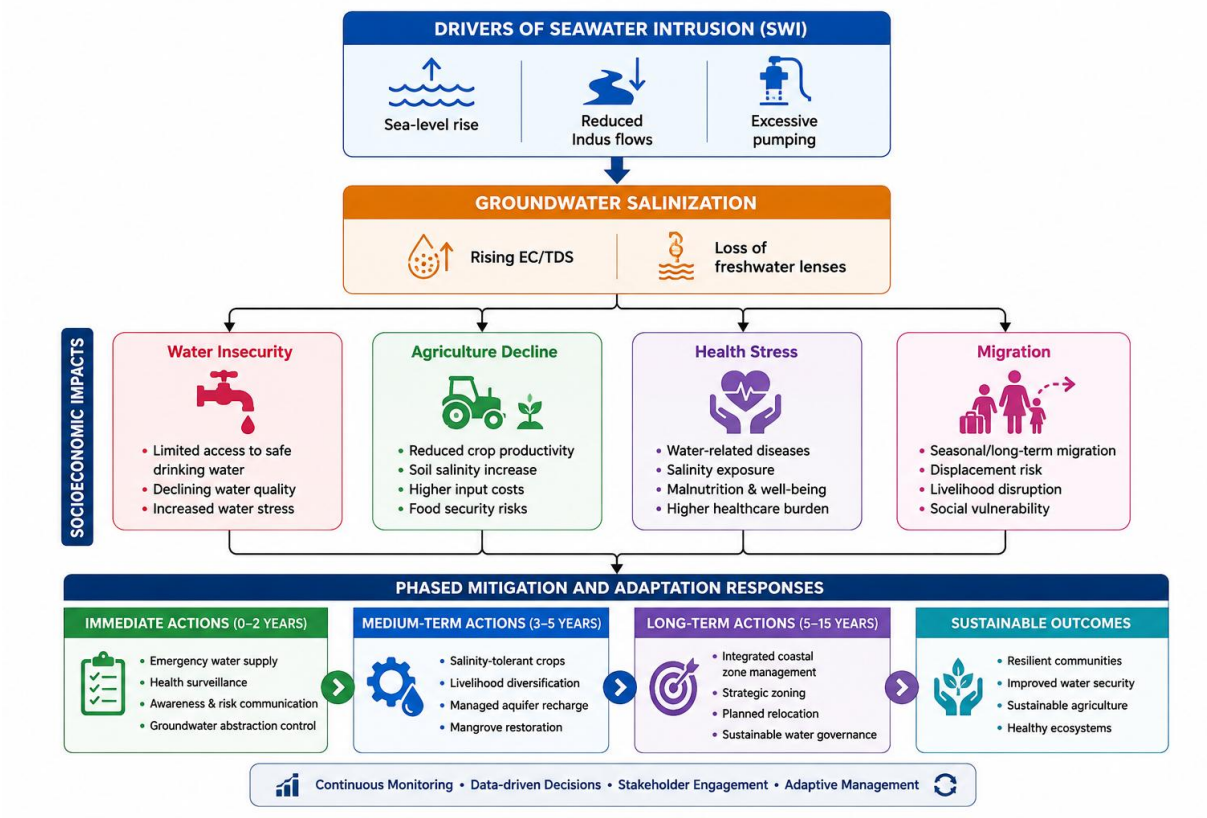


Figure 10.1: *Integrated framework linking drivers of SWI, GW salinization, socioeconomic impacts, and phased mitigation and adaptation responses.*

10.2 Scientific and Empirical Basis for Intervention

Hydrogeological monitoring through piezometers confirms that much of the coastal aquifer system is characterized by saline to highly saline GW, with limited seasonal access to surface freshwater supplies. International experience from deltaic regions such as the Ganges-Brahmaputra, Mekong and Nile deltas shows that once salinity intrusion advances beyond critical thresholds, recovery of freshwater aquifers becomes technically difficult and economically prohibitive (FAO, 2020; IPCC, 2021). Consequently, effective responses must combine mitigation measures that limit further salinity ingress with adaptation strategies that enable communities to cope with residual and unavoidable risks.

10.3 Strategic Approach and Time Horizons

The proposed framework adopts a phased approach across three time horizons. As illustrated in Figure 10.2 an immediate measures focus on protecting human health and essential services; medium term measures aim to transform livelihood systems and strengthen adaptive capacity; and long term measures address structural and spatial dimensions of coastal risk. This approach reflects global good practice in climate adaptation planning and allows prioritization of investments based on urgency, feasibility and sustainability.

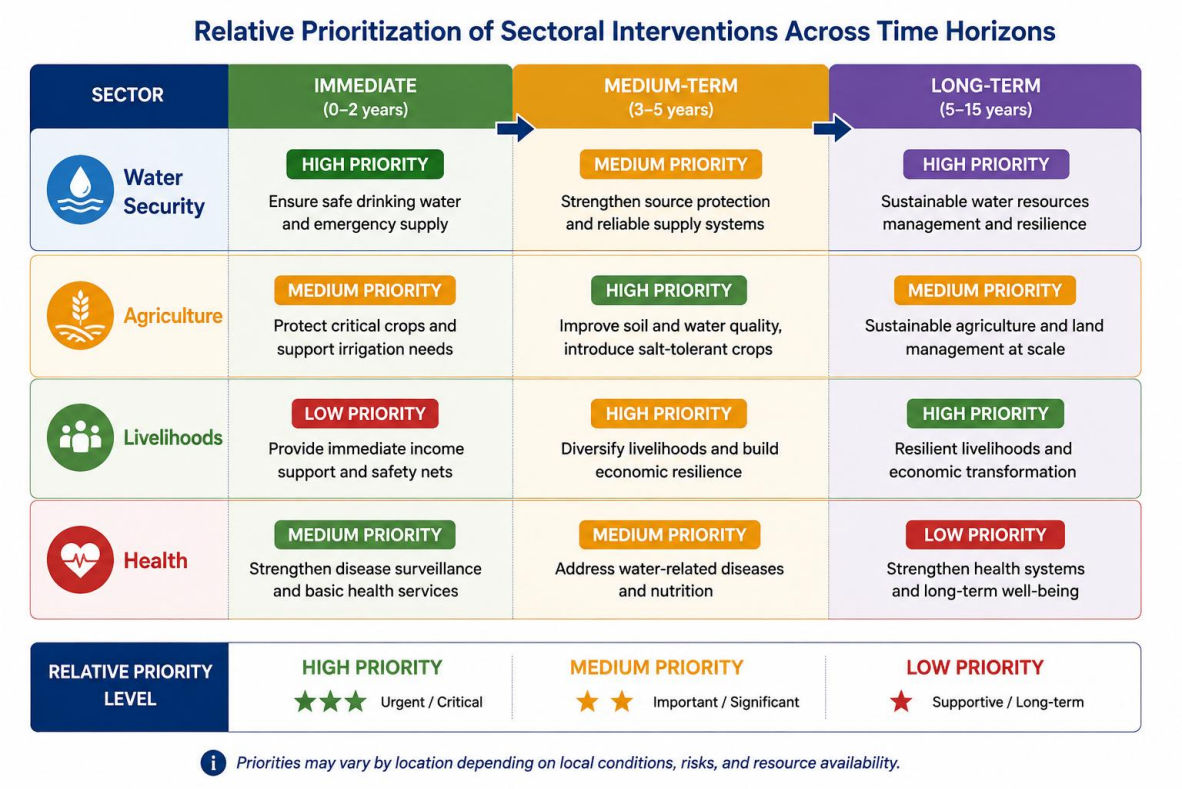


Figure 10.2: *Relative prioritization of sectoral interventions across immediate, medium term and long term time horizons.*

10.4 Immediate Measures (0-2 Years)

10.4.1 Drinking Water Security and Health Protection

Immediate interventions must prioritize risk reduction in high salinity exposure zones, particularly those where piezometer monitoring indicates persistent saline to highly saline GW and where more than 70% of households rely on GW for drinking (Chapter 6). Short term responses should therefore focus on safe water substitution rather than aquifer recovery. As shown in Figure 10.3 interventions related to drinking water security and health surveillance rank highest in both feasibility and risk reduction potential.k

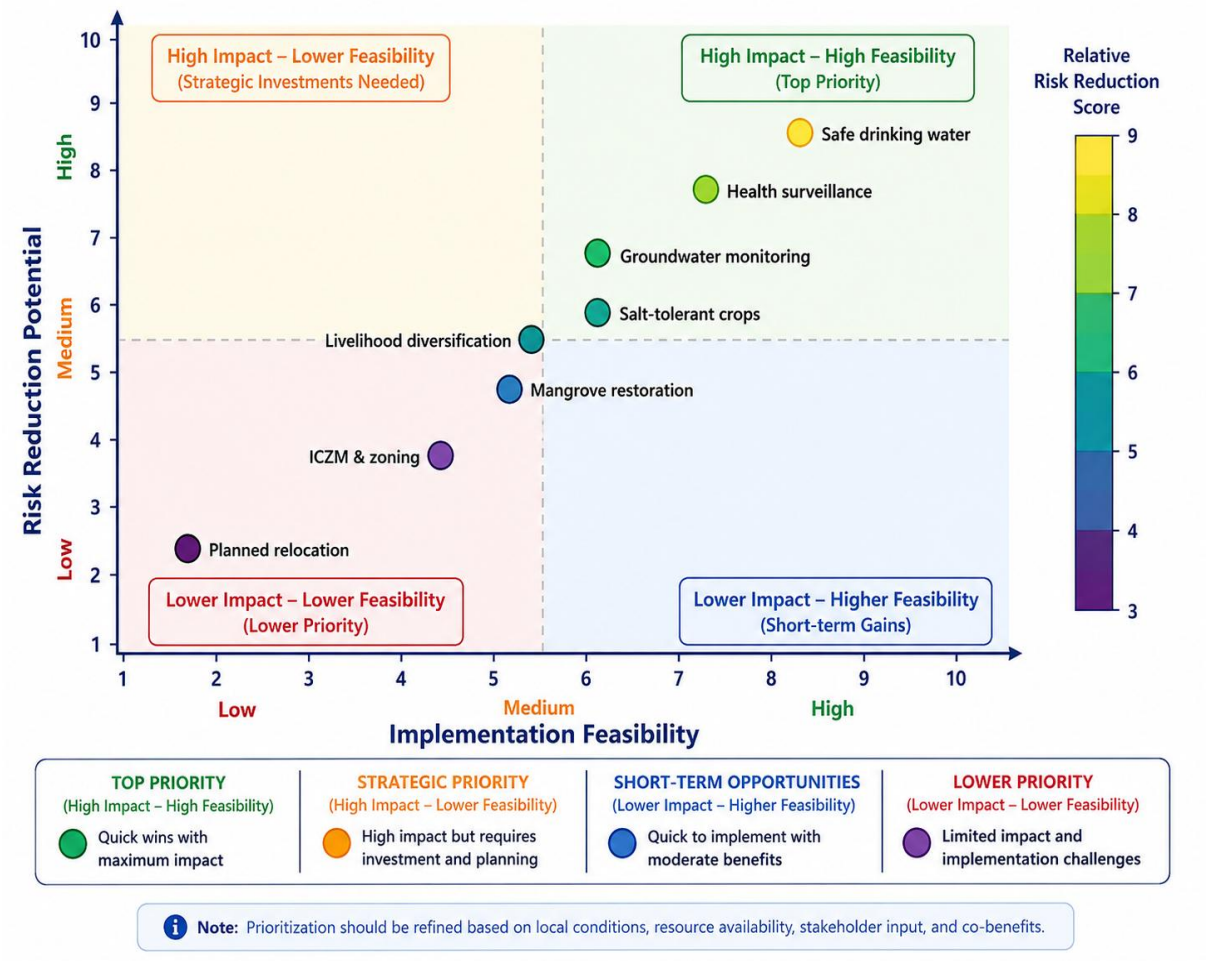


Figure 10.3: *Prioritization matrix for SWI mitigation and adaptation measures based on relative risk reduction potential and implementation feasibility.*

Priority actions include rehabilitation and operational stabilization of canal based surface water schemes during peak supply windows, deployment of community scale water treatment or desalination units in severely affected grids and provision of emergency tanker or packaged water supplies during periods when canal flows cease. Evidence from comparable

coastal settings shows that even partial substitution of saline GW with treated surface water can significantly reduce acute health risks within one to two years.

Targeted health screening and surveillance, particularly for skin diseases, gastrointestinal illness and hypertension related symptoms, is essential in districts where over 80-90% of households reported negative health impacts linked to saline water exposure (Chapter 6). Public awareness campaigns focusing on safe water handling and household level filtration can further reduce exposure risks, especially among women and children, who bear disproportionate water collection and care burdens (WHO, 2017).

10.4.2 GW Protection and Monitoring

Preventing further degradation of remaining freshwater pockets requires immediate regulatory and monitoring action. Survey and hydrochemical evidence shows that shallow to intermediate aquifers are already predominantly saline, indicating that unmanaged abstraction accelerates salinity up coning and lateral intrusion.

The existing 100 piezometer monitoring network represents a critical asset and should be institutionalized as an operational early warning system. Routine reporting of GW levels and EC/TDS trends at quarterly intervals can support adaptive decisions on abstraction control, emergency water provisioning and targeting of safe water investments at district level. Immediate abstraction controls, particularly in shallow freshwater lenses within canal command areas are essential to slow irreversible salinization.

10.5 Medium Term Measures (3-5 Years)

10.5.1 Climate Resilient Agriculture and Soil Management

Medium term adaptation must shift agriculture from salinity sensitive to salinity resilient production systems. Chapter 6 findings indicate that while approximately 78% of households own agricultural land, more than 85-90% report declining yields due to salinity stress. This mismatch between land ownership and productive capacity necessitates targeted system transformation.

Key measures include scaling up salt-tolerant crop varieties, improving field level drainage and promoting conjunctive use of surface water during canal supply periods. International experience from South Asia shows that such measures can stabilize yields and delay land abandonment when coupled with extension services and farmer training, even under

moderate salinity conditions (FAO, 2020). District specific demonstration plots and farmer field schools should be prioritized to accelerate adoption.

10.5.2 Livelihood Diversification and Ecosystem Based Adaptation

Given the simultaneous stress on agriculture, livestock and fisheries documented in this study, reducing dependence on any single climate sensitive livelihood is critical. Survey data indicate growing income instability and increasing reliance on coping strategies that offer only temporary relief.

Livelihood diversification options include brackish water aquaculture, fisheries value addition, small scale processing enterprises and vocational training for nonfarm employment. In parallel, mangrove and wetland restoration offers dual benefits: reducing coastal erosion and salinity intrusion while supporting fisheries productivity. Global evidence demonstrates that ecosystem based adaptation can yield measurable livelihood and risk reduction benefits within 3-5 years when integrated with local livelihood planning (World Bank Group, 2020).

10.6 Long Term Measures (5-15 Years)

10.6.1 Integrated Coastal Zone Management and Spatial Planning

Long term resilience requires adoption of Integrated Coastal Zone Management (ICZM) frameworks that align land use planning, water resource management, infrastructure development, and ecosystem conservation. Strategic zoning based on salinity risk, GW vulnerability, and livelihood exposure can prevent further investment in high risk areas while guiding development toward more resilient zones.

Such planning must be informed by continuous hydrogeological monitoring and updated socioeconomic vulnerability assessments to remain responsive to evolving risk patterns. Figure 10.4 illustrates how structural interventions such as ICZM and planned relocation are necessarily long term responses, requiring sustained investment beyond five years.

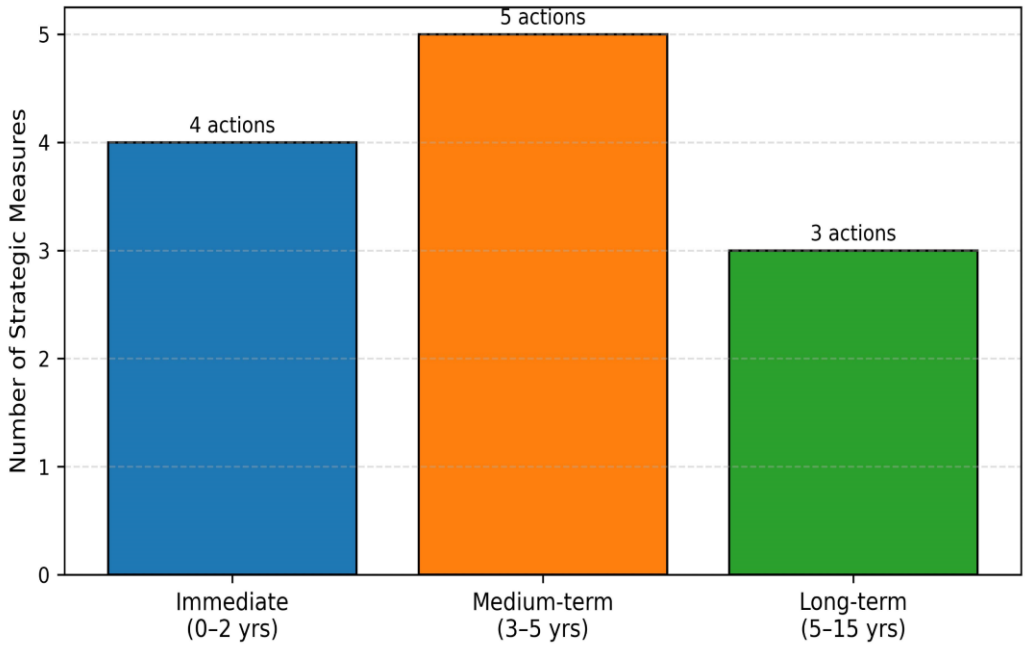


Figure 10.4: *Time phased implementation pathway for SWI mitigation and adaptation along the Sindh coast.*

10.6.2 Managed Retreat and Planned Relocation

In severely affected hotspots where salinity intrusion, land degradation, and water insecurity become irreversible, managed retreat and planned relocation may be unavoidable. International experience underscores that relocation is most successful when implemented proactively, with strong community participation, livelihood restoration measures and social safeguards (IPCC, 2021). Delayed or unplanned displacement risks exacerbating poverty, social fragmentation and inequality.

10.7 Institutional, Governance and Financing Considerations

Effective implementation of this framework requires cross sectoral coordination among water, agriculture, health, environment and planning institutions. Establishing a provincial coastal resilience coordination mechanism could facilitate data sharing, integrated planning, and alignment of investments.

Financing options include provincial development allocations, federal climate initiatives, international climate finance and partnerships with development agencies. Monitoring and evaluation systems should be explicitly linked to the piezometer network and periodic socioeconomic surveys to ensure evidence based adaptive management.

10.8 Conclusion

The mitigation and adaptation framework presented in this chapter translates empirical hydrogeological and socioeconomic evidence into a phased, actionable response to SWI along the Sindh coast. By integrating immediate risk reduction with medium and long term structural transformation, the framework provides a credible pathway toward improved water security, resilient livelihoods and sustainable coastal development under accelerating climate and environmental change.

CHAPTER

11

POLICY RECOMMENDATIONS

Chapter 11.
POLICY RECOMMENDATIONS

11.1 Policy Recommendations

The findings of this study clearly demonstrate that SWI along the Sindh coast is not a single sector environmental issue, but a systemic development challenge with interconnected impacts on water security, agriculture, livelihoods, health, gender equity and migration. Addressing these impacts requires an integrated, multi sectoral policy response that combines immediate risk reduction with medium- and long-term structural adaptation. The following policy recommendations are grounded in the study's hydrogeological evidence, socioeconomic survey findings and community perspectives and are aligned with international best practices for coastal resilience.

i. Sustainable Water Management and Protection of Freshwater Resources

Ensuring access to safe and reliable freshwater should remain a key priority for sustainable development in the Sindh coastal region. The study highlights widespread dependence on saline groundwater and seasonally available surface water, emphasizing the importance of integrated surface water and groundwater management. Priority actions should include enhancing freshwater resource management, promoting sustainable groundwater abstraction, particularly from shallow aquifers, protecting remaining freshwater lenses, and strengthening long-term groundwater quality and salinity monitoring. Investments in decentralized water treatment solutions, such as community scale desalination and filtration units, should be targeted to the most affected settlements. Rainwater harvesting and managed aquifer recharge can provide supplementary buffers where feasible. International experience indicates that integrated surface GW management is essential to slow SWI and reduce chronic water insecurity (FAO, 2020; World Bank Group, 2020).

ii. Climate and Salinity Resilient Agriculture and Land Management

Given the documented extent of soil salinization and declining crop yields, agricultural policy must shift toward salinity adaptive systems rather than attempting to restore pre intrusion conditions. This includes promoting salt tolerant crop varieties, improving drainage and soil management practices and encouraging conjunctive use of surface water during low salinity periods. Land rehabilitation measures such as soil amendments, agroforestry and controlled fallowing should be prioritized in moderately affected areas to prevent irreversible degradation.

Strengthening agricultural extension services is critical to ensure that farmers can access technical guidance, inputs, and timely information. Evidence from South Asia shows that such measures can stabilize production and slow land abandonment when adequately supported (FAO, 2020).

iii. Livelihood Diversification and Local Economic Resilience

The study highlights increasing livelihood stress and income instability as agriculture, livestock, and fisheries are simultaneously affected. Policy responses should therefore promote diversification beyond climate sensitive activities. Skills development, vocational training, microfinance and support for small enterprises can help households access alternative income sources. In coastal areas, opportunities such as value added fisheries, brackish water aquaculture (where environmentally appropriate), handicrafts and eco based enterprises can reduce dependency on declining land based livelihoods. Targeted support should prioritize youth and landless households, who face the highest employment stress.

iv. Strengthening Health Systems and Water Related Public Health Protection

Widespread health impacts linked to saline and unsafe water require a stronger public health response. Policies should improve access to primary healthcare in coastal areas through mobile clinics, expanded outreach and improved referral systems. Investments in safe drinking water infrastructure are essential to reduce waterborne and salinity related health risks. Public awareness programs focusing on water quality, sanitation and preventive health practices should complement infrastructure investments. International evidence emphasizes that improving water quality is one of the most cost effective public health interventions in vulnerable coastal regions (WHO, 2017).

v. Managing Migration and Reducing Distress Displacement

Migration has emerged as an important coping strategy, but often reflects distress rather than opportunity. Policy frameworks should recognize climate and water induced migration as a development issue rather than an ad hoc outcome. Rural development and local employment programs can help reduce forced migration, while urban planning policies must account for incoming populations by ensuring access to housing, services and livelihoods. Social protection mechanisms and safety nets are critical to safeguard migrant households during transition periods. The IPCC identifies planned, supported mobility as a necessary component of adaptation in highly exposed coastal zones (IPCC, 2021).

vi. Community Engagement and Locally Led Adaptation

The study demonstrates high awareness of environmental change and widespread use of local coping strategies, though many are constrained by limited resources and institutional support. Policies should therefore strengthen community based adaptation by involving local stakeholders in water management, agricultural planning and disaster risk reduction. Supporting women's participation, cooperative models and local institutions can enhance ownership and effectiveness of interventions. International experience shows that locally led adaptation improves sustainability and equity outcomes (World Bank Group, 2020).


سجاول ۾ سامونڊي جي تباهڪاريءَ کاري پاڻي جي روڪٿام لاءِ پي سي آر پليلو آبپارن سيمينار ورڪشاپ ۽ شرڪت

ترتيب ۽ تحقيق ڪندڙ ڊاڪٽر غلام مرتضيٰ، انوار احمد قريشي، محمد جنيد، جبار ڏاهر، محمد طارق، آباد گارن ۽ ٻيا شريڪ

سيمينار جو مقصد حڪمت عملي جوڙڻ، عالمي جوهائڙ ونڊ ۽ مقامي ڄاڻ ماڻهن سان گڏجاڻين ڪري معلومات حاصل ڪرڻ آهي، جعفر

ٻڌ پاڻي مناسب مقدار ۾ سمنڊ ۾ وڃڻ ڪري سامونڊي ڪارائن ريزرو ڊاڊي پئي وڃي جهنگي سبب زمين ۽ ڪوٽ تباهه ٿي رهيا مقامي ماڻهو

سامونڊي پاڻي ۽ ڪارائ روڪڻ لاءِ سنڌ بئراج رنا ڪي بحال ڪري ڪارپجاڻ کان شاهبندر ۽ زيرو پوائنٽ کان ٻدين تائين پاڻي جي رسد وڌائي وڃي

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جي ماڻهن ۽ صحافين وڏي آنڪ و شرڪت ڪئي. ترتيب و تحقيق ڪندڙ

ريجنل ڊائريڪٽر ڊاڪٽر غلام مرتضيٰ

سجاول : سامونڊي ڪناري تي تباهڪاري بابت سيمينار ۾ آڪاڻ ويندل آهن

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رپورٽ حنيف ملاح

vii. Institutional Coordination and Evidence Based Planning

Given the cross sector nature of SWI, institutional coordination is essential. Provincial and district authorities responsible for water, agriculture, health, environment and planning should work through a coordinated framework for coastal resilience. The study's monitoring and evaluation framework linking piezometer data with socioeconomic indicators should be institutionalized to support adaptive planning and timely policy adjustment. Strengthening data systems and research partnerships will ensure that responses remain evidence based and responsive to evolving risks.

Without coordinated and sustained intervention, SWI will continue to erode livelihoods, deepen poverty and undermine development gains along the Sindh coast. Conversely, timely, integrated and inclusive policy action grounded in scientific monitoring and community evidence can significantly reduce vulnerability and support resilient coastal development. The recommendations outlined above provide a practical roadmap for translating the study's findings into effective policy and planning responses.

CHAPTER

12

LIMITATIONS OF THE STUDY

Chapter 12.
LIMITATIONS OF THE STUDY

Despite its strengths, the study is subject to the following limitations:

i. **Cross-Sectional Design**

The research captures conditions and perceptions at a specific period in time. While respondents provided retrospective insights, the study does not constitute a longitudinal analysis capable of tracking long term trends or causal trajectories of SWI impacts.

ii. **Reliance on Self-Reported Socioeconomic Data**

Household survey responses reflect perceived impacts and lived experiences, which, while essential for understanding vulnerability and adaptation, may be influenced by recall bias or subjective interpretation. These perceptions were triangulated with hydrogeological measurements to enhance reliability.

iii. **Gender Representation Constraints**

The study faced limitations in achieving balanced gender participation, particularly with respect to direct engagement of women in household surveys and focus group discussions. Due to prevailing local cultural norms and social practices in the coastal districts, female household members were often unavailable or not permitted to participate directly in interviews or group discussions. As a result, most survey responses and qualitative inputs were provided by male household members.

iv. **Depth and Spatial Coverage of Hydrogeological Monitoring**

Piezometer monitoring was limited to shallow and intermediate aquifer depths (up to ~80 ft). Deeper aquifer dynamics and regional GW flow systems were beyond the study's operational scope.

v. **Limited Availability of Disaggregated Secondary Data**

District-level statistics on GW salinity, health outcomes and migration remain limited or inconsistent, necessitating reliance on primary data for several indicators. This constrains direct comparison with historical baselines in some cases.

vi. **Non-Predictive Analytical Framework**

The study does not employ numerical GW modeling or climate scenario projections. Accordingly, conclusions are framed around observed patterns, reported impacts and policy relevant insights rather than future forecasts.

These limitations do not undermine the validity of the findings; rather, they define the boundaries within which results should be interpreted. The strength of the study lies in its integration of scientific monitoring with community level evidence, offering a grounded understanding of current conditions and vulnerabilities. The findings are therefore best used to inform adaptive planning, targeted interventions and further in depth or longitudinal research.

CHAPTER

13

CONCLUSION

Chapter 13.
CONCLUSION

SWI has emerged as a systemic environmental and development challenge along the Sindh coast, with far reaching consequences for water security, livelihoods, health and social stability. This study demonstrates that seawater intrusion (SWI) is not an isolated hydrogeological phenomenon but the result of interacting natural and anthropogenic processes. Its impacts are further influenced by variations in freshwater availability, climate variability, and socioeconomic vulnerability, leading to cascading effects across water resources, ecosystems, agriculture, and local livelihoods. By integrating hydrogeological monitoring with district level socioeconomic evidence, the study provides a comprehensive picture of how physical salinity processes translate into lived human impacts.

Agricultural decline is identified as one of the most severe and widespread consequences. Persistent soil salinization, limited availability of freshwater for irrigation and reliance on saline GW have reduced crop productivity, degraded land quality and undermined farm viability across all four coastal districts. Although agricultural land ownership remains high, productive capacity is rapidly eroding, forcing farmers to shift toward low value salt tolerant crops, leave land fallow or abandon cultivation altogether. These trends pose serious risks to food security, rural incomes and long term land sustainability.

Livelihood stress extends beyond agriculture. Livestock health and fisheries productivity are increasingly affected by saline water exposure and changing coastal and estuarine conditions. The combined effects of declining farm yields, livestock stress and fisheries variability translate into direct income losses and rising indirect costs, including water purchases, health expenditures, and increased time burdens. These pressures disproportionately affect landless households, small-scale fishers and informal workers, accelerating poverty cycles and weakening household resilience.

Health impacts linked to saline and unsafe water are widespread and persistent. High reliance on saline GW and limited sanitation coverage have contributed to increased incidence of water related illnesses, particularly skin and gastrointestinal conditions. Women and children bear a disproportionate share of these impacts through caregiving responsibilities, lost productive time and heightened health risks. The study highlights how water insecurity, health burdens and economic stress reinforce one another, compounding vulnerability in already resource-constrained communities.

Migration has emerged as an important, though often distress driven, coping strategy. A significant share of households reported migration of at least one member, driven by declining livelihoods, lack of employment, water scarcity and health concerns. While migration may provide short-term income relief, it also introduces new risks, including precarious employment, inadequate housing, social dislocation and the erosion of local labor and social capital. Over time, these dynamics may contribute to demographic imbalance and long-term developmental challenges in both sending and receiving areas.

The study also reveals pronounced inequality in how SWI impacts are experienced. Women face a disproportionate water collection burden, youth encounter rising employment stress as traditional livelihoods decline and vulnerable groups including landless households, elderly persons and female headed households exhibit the lowest adaptive capacity. Although community awareness of environmental change is high and households employ diverse coping strategies, many of these responses provide only temporary relief and are constrained by financial limitations, weak technical support and limited institutional engagement.

Overall, the findings underscore that SWI in coastal Sindh constitutes a cross sector development risk rather than a single sector environmental issue. Its impacts are cumulative, spatially concentrated, and mutually reinforcing, cutting across water supply, agriculture, health, livelihoods, gender equity and migration. Addressing these challenges requires coordinated, evidence-based responses that combine protection of freshwater resources, climate and salinity resilient livelihoods, improved health and water services and inclusive social protection.

The study highlights the importance of sustained monitoring, evaluation and knowledge integration to support adaptive planning. Linking scientific GW monitoring with socioeconomic data and community feedback is essential for tracking risks, targeting interventions and ensuring accountability. Without timely and coordinated action, SWI will continue to erode development gains and deepen vulnerability along the Sindh coast. Conversely, strategic, inclusive and data driven responses can help safeguard livelihoods, improve water security and strengthen the long term resilience of coastal communities.

This study adopts an empirical and perception based analytical approach. Accordingly, conclusions are framed around observed hydrogeological patterns, community reported impacts, and policy relevant insights, rather than predictive or scenario-based modeling. This evidence-based framing ensures that recommendations remain grounded in measured conditions and lived experiences of coastal communities.

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