Climate Change and Water-Related Challenges in Pakistan

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Tangible Solutions

Edited by

Zulfiqar A. Bhutta and Jai K. Das

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Dedicated to the under-privileged women and children of Pakistan, who silently bear the brunt of climate change and its consequences!

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FOREWORD

Climate change poses an existential threat to Pakistan, a nation experiencing severe and escalating impacts. Despite contributing less than 1% to global carbon emissions, Pakistan ranks among the top ten most vulnerable countries to climate change.

The implications for water resources are dire. Pakistan is facing increasingly frequent and intense extreme weather events, including devastating floods and prolonged droughts, which severely disrupt water availability and quality. For instance, the catastrophic flooding of 2022 submerged over one-third of the country, killing over 1,700 people, displacing millions, and causing over $30 billion in damages. This event underscored Pakistan's acute vulnerability to climate impacts despite its minimal contribution to global emissions.

Climate change accelerates glacial melt in the Himalayas, altering river flows and increasing flood risks. Rising temperatures further intensify water scarcity through increased evaporation and shifting precipitation patterns. By 2025, it is projected that half of Pakistan's population will face water stress conditions. Additionally, water quality deteriorates due to temperature fluctuations and rainfall variability, which affect chemical and biological processes in water bodies. Extreme events like floods often contaminate water sources with sewage and pollutants, heightening the risk of waterborne diseases. Unpredictable and often unmanageable precipitation patterns also have an adverse effect on agriculture and livestock, leading to aggravated food insecurity. Compelled by population growth, these challenges strain Pakistan’s capacity to improve its human development index.

A valid critique of the challenges of social sector development are that they are analyzed in highly “specialized” silos, leading to isolated recommendations that often fail to deliver the intended results. One must take an interdisciplinary approach, combining insights from various fields to provide a comprehensive perspective on challenges and solutions to break the above-mentioned policy silos and eliminate policy inconsistencies.

It is noteworthy that the editors of this volume have adopted an interdisciplinary approach to exploring the challenges associated with climate change and water management in Pakistan, and have developed holistic policy recommendations.

This volume, "Climate Change and Water-Related Challenges in Pakistan: Tangible Solutions," is a timely and crucial contribution to understanding and addressing these issues. Edited by Dr. Jai K. Das and Dr. Zulfiqar A. Bhutta, this book brings together contributions from distinguished experts who comprehensively explore the pressing issues and practical solutions related to climate change and water management in Pakistan.

The book is structured into three main themes.

Issues and Challenges: This section explores the multifaceted challenges posed by climate change on Pakistan's water resources. It includes detailed case studies and empirical research, providing valuable context-specific insights. For example, the chapters on the Indus River Basin highlight historical trends, current challenges, and future projections, emphasizing the need for integrated water management strategies.

Health, Agriculture and Nutrition: The second section examines the health impacts of climate change, particularly on vulnerable populations such as women and children. It also explores the implications for agriculture, food security, and livestock, proposing solutions like climate-smart agriculture and enhancing water use efficiency.

Tangible Solutions: The final section focuses on actionable solutions and policy recommendations. It discusses strategies for improving water governance, investing in climate-resilient infrastructure, promoting water conservation, and enhancing disaster preparedness and early warning systems.

In the opening chapter, the editors introduce the multifaceted water-related challenges of climate change in Pakistan, mainly focusing on the Indus River Basin. By identifying critical problems such as water scarcity, inefficient water management, and the exacerbating effects of climate change, Dr. Bhutta and Dr. Das emphasize the importance of protecting vulnerable populations. They propose solutions involving integrated policies across agriculture, industry, and urban sectors, supported by technological innovations and community participation, setting the stage for deeper exploration in subsequent chapters.

Chapter Two, “Climate Change and Critical Water Problems in the Indus River Basin of Pakistan: Lessons from the First 30 Years of Research,” explores specific water issues faced in the Indus River Basin. It presents insights from three decades of research, discussing historical trends, current challenges, and future projections. The chapter offers a comprehensive overview of the water-related impacts of climate change, highlighting historical neglect and research gaps that have increased flood risks. The suggested way forward involves strengthening research frameworks, improving flood management policies, and focusing on implementation strategies to reduce vulnerability.

The third chapter, “Climate Change and Water Resources in Upper Indus Basin (UIB), Pakistan,” provides a detailed examination of how climate change affects water availability and distribution. It examines hydrological changes and glacier melt patterns that lead to altered precipitation patterns and glacial retreats, discussing their implications for water management. Proposed solutions involve adopting adaptive water management strategies, enhancing monitoring systems, and promoting climate-resilient infrastructure. This discussion naturally leads to the next chapter's exploration of glaciers' role in water security in Pakistan.

Chapter Four, “Glaciers and Climate Change: What is Their Relevance to Future Water Security in Pakistan?” explores the significance of glaciers for Pakistan's water security, addressing the impact of climate change on glacier dynamics and downstream water availability, especially increased flood risks due to accelerated glacial melt. The author endorses the recommendations of the previous chapter and highlights the importance of implementing adaptive management practices, improving glacial monitoring, and developing strategies to mitigate impacts on water security. The discussion on glacier melt and water security transitions into the compounded risks of extreme heat and water scarcity in urban areas, covered in the next chapter.

Chapter Five, “Interacting Risks of Extreme Heat and Water Scarcity: Impacts of Climate Change in Cities in Pakistan,” examines the compounded risks of extreme heat through urban heat island effects, water scarcity in urban areas, and inadequate urban planning. Proposed solutions involve integrated urban planning, enhancing green infrastructure, and promoting water conservation measures. This urban focus sets the stage for a deeper look at the health impacts of climate change in the following chapter.

Chapter Six, "Health and Climate Change in Pakistan," builds on the discussion of urban vulnerabilities, outlining the direct and indirect health impacts of climate change in Pakistan and highlighting increased incidences of heat-related illnesses, vector-borne diseases, and waterborne diseases. It suggests that inadequate health infrastructure and lack of awareness worsens the impact of climate change on health. As a way forward, it recommends strengthening health systems, improving disease surveillance, and promoting public health awareness. This discussion on health impacts graduates into specific vulnerabilities related to sexual and reproductive health (SRH) in Chapter Seven.

Chapter Seven, "The Intersection of Climate Change & Sexual Reproductive Health," explains how climate-induced stresses impact SRH outcomes through increased vulnerability of women and lack of access to SRH services. The authors propose gender-sensitive climate policies, improving access to SRH services, and enhancing community resilience as possible ways forward.

Another crucial and often neglected aspect of the climate change and health nexus is addressed in Chapter Ten, "Planning & Implementing One Health Solutions in Pakistan." The author advocates for the One-Health approach – implementing holistic health solutions, enhancing intersectoral collaboration, and promoting sustainable practices to address climate change impacts on human, animal, and environmental health.

Agriculture, food security, and livestock vis-à-vis climate change are dealt with in detail in Chapters Eight and Nine. Chapter Eight discusses the impacts of climate change on agriculture, including reduced crop yields, food security, and livestock stress. It highlights the vulnerabilities of agricultural systems to climate variability and proposes solutions such as promoting climate-smart agriculture, enhancing water use efficiency, and developing resilient agricultural practices.

Chapter Nine links climate change to nutritional outcomes in Pakistan, discussing how changing climate conditions lead to malnutrition and food scarcity. Proposed solutions include diversifying food production, improving nutritional education, and enhancing food security policies.

The remaining two chapters of the volume deal with water resources management. Chapter Eleven evaluates the role of dams in managing water resources amidst climate change, discussing the benefits and challenges of large and small dams. It proposes that developing sustainable dam projects, enhancing water storage capacity, and promoting efficient water use are

essential in the context of climate change. This discussion on infrastructure leads to community-based solutions in the final chapter.

The final chapter examines community-based water management practices in Gilgit-Baltistan and presents case studies from the region. It highlights the community water management's sustainability and scalability challenges and proposes solutions that involve promoting community engagement, enhancing local capacities, and scaling successful models to other regions.

A recurring theme throughout the book is the urgent need for integrated and adaptive management strategies to address the multifaceted challenges of climate change. The chapters consistently highlight the importance of cohesive approaches that combine water management, health policies, agricultural practices, and community engagement. The authors across different disciplines seem to have a consensus that building resilience at both community and national levels is crucial, necessitating investments in climate-resilient infrastructure, climate-smart agriculture, gender-responsive climate policies, better water governance, more robust public health systems, and policies such as the One Health approach.

The volume's focus on actionable solutions and policy recommendations makes it a vital resource for policymakers, academics, and development practitioners. Additionally, its emphasis on vulnerable populations, such as women and children, highlights the social dimensions of climate change, advocating for inclusive and equitable solutions.

Effective climate action requires collaboration among government entities, local communities, international organizations, and the private sector. Esteemed contributors to this volume represent these diverse stakeholders, offering a comprehensive review of the challenges and solutions related to climate change and water in Pakistan. Their collective expertise aims to safeguard Pakistan's future in the face of climate change, ensuring sustainable development and improved quality of life for its people.

Dr. Abid Qaiyum Suleri
Member, COP29 International Advisory Committee (COP29IAC)
Executive Director, Sustainable Development Policy Institute
Pakistan

PREFACE

Climate change poses a significant threat to Pakistan, with the country experiencing increasingly severe impacts in recent years. Despite contributing less than 1% to global carbon emissions, Pakistan ranks among the top 10 most vulnerable countries to climate change. Over the last 50 years, Pakistan's annual mean temperature has increased by approximately 0.5°C (and some regions, more than this), with heat wave days increasing nearly fivefold in the last 30 years. By the end of this century, temperatures are projected to rise by 3-5°C under a central global emissions scenario, or 4-6°C under higher emissions.

Pakistan also faces severe water challenges, exacerbated by climate change. The country is experiencing more frequent and intense extreme weather events, particularly devastating floods and prolonged droughts, which are disrupting water availability and quality. In 2022, Pakistan suffered catastrophic flooding that submerged over one-third of the country. While monsoon rains are typical, climate change likely intensified the rainfall, with some regions receiving over 190% of their normal precipitation. The floods killed over 1,700 people, displaced millions, and caused over $30 billion in damages from which the country has not yet recovered. This disaster highlighted Pakistan's vulnerability to climate impacts, despite contributing less than 1% of global carbon emissions.

Climate change is also causing glaciers in the Himalayas to melt rapidly, altering river flows and increasing flood risks. Rising temperatures also intensify water scarcity through increased evaporation and changing precipitation patterns. By 2025, it is projected that half of Pakistan's population will face water stress conditions. Water quality is deteriorating due to climate change as well. Temperature fluctuations and rainfall variability affect chemical and biological processes in water bodies. Extreme events like floods can contaminate water sources with sewage and pollutants, increasing waterborne disease risks. Population growth compounds these challenges by increasing water demand and pollution. Pakistan's water management practices are often inefficient, with aging infrastructure, over-extraction of groundwater, and poor governance exacerbating scarcity issues. In some areas improper irrigation techniques also contribute to waterlogging and salinity with loss of arable land. The

impacts of water stress and climate change disproportionately affect Pakistan's most vulnerable communities. Rural and low-income populations have limited resources to cope with disasters or access clean water alternatives. This creates a cycle of poverty and environmental degradation.

This book is a compilation of key papers from two sequential national conferences between November 2022 and 2023 on the issues of climate change, health and importantly issues related to water security and safety in Pakistan. The respective sections of the book highlight the key issues affecting water security in both the northern areas and plains of Pakistan, potential impacts of climate change on the health and nutrition of vulnerable women and children, and, importantly, solutions for both the water and health sectors.

As climate change intensifies, Pakistan's water challenges will likely worsen without significant action. Addressing these issues is not just an environmental imperative but a matter of national security and human development. As several chapters in this book suggest, addressing Pakistan's water crisis requires a multifaceted approach including improving water governance and management practices.

1. Investing in climate-resilient infrastructure.
2. Promoting water conservation and efficiency.
3. Protecting and restoring watersheds and ecosystems.
4. Enhancing disaster preparedness and early warning systems.
5. Increasing public awareness and education on water issues.

By prioritizing water management and climate resilience, Pakistan can work towards a more sustainable and water-secure future. This scientific compilation is a small step in supporting national and regional discussion and consensus in this regard, and some of the proposed solutions should be food for thought and action.

Prof Zulfiqar A. Bhutta FRS, S.I., O.C.
Dr Jai K. Das

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SECTION 1:

ISSUES AND CHALLENGES

CHAPTER 1

CLIMATE CHANGE AND WATER-RELATED CHALLENGES IN PAKISTAN

JAI K. DAS, ZULFIQAR A. BHUTTA

Abstract

This chapter delves into the multifaceted challenges of water resource management in Pakistan, framed against a backdrop of global and regional dynamics. Water, covering 70% of Earth's surface, remains a scarce resource, with only 1% suitable for human consumption. Pakistan faces severe water scarcity exacerbated by population growth, climate change, and inadequate infrastructure. The Sustainable Development Goal 6 underscores the imperative of universal access to safe water and sanitation, yet global water scarcity affects over 40% of the population annually. Historically, Pakistan has relied heavily on its irrigation systems, allocating 93% of water to agriculture, amid dwindling overall water resources. Groundwater depletion and pollution compound the crisis, affecting water quality and availability. The Indus Waters Treaty governs river water sharing between India and Pakistan, yet tensions persist over water distribution and use. Environmental impacts such as riverine forest depletion and mangrove loss further strain ecosystems and livelihoods. Rapid urbanization has compounded water stress, necessitating improved governance, infrastructure, and conservation efforts. Addressing Pakistan's water challenges requires integrated policies spanning agriculture, industry, and urban sectors, supported by technological innovations and community participation. The chapter advocates proactive measures to mitigate climate impacts, improve water infrastructure, and safeguard water resources for future generations.

Keywords: water scarcity, Pakistan, climate change, water management, sustainable development

Introduction

Water resources in the broadest sense include all the water in the hydrosphere including the water present in lakes, rivers, oceans, glaciers, and underground. Water covers around 70% of the Earth's surface, but still only 1% is suitable for human consumption (Water Resource 2023). The hydrologic cycle of water keeps a continuous circulation of water in the Earth's atmosphere through various processes including evaporation, condensation, transpiration, precipitation, and runoff.

Water has many important uses and the three most common amongst these are its use for agriculture, industrial, and domestic purposes. Agriculture and livestock sector is responsible for around 70% of the total water consumption globally and is used mostly for irrigation, fertilizer, and pesticide applications. The industrial sector is responsible for 19% of the global consumption and is used mostly for cooling, diluting, processing etc., while around 11% is domestic consumption. The other important uses include creating hydroelectric power, transportation and tourism.

The Sustainable Development Goal (SDG) 6 calls to ensure that access to water and sanitation is for all and that access to safe water, sanitation, and hygiene is the most basic human need for health and well-being. But the supply of fresh water has not kept pace with the rise in the global population and hence many countries are facing water scarcity, and this global water scarcity is driven by both water quantity and water quality. Unfortunately, water scarcity has been escalating and the percentage of the world's population suffering from severe water scarcity has increased from an annual average of 30% to 40% (Van Vilet et al., 2021).

Climate change has led to more frequent and severe hydro-climatic extremes such as floods and droughts (Dankers et al., 2014). Combined with growing urbanization, intensified agriculture, industrialization, and increased water extraction, this has worsened the water scarcity crisis and deteriorated water quality. Between 1984 and 2015, both climate and human activities contributed to a loss of approximately 90,000 km² of surface water, though new surface water areas have emerged mainly through reservoir construction (Scanlon et al., 2023). Beyond the reduction in water quantity, water quality is also being compromised, primarily due to industrial pollution and inadequate treatment, especially in resource-limited areas that often face problems with raw sewage, untreated industrial wastewater, and irrigation runoff.

Over the past century, trends in total water storage have varied by region. Data from the Gravity Recovery and Climate Experiment (GRACE) indicates that, in the last two decades, some regions have experienced declines, and others have shown increases in water storage globally. Long-term groundwater monitoring reveals that water storage has increased in northwest India, central Pakistan, and the northwest United States, while it has decreased in the US High Plains and Central Valley (Scanlon et al., 2023). Evaluating both annual hydrological means and seasonal variations can provide better insights into societal and ecological vulnerabilities. For example, increased seasonal variability in precipitation could disrupt the consistent atmospheric water supply, leading to prolonged dry spells in areas with unimodal precipitation patterns. Conversely, regions with high precipitation might experience more intense rainfall over shorter periods, causing flooding and challenges in reservoir management. Additionally, greater seasonal variation in evaporation could alter the monthly terrestrial water budget based on the water supply regime (Pascale et al., 2016). Thus, understanding the combined effects of future changes in mean precipitation, evaporation, and their seasonal fluctuations is crucial for assessing impacts on water supply systems (Konapala et al., 2020).

Pakistan

Pakistan is a South Asian country with diverse landscapes ranging from towering mountain ranges to glaciers, to vast plateaus to plains, deserts, and coastal areas. Pakistan is amongst the top ten most climate vulnerable countries and rated amongst the ‘extremely high-water risk’ countries. Pakistan, apart from its existing long ensuing socio-economic challenge, is facing significant challenges due to climate change, particularly in its water management sector. Climate change through increasing temperatures, altered precipitation, and glacial melt is disrupting the traditional hydrological cycle and has had profound implications for Pakistan's water resources. The designed live storage capacity existing in Pakistan is one of the lowest in the world at around 144 m^3 per person, which is comparable to the most arid regions of the world, while USA has the highest live storage of around 6,000 m^3 per person, followed by Australia and China having 5,000 and 2,300 m^3 per person respectively (Iqbal et al., 2018).

With a predominantly agrarian economy and a growing population, the availability and management of water resources have become critical issues. The Hindu Kush-Karakoram-Himalaya (HKH), which feed the country's major rivers, are experiencing accelerated glacier retreat. This leads to

short-term increases in river flow followed by long-term declines as glaciers diminish; this variability is posing challenges for agriculture which relies heavily on seasonal river flows for irrigation. Over the last few decades, Pakistan has drastically changed from being a water-abundant country to a water-stressed country. Pakistan has 2.8% of the global population but accounts for only 0.5% of global renewable water resources; they rank 36th in total renewable water resources compared to India's rank at 8th and Bangladesh's at 12th (Maqbool et al., 2022). Agriculture in Pakistan consumes around 93% of available water, while domestic consumption is responsible for 5%, and the rest is mostly consumed for industrial use. In the last fifty years, agriculture was able to triple production with the same water volume, while more industrial production and municipal water supply depends on water-efficient agriculture, and as the water volumes cannot increase anymore, there is competition amongst sectors (Siyal et al., 2023).

This book explores the specific impacts of climate change on water resources in Pakistan and the impact on health and agriculture, amongst others, and proposes tangible solutions to mitigate these challenges both in the short-midterm and long term.

History

Water is a lifeline for an agrarian economy like Pakistan. Pakistan being at the downstream path of rivers originating from India and Afghanistan in the Indus Basin, is largely dependent on the releases of water from both countries. The 1960 Indus Waters Treaty dividing the river waters of the Indus system between India and Pakistan has continued to function through wars and numerous geo-political tensions. But the buildup of various dams and hydroelectric projects like Kishanganga and Ratle hydroelectric projects are also a cause of serious concerns and conflict between the two countries. There is no formal accord with Afghanistan and the continuing building of dams along the Kabul River is further threatening the downflow.

Glacial Melting and River Flows

Pakistan's northern regions host glaciers that feed major rivers, crucial for agricultural and domestic water supply, and Pakistan heavily relies on its glaciers and rivers for freshwater supply, particularly from the HKH region.

Climate change has accelerated the melting of these glaciers, affecting river flows throughout the year and potentially leading to water shortages,

especially during dry seasons. But there is variability in glacier mass balance which can be attributed to varying temperature and precipitation gradients and debris cover (Ali et al., 2024). Recent glacier mass loss can be linked to seasonal temperature anomalies at higher elevations during winter and autumn, and the warmer rainwater over the snow and glacier surfaces also contributes to excessive melting. Given the reliance of mountain populations on glacier melt, seasonal temperature trends can disturb water security and the well-being of dependent communities, and this variability poses challenges for irrigation planning and water availability downstream.

The retreating behavior of glaciers observed in most of the HKH region has also given rise to the formation and expansion of numerous glacial lakes in the region, and this poses risks to the glacial lake outburst flood (GLOF) hazard for the downstream communities (Ashraf et al., 2021). A study revealed a total of 3044 lakes with a total surface area of 134.8 km^2 in the three HKH ranges and suggested an increase of 26% in the total number and 7% in the area during the years 2001 - 2013 (Ashraf et al., 2021). Shishper lake is an ice-dammed lake in northern Pakistan that has drained twice within one year and has the potential to cause severe damages if it bursts abruptly (Khan et al., 2021).

Rainfall Patterns

The monsoon season is vital for replenishing water reservoirs and sustaining agriculture and daily life in Pakistan. However, changing climate patterns have led to erratic monsoon behaviors, including increased intensity of rainfall events and extended dry periods. These changes have disrupted the traditional farming practices and stressed water management systems.

Over the years there has been a noticeable shift in rainy seasons across the country. The variability in these rain patterns greatly impacts several aspects of ecosystems including river flows, water availability and scarcity, agriculture production, and soil fertility (Kundu et al., 2019). A study of 82 different meteorological stations from the years 1961 – 2020 suggested that there was a decreasing rainfall pattern with spatial variation in the rainfall from south to north with the highest rainfall estimated for Malam Jaba (1700 mm) and the lowest at Nokundi in Balochistan (50 mm) (Ali et al., 2021). These changing rainfall patterns escalate the likelihood of droughts, thereby affecting the agricultural sector and food security in an agrarian country which is already prone to the effects of global warming. On the other hand, studies also show that rainfalls have become heavier, and some models

suggest that rainfall intensity has increased up to 50% (Otto et al., 2023). These have had devastating impacts on the infrastructure, health, and economy of the country, and Pakistan has witnessed major floods post 2010; the worst instance being in 2022, in which the flooding affected one-third of the geographic land and more than 33 million of its population. The outdated river management system, aberrant land use and growth of population in proximity of riverine flow, and limited disaster management capacity have further escalated these risks.

Sea Level Rise and Coastal Vulnerability

The coastal areas of Pakistan are vulnerable to sea level rise, leading to saline intrusion into freshwater sources and threatening livelihoods of coastal communities dependent on agriculture and fishing. Over the decades, property developers have reclaimed hundreds of acres of the peri-urban land for infrastructural and developmental projects especially in cities like Karachi.

The Indus water flow keeps the sea water at bay and does not let it intrude into the surface and subsurface water resources, but with the rising sea levels and the decline in water flow to the sea, the sea intrusion has extended beyond 100 kilometers north of the sea (Memon et al., 2002). This intrusion has added to the salinity of the surface and sub-surface water, threatening agriculture and freshwater availability for coastal communities, and amplifying socio-economic challenges. A study suggested that about 88% of the Indus delta is affected by the subsurface seawater intrusion, and this intrusion has been observed in the wells near the Thatta and Sujawal districts (Solangi et al., 2022). The Lar area of Sindh is adversely affected, and this has been further aggravated after the floods, with people now compelled to drink brackish water and thus are exposed to various diseases.

Riverine Forests and Mangroves

The total area of riverine forests has been decreasing for several years due to water shortages and the expansion of agricultural activities. The Indus delta's mangrove forests, which cover approximately 650,000 acres, are the sixth largest globally. These mangroves rely on the water, nutrients, and silt carried by the Indus River as it flows into the sea, which sustains their growth and supports the coastal ecosystem. These forests are crucial for numerous species, providing timber, fuelwood, fodder, and wildlife habitat, while also serving as major breeding grounds for fish, shrimp, and crabs.

Additionally, mangroves act as natural windbreakers, shielding inland areas from storms.

Hundreds of thousands of people rely directly on mangroves for their livelihoods, and this number swells into the millions when considering indirect benefits, such as those received by fishermen. However, water shortages, coupled with pollution and deforestation, are severely impacting various forms of wildlife, including plants, aquatic species, birds, and other flora and fauna. Many of these species are suffering due to water scarcity and are facing extinction. Consequently, biodiversity is under threat, and the reproductive potential of numerous species is diminishing, with some potentially facing irreversible loss if the environmental damage from water shortages is not addressed or effectively managed.

Groundwater Depletion

Agricultural output declined in the early years of Pakistan's existence due to land depletion and water shortages, resulting in mass relocations from rural to urban areas. Recognizing the benefits of groundwater cultivation, the government supported the expansion of irrigation facilities and energy supply to maintain high levels of production. The introduction of groundwater wells (tubewells) to irrigate crops was a very impactful strategy and the free use of groundwater has proven to be important for the local economy and food security of the poor.

Over time, agricultural intensification and urbanization have led to increased groundwater extraction, and combined with changing precipitation patterns, this has resulted in declining groundwater levels in many regions. Over-extraction, especially during the dry seasons has also exacerbated water scarcity. The traditional underground water canal known as 'Karez' in the province of Balochistan is a system that is connected to the ground surface with a series of upright shafts; it receives groundwater by natural aquifer discharge from piedmonts which flows to the valley floor by gravity. The Karez irrigation system was threatened by both the lowering of water table and uncontrolled installation of tubewells in the command area, and now more than 90% of the system is not in use. There have been strategies and innovations tested for improving ground water including Leaky Dams as an alternative to conventional Delay Action Dams in Balochistan and monitoring of groundwater storage with gravity satellite GRACE.

When groundwater withdrawal rates exceed recharge rates, sediments in aquifers become compressed, which causes the overlying land surface to